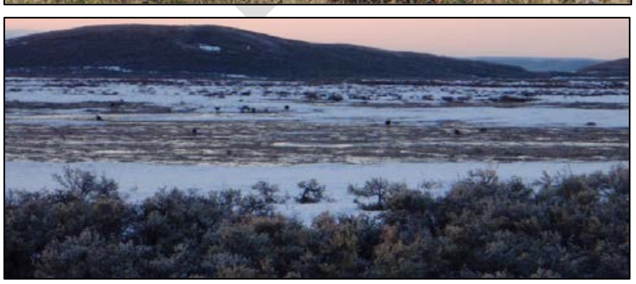
Greater Sage-Grouse Habitat Quantification Tool: A Multi-Scaled Approach for Assessing Impacts and Benefits to Greater Sage-Grouse Habitat

Scientific Methods Document, Version 2



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Science Team

Matt Holloran, Ph.D., Chief Scientist, Wildlife Management Research Support and Principal and Senior Ecologist, Wyoming Wildlife Consultants
Amy Pocewicz, Ph.D., Landscape Ecologist, The Nature Conservancy, Wyoming Chapter
Dave Anderson, Director and Chief Scientist, Colorado Natural Heritage Program
Anthony D. Apa, Ph.D, Avian Research Biologist, Colorado Parks & Wildlife
Danielle Bilyeu Johnston, Ph.D., Habitat Researcher, Colorado Parks & Wildlife

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Executive Summary

To be completed at a later date.

1.0 HQT Overview

The Greater Sage-Grouse Habitat Quantification Tool (HQT) is an approach to estimating the condition, or habitat value, of a given location on the landscape for Greater Sage-grouse (*Centrocercus urophasianus*; hereafter GRSG). The HQT uses a "functional acre" approach, applied through a set of measurements and methods that relate to the habitat attributes influencing GRSG selection of seasonal habitats across varying spatial and temporal scales (Stiver et al. 2010). The purpose of the HQT is to serve as a means of quantifying the change in condition of habitats for GRSG resulting from management action—either as an impact ("debit") or as a benefit ("credit") in the Wyoming Conservation Exchange (Exchange).

The HQT describes how the quality of GRSG habitat and change in quality resulting from management actions is quantified. Conditions specific to each seasonal habitat type (i.e., breeding, summer, and winter) are accounted for independently. In other words, the HQT calculates a separate functional acre score for each seasonal habitat type. The Exchange Operations Manual (Exchange Manual) defines how these scores are used by the Exchange.

To quantify the quality of GRSG habitat, the pre-project conditions at the site are measured to determine the current ecological performance of the site based on specific, pre-determined habitat requirements of the species, measured as a preliminary "functional acre" score. The number of functional acres is then adjusted to account for local context, landscape condition and position, which can decrease the site score. Next the projected (not actual) post-project condition is evaluated to determine the extent to which the site's ability to support the species is projected to change as a result of the project. The post-project condition is the basis for the credit/debit estimate for the proposed project. Once the project is underway, the actual changes in conditions are verified using the HQT and credits are released according to the actual credit/debit amount and the credit release schedule for the project, as defined in the Exchange Manual.

This version of the HQT has been developed for use in the Exchange but is a framework that can be easily adapted for use throughout the species' range. The intent of the Exchange is to provide financial incentives for achieving a net habitat benefit through conservation investment and compensatory mitigation for GRSG across large landscapes. Using the "functional acre" as its basic unit of currency, the Exchange provides a trading platform for conservationists, private landowners and developers that simultaneously takes into account both habitat quantity and quality.

1.1 The Functional Acre Approach

The HQT describes how to determine the number of "functional acres" of impact or benefit generated by a given project. The term "functional acres" refers to the size of a site (acres) multiplied by its quality (or "functionality"). The functionality of a site represents its level of performance relative to optimal conditions and takes into account species-specific habitat features at multiple scales that are known to be meaningful to GRSG, including the quality and structure of vegetation on the site and the degree of human disturbance on and surrounding the site.

The "functional acre" approach provides several advantages over traditional mitigation approaches. First, it establishes a common "currency" (functional acres) for the Exchange. The integration of habitat area and quality allows for accurate accounting of biological impacts and benefits because they can be compared directly, as "apples to apples", which provides a clearer understanding of whether or not conservation goals are being met (McKenney and Kiesecker 2010, Gardner et al. 2013). A common currency also allows for standardization in the calculation of credits and debits, which affords the opportunity to conduct mitigation consistently across projects, land ownership and jurisdictional boundaries. It also provides a common language and metric for mitigation across agencies and industries, while striving to be responsive to new science as it emerges.

Second, the functional acre approach accounts for not only the physical footprint of development, but also for biological impacts knows as "behavioral avoidance," by accounting for distance-effects associated with anthropogenic infrastructure (Manier et al. 2013). Accounting for behavioral avoidance as part of the currency of the Exchange offers two strengths: 1) a more accurate representation of the full biological impact on GRSG; and 2) a strong incentive for targeting debits and credits to the most appropriate places on the landscape, clustering development where it will have the least species impact and focusing conservation efforts where they will have the greatest benefit. Furthermore, in step with current thinking about full life cycle conservation, the HQT strives to reflect the species' needs throughout the annual cycle, based on best available science.

Third, fundamental to the functional acre approach is a focus on the measured habitat conditions resulting from impactful or beneficial management. Rather than rewarding the completion of management actions or practices that may or may not succeed, the Exchange focuses the activities of developers, ranchers and conservationists on what matters most to the GRSG – the resulting habitat outcomes of the practices, not the practices themselves. Paying for outcomes rather than practices has also been shown to achieve more conservation per dollar spent than paying for management practices (Just and Antle 1990, Antle et al. 2003). The outcomes-based functional acre approach of the HQT enables the Exchange to provide strong incentives to achieve habitat and landscape outcomes required by GRSG.

1.2 A Framework for Quantifying Habitat Functionality

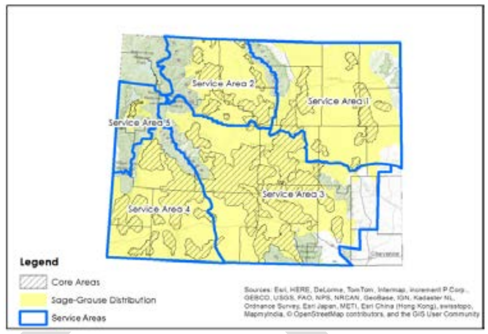
The HQT was developed to account for the habitat characteristics or attributes, both natural and anthropogenic, which influence GRSG habitat selection across multiple scales. These habitat characteristics were based on different orders of selection (Stiver et al. 2010), which represent four levels of spatial scale at which habitat attributes influence where GRSG reside and obtain resources necessary for survival and reproduction. Johnson (1980:69) describes this hierarchical nature of selection as: "a selection process will be of higher order than another if it is conditional upon the latter." As an example, selection of food items will be of a higher order than selection of feeding site because selection of a particular feeding site determines the array of food items available to be selected. While the term "selection" may be interpreted as relating to individual bird behavior, in this context we apply the term broadly (per Johnson 1980, Connelly et al. 2003, Stiver et al. 2010) to describe the four geographic scales at which GRSG occur, are organized into populations and use habitat. These four scales also correspond to scales at which GRSG policy and management are typically implemented (Stiver et al. 2010). Connelly et al. (2003) describe the progression of habitat selection across orders as follows:

- 1st order selection represents the geographic range of the GRSG population of interest—1st order habitat attributes are those necessary for the species to occur.
- Within this geographic range, 2nd order selection is based on habitats required by subpopulations; for example, the habitats necessary to support the GRSG associated with a lek or lek complex.
- 3rd order selection refers to the habitats used by individuals in the subpopulation and is defined by the attributes necessary for an individual to survive and thrive throughout a year; this order is relevant at the scale of a home range.
- 4th order selection establishes the food and cover attributes at particular sites.

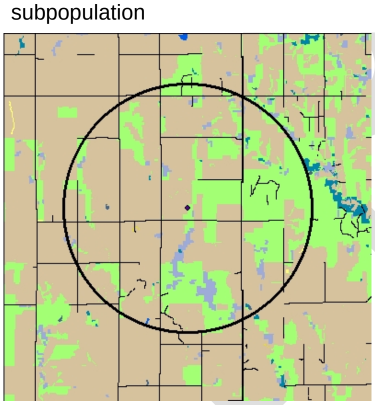
Although the orders of selection are described as stand-alone, these orders are inherently related and the value of a location for GRSG as quantified at a given order is only as good as the values measured at other orders. For example, the habitat conditions within a patch of sagebrush (4th order) may be highly conducive to successful nesting and early brood-rearing, but if suitable late brood-rearing habitat is not accessible from that patch (3rd order) or that patch is located in the middle of a forest (2nd order), the value of that patch for GRSG is diminished or negligible. The orders considered in the HQT are illustrated in Figure 1.

1st Order
Occupied range for the species in WY

2nd Order
Habitats required by subpopulations



3rd Order
Habitats used by individuals in the subpopulation



4th Order
Habitat conditions at the site of proposed activities

Figure 1. Orders of Selection Specific to the Wyoming Conservation Exchange for Greater Sage-Grouse

The use of multiple scales of measurement enables the HQT to accomplish three essential tasks to program management:

1. **Measure impacts (debits) and benefits (credits) for transactions.** This is a measurement of the functionality at the 4th order (site) and how it affects, and is affected by, the 3rd order (local

context). This measure is the basis for calculating debit and credit amounts as defined in the Exchange Manual.

2. **Ensure that credits and debits reflect habitat quality in order to facilitate net habitat benefits across large landscapes.** This is a measurement of the relative quality or “value” of landscapes in which development or mitigation sites are located (2nd order).
3. **Track the contribution of the Exchange to species habitat and population conservation goals in Wyoming over time.** This is a measure of the overall performance of the Exchange by evaluating the program’s cumulative net benefit and understanding how habitat benefits contribute to conservation goals in Wyoming (1st order).

1.3 Components of the HQT

There are three components of the HQT:

1. This **HQT Scientific Methods document** includes a description and definition of the attributes measured and scored at each of the four scales of habitat selection, methods of measurement for each attribute, and supporting documentation (e.g., peer-reviewed literature, gray literature and datasets, expert opinion and knowledge) illustrating why those specific attributes and methods are used. It also includes the data collection methods (Appendix E) and describes the monitoring and adaptive management process for monitoring and evaluating the accuracy, effectiveness, and efficiency of the HQT and subsequent adaptation of the HQT (section 6.0).

2. The **HQT Calculator** is a Microsoft Excel-based spreadsheet that performs the calculations using field data and the information contained in the HQT Scientific Methods document. It also includes use instructions for the Calculator.

3. The **HQT User’s Guide** is a description of how to apply the desktop analyses portion of the HQT.

2.0 Habitat Quality and Species Performance

Habitat represents a particular combination of resources (e.g. food, shelter, and water) and environmental conditions that support survival and reproduction (Morrison et al. 2006). Habitat can vary in quality and therefore its ability to support survival and reproduction over time. Inherent in the HQT approach is that there is a direct relationship between high quality habitat and population resiliency. Conversely, poor quality habitat is assumed to result in low survival and reproduction (Van Horne 1983), leading to poor population resiliency. Marginal habitat may support some amount of occupancy by a species, but these marginal conditions may still result in low survival and/or reproduction and questionable resiliency, which will likely lead to population declines without high levels of immigration.

Vegetation vertical and horizontal structure and diversity are important attributes influencing habitat selection by birds (Cody 1985). These structural elements influence cover and food resources. Animal species range in their ecological niche from generalists to specialists in their habitat requirements (Ricklefs 1979), and the life history traits and habitat use of a specialized species like GRSG can be influenced more dramatically if the vegetation composition, structure, and/or juxtaposition are changed. Vegetation composition and structure makes a difference in quantity and quality of habitat for GRSG, and therefore the HQT considers specific vegetation features that are known to be particularly important to GRSG when evaluating habitat quality.

GRSG population persistence has been linked to the availability of sagebrush habitat; the dependence of the species on sagebrush through all seasonal periods has been well documented and cannot be over-emphasized (Connelly et al. 2004). Different vegetation structure and composition is required for different seasonal periods of habitat use. Although GRSG use a variety of habitats throughout the year, sagebrush is a common and required component (Connelly et al. 2000; Connelly et al. 2011c).

The HQT focuses on three seasonal periods and their habitat associations. There are many citations outlining these seasons, summarized by Hagen et al. (2007), Connelly et al. (2011c) and Connelly et al. 2004, and it is not the goal of this document to conduct an exhaustive review of the literature on GRSG seasonal habitat nomenclature. The seasonal periods include breeding, summer, and winter habitat, and the HQT does not consider transitional periods where habitat selection is less uniform (Connelly et al. 2000). The breeding season includes habitats associated with the pre-nesting, nesting and very early brood-rearing season (approximately mid-March – June); the summer season includes habitats associated brood-rearing females, males, and unsuccessful females (approximately July – September); and the winter season includes habitats that are almost exclusively sagebrush dominated (November – mid-March) (Connelly et al. 2011c).

GRSG leks are situated in areas with minimal shrub cover adjacent to relatively dense sagebrush stands where strutting male exposure is maximized, but escape, thermal, and feeding cover is readily available (Patterson 1952, Gill 1965). One of the most important landscape characteristics for leks may be their proximity and configuration with nesting habitat (per theories of lek evolution and mating behavior; Gibson 1996). Across the range of the species, nesting GRSG consistently select areas with more sagebrush canopy cover and taller grasses compared to available habitats (Hagen et al. 2007), and tall, dense herbaceous cover – including residual (e.g., standing dead) grasses – in selected dense sagebrush stands tends to increase the probability of a successful hatch (Holloran et al. 2005). GRSG females generally rear their broods for the first two to four weeks following hatch in the immediate vicinity of their nest within sagebrush-dominated habitats (Connelly 1982,Thompson 2012). Thermal and predator protection of young chicks (e.g., dense sagebrush stands; Thompson et al. 2006) and food availability (e.g., insects and succulent forbs; Johnson and Boyce 1990, Drut et al. 1994) are important for chick survival during the early brood-rearing period. Lekking, nesting and early brood-rearing habitats are generally considered together as breeding habitats (Connelly et al. 2000).

Post-nesting, GRSG broods remain in sagebrush-dominated habitats until range desiccation induces them to move to habitats still supporting succulent herbaceous vegetation; GRSG may use a variety of sagebrush and other habitats (e.g., springs and seeps, riparian corridors, stock ponds, wet meadows and irrigated agricultural fields adjacent to sagebrush habitats) during summer (Peterson 1970, Wallestad 1971, Neel 1980, Fischer et al. 1997). Selection of wintering habitats by GRSG is influenced by snow depth and hardness, topography (i.e., elevation, slope, and aspect), and vegetation height and density (Gill 1965, Greer 1990, Schroeder et al. 1999). During the winter GRSG rely almost exclusively on sagebrush exposed above the snow for forage and shelter (Patterson 1952, Remington and Braun 1985, Robertson 1991, Schroeder et al. 1999, Connelly et al. 2000, Crawford et al. 2004).

2.1 The Importance of Spatial and Temporal Scale

As with many ecological processes, habitat selection occurs at multiple spatial scales, with individuals choosing to settle in a location by keying in to different features at different scales (Hilden 1965, Johnson 1980, Wiens et al. 1987, Wiens 1989, Orians and Wittenberger 1991, Fuhlendorf and Smeins 1996, Fuhlendorf et al. 2002, Morrison et al. 2006). This applies to vegetation in particular, as birds may perceive physical vegetation structure first over a relatively large, landscape scale, and then settle across the landscape according to more fine scale vegetation composition and other factors (Wiens et al. 1987). Temporal (time) scales also vary among ecological processes and may not be linear especially in varying environments (Wiens 1989). The time required for a vegetation community to respond to management practices or changes in habitat and its influence on GRSG vital rates varies by ecosystem, geography, climate, and land use. For GRSG, time lags of two to ten years have been observed for population response to infrastructure development (Holloran 2005; Harju et al. 2010; Walker et al. 2007) or even longer with changes in habitat structure (e.g. fire) (Connelly et al. 2011b). Despite the uncertainty that will inevitably arise around this topic, temporal scales must be taken into consideration when establishing a mitigation project, and as spatial scales of a project or evaluation area increase, so should temporal scales.

Temporal scale for sagebrush projects deserves especially close consideration given that recovery of sagebrush is an especially difficult and slow process due to abiotic variation, short-lived seedbanks, and long generation time of sagebrush; where soils and vegetation are highly disturbed, sagebrush restoration can be challenging if not impossible (Monsen 2005).

3.0 Habitat Quantification Methods and Attributes

The ultimate objective of the Exchange is to contribute to conservation of GRSG by providing net habitat benefit to the species through compensatory mitigation. It is assumed that improved habitat conditions ultimately result in larger and more secure GRSG populations. Therefore, the Exchange should monitor and report cumulative habitat impacts and benefits that are anticipated to have a net habitat contribution to populations.

To make a direct link between habitat management and population response, an estimate of population impacts from activities at the 4th and 3rd orders would be needed. That is not currently feasible and it is not an objective of the Exchange to directly link site level management actions to a population-level response of GRSG. The Exchange is focused on actions that occur at the site level, and the methods required to accurately measure conditions at that scale (e.g., vegetation plots) are not conducive to large-scale assessments. However, additional research could contribute to a greater understanding of how cumulative habitat changes contribute to population viability. Furthermore, as long as debits are offset by credits, and as credits accumulate beyond debits, the Exchange will contribute to net increases in high quality habitat that we believe to be likely to sustain resilient GRSG populations over time.

3.1 Greater Sage-Grouse Occupied Range in Wyoming

The 1st order is the current estimated occupied range (EOR) of GRSG in Wyoming. The species' distribution is thought to have varied substantially over the species' history, and GRSG currently occupy 56% of their potential pre-settlement distribution (Schroeder et al. 2004). The reduction in distribution in North America appears to be a consequence of altered sagebrush habitat quality and quantity (Schroeder et al. 2004). Documented changes to the EOR will be tracked and incorporated into the HQT over time through the adaptive management process described in the Exchange Manual.

Credits and debits are tracked, exchanged and reported within a distinct mapped geographic region called a service area. The Exchange's service areas are depicted in Figure 2.

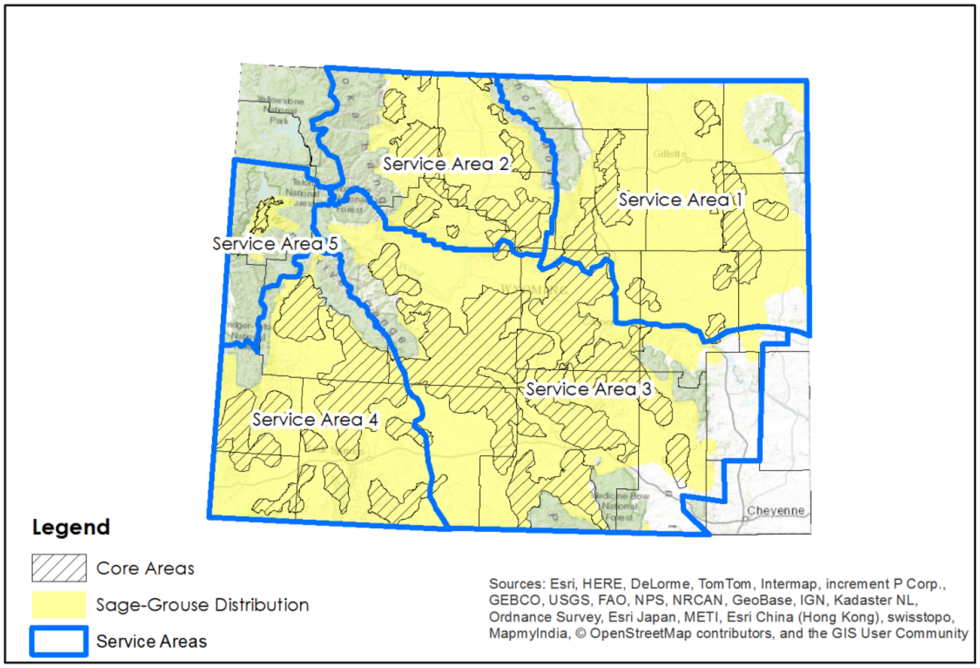


Figure 2. Service Areas in Wyoming

3.2 Assessment of Site Condition

When a project area is within the occupied range of GRSG in Wyoming, the HQT is an approach to establishing the conditions or "function" of a project area, defined as the area of a debit project (i.e., the project footprint) or the area of a credit project (i.e., the area that has been delineated for credit generation within a participant's contract). The HQT initially focuses on quantifying the condition of a site at the 4th order based on vegetative cover, structure, composition and topography. The 4th order attributes are indicative of habitat suitability and quality for the GRSG, including conditions that support breeding, summer, and winter habitats, and in part, are identified as components of structural habitat guidelines and are important in GRSG habitat selection (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007). The functional acre score resulting from these 4th order measures is then modified based on the local and landscape context of that site. The concept model presented in Figure 3 illustrates the attributes being measured and the role they play in providing suitable breeding, summer, and winter habitat for GRSG.

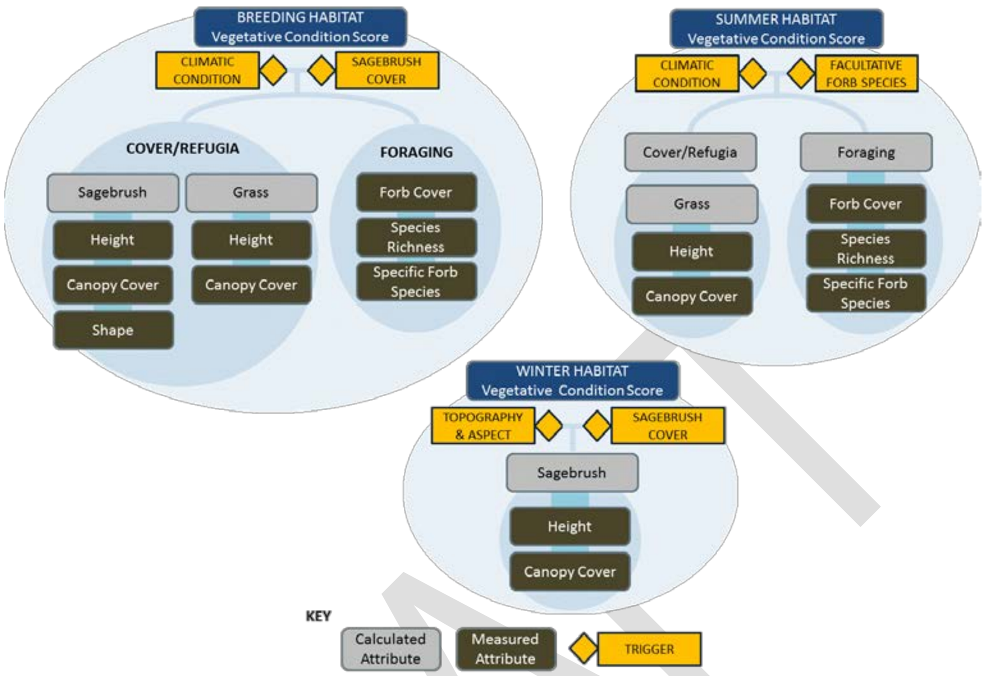


Figure 3. Conceptual Model Depicting GRSG Life History Requirements

3.2.1 Decision Triggers

A set of criteria or decision triggers determine whether a location can be considered GRSG seasonal habitat and whether it is in arid or mesic conditions. For example, sagebrush cover has to be greater than or equal to 5% to consider a site potential breeding habitat, so 5% sagebrush cover is a trigger for breeding habitat. If sagebrush cover is <5% at a site it cannot be considered suitable breeding habitat and therefore is not scored for breeding habitat value; that value is 0. Triggers are also used to establish which set of scoring curves needs to be used for a given site, either scoring curves meant for mesic conditions (i.e., sites generally in >30 cm annual precipitation zone) or curves meant for arid/xeric conditions (i.e., sites generally in 18-30 cm annual precipitation zone). The triggers used in the HQT are described in Table 1.

Table 1. Decision Triggers Used in the HQT

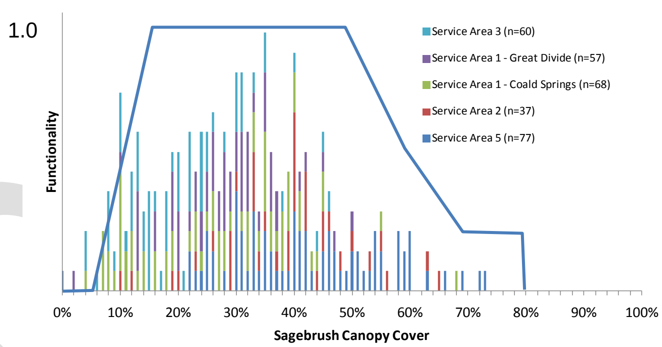
Attribute	Trigger	Definition
Sagebrush Canopy Cover	≥5% required for breeding and winter habitat	A primary factor influencing the functionality of a site for GRSG is the presence of sagebrush (Connelly et al. 2000, Hagen et al. 2007, Connelly et al. 2011c). GRSG require sagebrush for food and cover during the breeding and winter seasons. Although a precise functionality value between 0 - 5% is unknown, it is the expert opinion of the Science Team that if a site has <5% cover in breeding habitat, the habitat function of a site is reduced to zero at the 4th order.
Microclimate Conditions	Determine whether site is either mesic conditions or arid/xeric conditions for breeding, summer, and winter habitats	The wide range of the GRSG results in different vegetation potentials regionally in Wyoming that are influenced primarily by soil characteristics and annual precipitation. Encouraging the identification of suitable and high quality habitat within each region of the state requires consideration of these conditions and how they impact functionality scores. For example, vegetation in arid conditions have different potential than sites in mesic conditions. These conditions influence plant community composition, productivity and presence (Winward 2004). The HQT addresses this site variability by using different scoring curves and tables for sites in mesic and xeric conditions, but annual precipitation changes are different than site conditions (e.g. drought conditions). • Arid condition: sites generally in 18-30 cm annual precipitation zone (Winward 2004); *Artemisia tridentata wyomingensis* is a common big sagebrush sub-species for this type of site; • Mesic condition: sites generally in a >30 cm annual precipitation zone (Winward 2004); *Artemisia tridentata vaseyana* is a common big sagebrush sub-species for this type of site
Mesic Forb Presence	Presence of mesic forbs required for summer habitat	GRSG use upland as breeding habitat (Connelly et al. 2011c). As the season advances and the understory herbaceous vegetation desiccates, GRSG move to more mesic conditions (Connelly et al. 2011c). GRSG preferentially select sites close to sagebrush, but seek the areas where moisture allows forbs to grow throughout the summer (Connelly et al. 2011c) and they have free access to water. Accordingly, the HQT classifies summer habitat based on the presence of specific plant species that indicate the vegetation at the site will remain green over the course of the summer. If there are mesic forb species present, then the summer score is calculated. If there are no mesic forb species present, the project site scores 0 for summer habitat.

Topography and Aspect	Determine the topography and aspect curves (slope <5% or >5%) for winter habitat	GRSG generally prefer relatively open sagebrush flats or open rolling sagebrush hills (Connelly et al. 2011c, Hupp 1987, Hupp and Braun 1998, Doherty et al. 2008), but this can be population specific. However, in winter GRSG inhabit areas with moderate to dense black (*A. nova*) and low (*A. arbuscula*) sagebrush and are also found on ridge tops with a south to west aspect (Hupp and Braun 1989, Doherty et al. 2008). Because some winter sites have relatively short sagebrush, there is no minimum height requirement for black and low sagebrush on ridge tops as there is in open sagebrush flats where snow accumulates. Sagebrush height > 10 cm is the minimum height for winter habitat. Accordingly, the 4th order winter score is based on the topography (percent slope) and aspect of the project site. There are two scoring curves and tables that correspond to the topography at which the sample point is taken: one scoring curve and table is used for slope greater than 5%, and a different scoring curve and table is used for slope less than 5%.

3.2.2 Scoring Curves

After establishing the specific seasonal habitats being scored and which scoring curves to use, each vegetation attribute measured at the site is scored using the appropriate scoring curve. For example, Figure 4 is the scoring curve and associated table for sagebrush canopy cover in breeding habitat.

Comment [LH1]: This figure will be updated with actual WY scoring curve and table.



% Cover	< 5	5-14	15-19	20-29	30-39	40-49	50-59	60-69	70-79	>80
Functionality	0	0.5	1	1	1	1	0.5	0.25	0.25	0

Figure 4. Sagebrush Canopy Cover Scoring Curve and Associated Table for Breeding Habitat

The scoring curve simply establishes the relationship between sagebrush canopy cover and breeding habitat value, the shape of which was established from literature and expert opinion. Sagebrush canopy cover at every potential GRSG breeding site is between 5 and 100%, and the scoring curve establishes the condition or value of each site relative to optimal conditions—from 0 (non-habitat) to 1.0 (optimal canopy cover). Zero functionality indicates that the site has no value for GRSG, while 100% functionality indicates that the site is fully functional for GRSG. The scoring curves for all of the vegetation attributes measured are included in Appendix A.

Scoring response curves for each attribute were developed by the Science Team.

Comment [LH2]: This section will describe the data and process that was used to develop the scoring curves. This version of the HQT will include only scoring curves for the Upper Green. Additional curves will be developed for each service area that reflect vegetation conditions for each area and grouse response to those conditions.

More detailed information on how the scoring curves are used to calculate scores is available in Section 4.1.

3.2.3 Vegetation Attributes

Vegetation attributes are quantified at the scale of a map unit. Map units are predefined for all Exchange participants and are the basis for all credit and debit calculations. A systematic grid provided by the Exchange for all participants delineates map units and indicates specific plot sampling locations at the center of each map unit. Vegetation attributes are measured at the sampling location within each map unit to calculate 4^{th} order habitat quality.

The height, structure, density, and cover of vegetation are important for providing cover and food resources adequate for productive seasonal habitat (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007, Connelly et al. 2011c). The rationale for vegetation attributes and scoring are established in Table 2. The attributes are repeatedly supported and justified by the aforementioned literature citations (and the citations within) that describe GRSG habitat (unless otherwise noted). Each habitat attribute is measured directly through vegetation plots (see Appendix E).

Table 2. Vegetation Characteristics Measured at Credit/Debit Project Sites

BREEDING		
Cover / Refugia	Sagebrush Height (quantitative measure)	This woody shrub overstory vertical attribute estimates the average height of a sample of sagebrush plants along a line transect.
	Sagebrush Canopy Cover (quantitative measure)	This woody shrub overstory horizontal attribute estimates the canopy (foliar) cover of sagebrush along a line-intercept or point-line intercept.
	Sagebrush Shape (qualitative measure)	This describes the growth-form of sagebrush. It is assumed that a columnar structure (Stiver et al. 2010) provides less horizontal structure (and less cover) at the ground level than more prostrate growth forms.
	Perennial Grass Height (quantitative measure)	This herbaceous vertical understory attribute estimates the average height of a sample of perennial grass heights along a line transect.
	Perennial Grass Cover (quantitative measure)	This herbaceous understory attribute estimates the percent grass horizontal cover structure along a line intercept or point-line intercept.
Foraging	Forb Cover (quantitative measure)	This herbaceous understory attribute estimates the percent horizontal forb cover. This attribute can be measured with line intercept or point-line intercept.
	Forb Species Richness (quantitative measure)	This is the simplest measure of forb diversity. The number of species detected is influenced by the size of the microplot sampled (Rosenzweig 1995). Sampling is conducted over 10 square meters with a1m^2 quadrat.
	Specific Forb Species Presence (qualitative measure)	A simple index to food availability (Appendix D)
SUMMER		
Cover / Refugia	Perennial Grass Height (quantitative measure)	See above
	Perennial Grass Cover (quantitative measure)	See above
Foraging	Forb Cover (quantitative measure)	See above
	Forb Species Richness (quantitative measure)	See above
	Specific Forb Species Presence (quantitative measure)	See above
WINTER		
Cover / Refugia and Foraging	Sagebrush Height (quantitative measure)	This woody shrub overstory vertical attribute estimates the average height of a sample of sagebrush plants along a line transect. It is a measure of food and cover.
	Sagebrush Canopy Cover (quantitative measure)	This woody shrub overstory horizontal attribute estimates the canopy (foliar) cover (and food) of sagebrush along a line-intercept of point-line intercept.

3.2.3 Vegetation Attribute Weighting

The score for each habitat attribute is then weighted as established in Table 3. The weights are based on expert opinion, are on a relative scale and add to 100. See also Connelly et al. 2011c for a review of habitat requirements for GRSG habitat, and aforementioned literature citations (and the citations within) that describe GRSG habitat. The scores are multiplied by the weight, and the weighted scores across all attributes for that season are then added to generate a final seasonal vegetation score for a site. With respect to scoring, the weights are only applied to the habitat attributes as described in Table 3. The four orders of habitat selection are not weighted in any way.

Table 3. Vegetation Attribute Weighting Values

BREEDING							
Cover / Refugia (50%)					Forage (50%)[A]		
Sagebrush Height 6%	Sagebrush Canopy Cover 15%	Sagebrush Shape 4%	Grass Canopy Cover 12.5%	Grass Height 12.5%	Forb Cover 16.7%	Forb Species Richness 16.7%	Presence of Specific Forbs 16.7%[B]

SUMMER [C]				
Cover / Refugia (30%)		Forage (70%)		
Grass Canopy Cover 15%	Grass Height 15%	Forb Cover 23.3%	Forb Species Richness 23.3%	Presence of Specific Forbs 23.3% [B]

WINTER	
Sagebrush Height 50%	Sagebrush Canopy Cover 50%

Reference: The weights are based on expert opinion. See also Connelly et al. 2011c for a review of habitat requirements for GRSG habitat, and aforementioned literature citations (and the citations within) that describe GRSG habitat.

[A] Cover / refugia is more important during the nesting portion of breeding season. However, during early brood-rearing the importance shifts as nutrient availability becomes equally as important. As a result both cover/refugia and foraging are weighted equally for breeding habitats.

[B] Forb cover 100% desirable (score 1.0); forb cover a mixture of non-native invasive/noxious weeds and desirable forbs (score 0.5); forb cover 100% non-native invasive/noxious weeds (score 0).

[C] During the summer, foraging is more important than cover/refugia. Barnett and Crawford (1994) found that diet of GRSG hens during the pre-laying period may influence reproductive success. Drut et al. (1994) found the protein-rich diet of forbs and insects of chicks enhanced the nutritional status of chicks and increased survival.

3.2.4 Assessing Value of Vegetation at a Site – An Example

Comment [LH3]: The numbers in this section will be updated based on the actual WY scoring curves.

A field team estimates the following vegetation measures on an arid location suitable for breeding (i.e., sagebrush canopy cover >5%): sagebrush height 28 cm; sagebrush canopy cover 22%; spreading sagebrush shape; perennial grass height 12 cm; perennial grass canopy cover 14%; forb cover 6%; forb species richness 4 species; and all the forbs present desirable (refer to Appendix D and Appendix E for desirable forb list and field vegetation measurement protocol, respectively). Using the scoring curves presented in Appendix A, these measures result in the following scores as established in the tables associated with each scoring curve: sagebrush height 0.5; sagebrush canopy cover 1.0; spreading sagebrush shape 1.0; perennial grass height 0.8; perennial grass canopy cover 1.0; forb cover 0.8; forb species richness 0.75; and all forbs present desirable 1.0. Using these scores with the weights presented in Table 3, the following calculations are made (and depicted in the table below): sagebrush height (0.5*0.06) = 0.03; sagebrush canopy cover (1.0*0.15) = 0.15; spreading sagebrush shape (1.0*0.04) = 0.04; perennial grass height (0.8*0.125) = 0.1; perennial grass canopy cover (1.0*0.125) = 0.125; forb cover (0.8*0.167) = 0.134; forb species richness (0.75*0.167) = 0.125; and desirable forbs present (1.0*0.167) = 0.167. The weighted scores are then summed across vegetation attributes to establish a final *breeding season* vegetation score for the site of 0.871. The value of the vegetation at the location for other seasons (i.e., summer and winter) will use the triggers, scoring curves and weights specific to those seasons.

Attribute	Sage-brush height: 28 cm	Sage-brush cover: 22%	Sage-brush shape: spreading	Perennial grass height: 12 cm	Perennial grass cover: 14%	Forb cover: 6%	Forb species richness: 4	All desirable forbs	
Scoring table values	0.5	1.0	1.0	0.8	1.0	0.8	0.75	1.0	
Weights	0.06	0.15	0.04	0.125	0.125	0.167	0.167	0.167	
Weighted scores	0.03	0.15	0.04	0.1	0.125	0.134	0.125	0.167	0.871

These scores are then "modified" based on the landscape context of the project area as described below.

3.2.5 Site Context (4th Order Modifiers)

Invasive Grass Cover

Invasive grass cover is a modifier for breeding and summer habitats, and is estimated through vegetation plots (see Appendix E). The influence of invasive grass cover on site-level condition scores is established in Table 4. Primary data from Wyoming was used to inform the values in Table 4. Cheatgrass cover was compared to shrub cover, perennial forb cover, and perennial grass cover. Shrub cover, perennial forb cover, and perennial grass cover all declined with annual grass cover.

Comment [LH4]: This will be updated to describe data used for the scoring curves.

Table 4. Modifications to Site-Level Condition Scores of Breeding and Summer Habitat Due to Invasive Grass Cover

Comment [LH5]: Values may be revised to reflect vegetation conditions. It may also be the case that there are additional tables for each service area.

Percent Cover of Invasive Grass	Percent Adjustment Multiplier
0 - 1%	100%[A]
1 – 5%	80%
5 - 10%	50%
10 - 15%	10%
>15%	0%

[A] For example, 100% value indicates that the site-level condition score is multiplied by 1, or no change in value if invasive grass cover is less than 1%. In contrast, if invasive annual grass cover is between 5 and 9%, then the site-level condition score is multiplied by 0.5, so the value of that location is reduced.

Invasive plants, especially invasive non-native grasses (e.g., cheatgrass and smooth brome) in sagebrush-steppe habitats, alter plant community structure, composition and productivity and may competitively exclude native plants important as cover and forage for GRSG (Vitousek 1990, Mooney and Cleland 2001, Rowland et al. 2010). The most pronounced negative consequence of non-native grass invasion into sagebrush habitats is the resulting change in fire frequency and intensity (Balch et al. 2013). Ultimately, non-native grasses promote fires and fires promote non-native grasses. Fire also facilitates the conversion of rangelands from perennial-dominated to annual-dominated systems by eliminating fire-intolerant species (e.g. big sagebrush) from these systems, rendering them permanently unsuitable to GRSG (Connelly et al. 2004, Epanchin-Niell et al. 2009, Davies et al. 2011). In central Nevada, recruitment of male GRSG to leks was consistently low in areas with high proportions of non-native grasslands interspersed in the landscape within 5 km of a lek, even during years when climatic conditions resulted in substantial recruitment to leks in the region (Blomberg et al. 2012). When invasive grass cover within the project area surpasses 15%, then the breeding and summer habitat functionality scores are reduced to 0; scores are decreased according to a negative decay relationship for invasive grass cover values less than 15% (Table 4).

Influence of Anthropogenic Activity on Habitat Value

Research has established a "distance-effect" associated with anthropogenic infrastructure whereby GRSG on leks are negatively influenced to a greater extent if infrastructure is located near the lek with the response diminishing as distances from lek to infrastructure increase (Manier et al. 2013). In the HQT the distance-effect is the influence infrastructure has on habitat function. The magnitude of this effect may be related to the levels of human activity associated with the infrastructure (Remington and Braun 1991, Dzialak et al. 2012). Holloran (2005) reported that impacts of natural gas development to the number of males occupying leks were discernable to 3 km for lower activity sites (producing well pads) and 6 km for higher activity sites (drilling rigs). Consistently negative effect of roads, natural gas development, urban development[1], and surface mining to GRSG populations have been reported (see Johnson et al. 2011,

[1] The available data on urban development do not include many rural houses and barns.

Knick et al. 2011, Manier et al. 2013); the impacts of these infrastructures are considered in the HQT. Research investigating other infrastructures with the potential to negatively influence GRSG habitat use (e.g., wind turbines, communication and meteorological towers; see Manier et al. 2013) is lacking or inconclusive. The HQT will consider only the footprint of these types of infrastructure until more conclusive data emerges.

We propose to develop a Landscape Disturbance Index (LDI) to establish the modifications of site-level condition scores based on the distance of a project site to anthropogenic infrastructure influencing GRSG. The LDI would model the effects of anthropogenic disturbance on habitat value and would be a continuous surface GIS raster representing the cumulative impact of anthropogenic disturbance on a landscape). The cumulative aspect of the LDI would account for the density effects of infrastructure on the functionality of the landscape (e.g., Doherty et al. 2010a, Harju et al. 2010; see Appendix C). For each anthropogenic infrastructure considered, both a distance over which the effects of the infrastructure extend and a relative weight would be assigned. Effect distances are based on human activity levels associated with the infrastructure. Weights represent the relative degree of disturbance of a type of infrastructure relative to the highest level of disturbance possible at the location of disturbance, and are based on expert opinion. The indirect effect relationship would be established by a sigmoidal curve with the y-intercept the weight, the x-intercept the distance (3 or 6 km), and the midpoint of the curve occurring at 50% weight and distance (Figure 5).

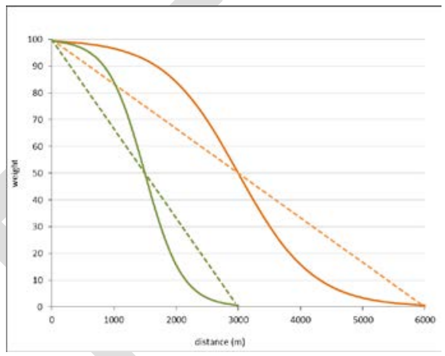


Figure 5. Example 3 km and 6 km Sigmoidal Decay Curves Showing the Shape and the Midpoint of the Curves at 50% Weight

Direct effects would be the footprint of the infrastructure at the weighted level. The weights and distances for infrastructure considered in the LDI are provided in Table 5. Because these modifications would be quantified in a GIS, the process results in a unique modification value between 0 and 1 for each 25×25 m pixel located within a project area. Appendix C provides a more detailed literature review of the anthropogenic attributes considered in the LDI.

Table 5. Anthropogenic Infrastructure Considered in the LDI with Weights and Distances Established for Each

Disturbance	Subtype	Weight	Distance (km)
Oil & Gas Wells [A]	Producing	100	3
	Non-producing	10	0
Towers (cell/met/etc)		50	0
Transmission Lines		100	3

Mines	Active – Large	100	3
	Active – Med or small	100	0
	Inactive – Large	50	0
	Inactive – Med or small	10	0
Agriculture	Tilled	100	*
	Untilled	10	0
Urban Development [B]	Med – High	100	6
	Low	75	3
Roads	Interstate	100	6
	State Highway [C]	100	4
	Unpaved roads	50	1.5
Reservoirs	Masked out		

Note that these results do not reflect distances for siting anthropogenic features around leks, but rather represent spatial impacts of these features on a variety of components of GRSG ecology on the general landscape.

* The edges of tilled agricultural fields were considered to have value for GRSG; the curve therefore is implemented into the field rather than an indirect effect away from the field.

[A] The HQT scores are based on the impact of the active production phase rather than the drilling phase.

[B] The available data on urban development do not include many rural houses and barns.

[C] "State highway" includes some unpaved roads that are major haul roads. These unpaved major haul roads are wide, heavily improved and experience high truck volume.

The LDI would quantify the value of a site for GRSG. An area degraded from anthropogenic structures would have a low LDI value, thus fewer debits will accumulate from adding additional infrastructure. Likewise, in the same degraded area the number of credits that are able to be generated would be limited due to the LDI value. Conversely, in areas with low levels of anthropogenic disturbance, the LDI value would be closer to 1, indicating that the landscape is of higher quality.

Accounting for Temporal Variation in Disturbance Levels

The Science Team recognizes the temporal variation in landscape disturbance (e.g. changes in activity level during different phases of well development or road traffic) with many anthropogenic features. However, there is a wide range of variation associated with the timing of activities among projects and companies, temporally and spatially. In addition, there is little to no available information on a site-by-site and day-by-day basis on this topic. Lastly, there is no research or information at the time of writing suggesting GRSG impacts change if anthropogenic activity levels change (e.g. no rigorous experimental manipulation of anthropogenic activity). As such, the Science Team is not able to provide a science-based recommendation or accounting method for temporal variation in disturbance levels.

3.3 Assessment of Surrounding Habitat

Habitat condition surrounding a project site may affect GRSG seasonal habitat use, dispersal, local persistence, and overall population trend (Connelly et al. 2011a, Connelly et al. 2011c). Thus, the HQT modifies site-level vegetation conditions based on the context of the site within the surrounding landscape. Each modifier is quantified as a value between 0 and 1 and each influences the vegetation condition score directly—i.e., the final vegetation score as described above is multiplied by each modifier score in succession to establish the final value score of the project area. The following sections describe the modifications made to site-level condition scores in more detail.

3.3.1 Landscape Context (3rd Order Modifiers)

The HQT considers three modifiers at the 3rd order:

- Conifer cover within a 1-km distance of a site;
- Distance to known lek – the distance from a site to the closest known active GRSG lek (modifier for breeding habitat);
- Presence of sagebrush cover – the distance from a site to the closest sagebrush patch (modifier for summer habitat).

Each of these modifiers is quantified with extant geospatial layers in GIS, which are provided to Exchange participants.

Conifer Cover[2]

Encroachment of conifers into upland sagebrush habitats – especially Utah Juniper (*Juniperus osteosperma)* and piñon (*Pinus edulis)*, which have expanded in recent years across most of the Intermountain West (Romme et al. 2009) – has the potential to transform sagebrush communities once suitable for GRSG into a less suitable state (Patten et al. 2005). Expansion of conifers into sagebrush communities can result in the elimination of the understory component important for GRSG and an increase in bare ground (Tausch and Tueller 1990, Miller et al. 2000, Petersen et al. 2009). Ongoing research in Colorado has found that in summer, GRSG use intact sagebrush habitats more frequently than similar areas which have encroaching piñon and juniper trees (Walker 2013). GRSG also strongly avoid conifer habitats in winter (Doherty et al. 2008) and during nesting (Doherty et al. 2010b). A study in Oregon found that the probability of lek activity declined with increasing conifer cover, with a 0% probability of activity with as little as 4 - 7% conifer cover within an area delineated by a 1-km buffer around a lek (Baruch-Mordo et al. 2013). Additionally, Miller et al. (2011) suggest that a negative

[2] In this case "conifer" refers to piñon and juniper species. However if other species are encroaching on GRSG habitat they should be considered in a similar fashion as described here.

relationship between sagebrush canopy cover and conifer cover exists; sagebrush canopy cover drops below 15% (Connelly et al. 2000) at between 10 and 15% juniper cover. The HQT therefore modifies all seasonal habitat types based on conifer cover, where habitats with <1% tree cover within the project area plus a 1-km buffer receive full value followed by a linear decline in value with habitats containing >10% conifer cover receiving 0 value (Table 6).

Table 6. Modifications to Site-Level Condition Scores for all Seasonal Habitat Types due to Conifer Cover

Comment [LH6]: Values may be revised to reflect vegetation conditions. It may also be the case that there are additional tables for each service area.

Conifer Cover within 1km Radius of Map Unit	Percent Value
0 – 1%	100%[A]
1 – 2%	85%
2 – 3%	75%
3 – 4%	65%
4 – 7%	40%
7 – 10%	20%
>10%	0%

[A] For example, 100% value indicates that the map unit score is multiplied by 1, or no change in value if conifer cover is ≤1%. In contrast, if conifer cover is between 1 and 2%, then the map unit score is multiplied by 0.85, so the value of that location is reduced.

A modifier which reduces GRSG habitat functionality according to conifer cover may provide incentive for piñon-juniper removal projects. Removal of the piñon-juniper cover can restore the productivity of shrubs and herbaceous vegetation in the understory, which is important for GRSG. However, not all piñon-juniper stands are suitable for this type of treatment. Miller et al. (2005) found that as juniper cover increases, sagebrush cover and the ability of the understory to respond positively to tree removal declines, with a threshold occurring at approximately 20% juniper cover (Miller et. al 2005). Beyond this threshold a positive response to tree removal should not be expected.

Therefore, a piñon-juniper project should only be eligible for credit generation if the pre-treatment piñon - juniper cover is 20% or lower. This criterion will help protect older piñon-juniper stands, and may aid in preventing unintended negative consequences of tree removal such as expansion of non-natives, such as cheatgrass (*Bromus tectorum*), which has been reported in several studies of piñon-juniper removal (Owen et al. 2009, Ross et al. 2012, Huffman et al. 2013).

Distance to Known Lek

GRSG breeding habitat is spatially tied to lek locations; the majority of females breeding on a given lek nest within 6 km of that lek (Holloran and Anderson 2005). However, a portion of the female population will move farther than 6 km from a lek to nest (Holloran and Anderson 2005, and see Doherty et al. 2011), so suitable breeding habitat located beyond 6 km from a lek does not have 0 value for GRSG. The HQT therefore modifies breeding habitats based on distance to closest known lek as follows: habitats within 6 km of a lek receive full value followed by a linear decline in value between 6 and 10 km from a lek, habitats farther than 10 km from a known lek receive 10% value as breeding habitat (Table 7).

Table 7. Modifications to Site-Level Condition Scores of Breeding Habitat Based on Distance to Lek

Distance to Known Lek (km)	Percent Value
0 – 6	100%[A]
6 – 7	50%
7 – 8	40%
8 – 9	30%
9 – 10	20%
>10	10%

[A] For example, 100% value indicates that the site-level condition score is multiplied by 1, or no change in value if the lek is located within 6km. In contrast, if a lek is located between 6 and 7km, then the site-level condition score is multiplied by 0.8, so the value of that location is reduced.

Presence of Sagebrush Cover

This modifier emphasizes the uniqueness of summer habitat used by GRSG. In the summer season, GRSG use a variety of habitats and mesic conditions (meadows and high elevation mesic communities, agricultural fields, etc.) with a common factor that sagebrush is nearby as escape or roosting cover (Connelly et al. 2000). During this season, GRSG use habitat that does not have sagebrush directly present, but it is in close proximity. Meadows, riparian areas, or other moist areas adjacent to sagebrush habitat can provide foraging areas during this season (Fischer et al. 1996a, Fischer et al. 1996b, Connelly et al. 2000, Connelly et al. 2011c). Given the range of distances presented in the literature across which GRSG will travel between meadows and similar areas to sagebrush cover, the Science Team chose a conservative estimate. Thus, the Science Team's expert opinion is as long as at least 5% sagebrush canopy cover is located with 300-m of each sample point, it is considered summer habitat and there is no effect to the score. If sagebrush is located beyond 300-m of the sample point, the score is reduced to zero (Table 8).

Table 8. Modifications to Site-Level Condition Scores of Summer Habitat Based on Presence of Sagebrush Cover

Presence of Sagebrush Cover (m)	Percent Value
0 – 300	100%[A]
>300	0

[A] For example, 100% value indicates that the site-level condition score is multiplied by 1, or no change in value if the sample point is located within 300m of sagebrush cover.

3.3.2 Proportion of Each Seasonal Range on the Landscape: Landscape Quality Index (2nd Order Modifier)

NOTE TO REVIEWERS: This section describes the LQI as it has been constructed for use in the Colorado Habitat Exchange. If suitable breeding, summer and winter habitat models are available for Wyoming, a similar methodology could be constructed for this Exchange.

There are 3 ways of assessing seasonal habitat availability:

1. **Use pre-existing models that show seasonal habitat locations.** The Fedy models (in review, citation needed) may be suitable for this modeling effort;
2. **Collect data to develop seasonal habitat models.** The practicality of this approach depends on data available, and could potentially be resource-intensive;
3. **Use expert opinion or pre-existing site-level data to determine seasonal habitat locations.** This approach would be site-specific and only available for projects in areas where suitable data exists.

We propose to use the Fedy models to determine seasonal habitat availability. If the Fedy models are not suitable, we propose the use of site-level data instead. We acknowledge that this site-level approach may not be available for all projects because it depends on the availability of suitable data.

If suitable seasonal habitat data are not available for Wyoming, the availability of seasonal habitat will not be part of the quantification of habitat value and as a result, habitat value for greater sage-grouse as calculated using the quantification approach described in this methods document will likely be over-estimated.

GRSG are sagebrush obligates, and populations typically occupy habitats with a diversity of species and subspecies of sagebrush (Connelly et al. 2011c). These sagebrush-dominated landscapes are typically intermixed with a variety of other habitats (e.g., riparian meadows, agricultural lands, grasslands, small conifer or deciduous tree patches) which are used by GRSG during certain times of the year (e.g., summer) or during certain years (e.g., above normal snow pack). The interspersion, juxtaposition and availability of the differing cover types used by GRSG during an annual cycle influence the effectiveness of a given landscape to provide GRSG with useable and high quality habitat (Connelly et al. 2011c).

We propose that a Landscape Quality Index (LQI) be developed as a modifier of site-level condition scores based on the proportion of seasonal habitats within the landscape surrounding a project area. In general, the process involves generating GIS layers across the range of GRSG that establish habitats suitable for breeding, summer and winter (see Appendix B for description of methods). Suitable breeding and summer habitats may be based on models presented in Fedy et al. (XXXX). Areas within the range of GRSG in Wyoming that do not provide the species with functioning habitat due to high levels of anthropogenic disturbance (e.g., urban developments, high-density energy developments) would be eliminated from the seasonal habitat layers. The total surface area of each seasonal habitat occurring within a 12.7-km radius buffer would be quantified; 12.7 km represents the spatial scale of a landscape used by an individual GRSG on an annual basis (Fedy et al. 2012). The total surface area estimates would be converted to proportions, and site-level condition scores would be modified as established in Table 9.

NOTE for each seasonal habitat, the value in the LQI modifier table that is **lowest** among the three seasonal habitat types is the LQI modifier. For example, if the proportion of breeding habitat is 45%, proportion of summer habitat is 32% and proportion of winter habitat is 34%, the LQI modifier is 50%.

Table 9. Modifications to Site-Level Condition Scores of Breeding, Summer and Winter Habitats Due to the Proportion of Each Seasonal Range Available on the Landscape

Landscape Quality Index Modifier Table			
Proportion of area ***breeding or winter***	Percent Value	Proportion of area ***summer***	Percent Value
>40%[A]	100%	>10%[C]	100%
35 – 40%	75%	8 – 10%	75%
30 – 35%	50%	5 – 8%	50%
25 – 30%	25%	2 – 5%	25%
<25%[B]	0%	<2%[D]	0%

[A] Literature referenced to establish 40%: Guidelines (2000); Wisdom et al. (2011); Knick et al. (2013).

[B] Literature referenced to establish 25%: Aldridge et al. (2008); Wisdom et al. (2011); Knick et al. (2013)

[C] Literature referenced to establish 10%: Johnson et al. (2011); Shepherd (2006)

[D] Literature referenced to establish 2%: Knick et al. (2013)

3.3.3 Final Value Assessment of a Site – Continuation of the Example

Comment [LH7]: This example will follow the previous in section 3.2.5, numbers will be updated based on the updated scoring tables.

To continue the example from above, initial site-level vegetation measures have yielded a preliminary breeding season vegetation condition score of 0.871. Next, the score is modified based on the surrounding context of the project area. Site-level information establishes cheatgrass cover on the project area of 4%. The proportion of suitable breeding, summer and winter habitats surrounding the project area is 60%, 9% and 55%, respectively. Conifer cover within 1 km of the site is 3%. The distance of the closest known lek to the site is 2.6 km. And the pre-project LDI score is 0.926. These measures result in the following scores as established in the tables associated with each scoring curve: cheatgrass cover 0.8; LQI 0.75; conifer cover 0.75; distance to lek 1.0; and pre-project LDI 0.926. By multiplying the vegetation score by these modifier scores, a final breeding season score of 0.417 is calculated for the site.

4.0 Calculating Functional Acres

Functional acres are calculated by the HQT to quantify impacts (debits) and benefits (credits) resulting from credit and debit projects. Functional acres account for the quantity and quality of the habitat impacted or benefited. The term “function” refers to the role of the habitat in providing for life history requirements of GRSG at a variety of spatial scales, from the site to the landscape scale. The calculation of functional acres includes both direct and indirect effects of anthropogenic disturbance.

Functional acres are the basis for credits and debits. Credits result when functional acres are enhanced and protected; debits result when functional acres are lost. Credits also represent a commitment to manage habitat at that level of quality into the future. Mitigation ratios may be applied when calculating credit and debit values as described in the Exchange Manual. The role of the HQT is to calculate functional acres, which can then be used to calculate credits and debits.

To calculate functional acres for a project, the project area is subdivided into map units. Vegetation attributes are measured within each map unit (4th order); translated to functional scores based on triggers, scoring curves and tables, and weighting; then modified to account for local context (3rd order) and landscape context (2nd order). For each map unit, habitat function (expressed as a percent) is multiplied by habitat area (expressed in acres) to calculate functional acres for the map unit. Functional acres for each map unit within the project are summed to calculate functional acres for the project. A functional acre value for each of the three seasonal habitat types is calculated. The basic formula for calculating functional acres is:

Functional Acres = Area x Vegetation Condition (4th Order) x Local Context Modifiers (3rd order) x Landscape Context Modifiers (2nd Order)

Table 10 depicts the calculation of functional acres for a hypothetical single map unit. The vegetation condition score is multiplied by each modifier score in succession to establish the final value score for each map unit

Table 10. Calculation of Functional Acres by Orders and Modifiers for Each Order

			Modifiers						
			4th		3rd			2nd	
Map Unit	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Pre- or Post-Project LDI	Conifer Cover	Distance to Lek	Presence of Sagebrush	LQI	Functional Acres
Breeding	**160**	0.5	0.95	0.755	1.0	1.0	N/A	1.0	57.38
Summer	**160**	0.6	1.0	0.921	1.0	N/A	1.0	1.0	88.42
Winter	**160**	0.8	1.0	0.873	1.0	N/A	N/A	1.0	111.74

To calculate credits or debits, first credit or debit baseline functional acres are calculated as defined in the Exchange Manual. Credits and debits are calculated from the difference between post-project functional acres and the credit or debit baseline functional acres, respectively. Credit projects may define multiple levels of increasing quality that are expected to be achieved over time, which will result in generation of additional credits once habitat function and performance standards have been met. Credits and debits are tracked, exchanged and reported within service areas.

The purpose of this section is to describe the basic mathematical formulas used to calculate functional acres. The HQT Calculator spreadsheet should be used to facilitate this calculation. The process for calculating credits and debits based on credit and debit baseline functional acres is described in the Exchange Manual. Throughout this section, example calculations are performed on a hypothetical map unit using example data in order to illustrate the calculation steps.

4.1 Scoring Approach

The scoring process requires both a desktop analysis and a field analysis. The desktop analysis is described in detail in the *User's Guide.* The field analysis is described in detail in the *Field Data Collection Methods in* Appendix E. The scoring process involves seven steps depicted in Table 11.

Table 11. Steps for Calculating Functional Acres

Steps	Detail
1. Determine project area	• Credit projects: credit project boundary area • Debit projects: based on the type of proposed anthropogenic disturbance
2. Set map units	Apply pre-existing grid of map units to project area.
3. Calculate pre- and post-project LDI modifiers	LDI values for existing and proposed disturbances are calculated. See *User's Guide* for more information.
4. Calculate 3rd order modifiers	Conifer cover, distance to lek, and presence of sagebrush are measured with geospatial layers in a GIS.
5. Calculate 2nd order modifier	LQI values for breeding, summer and winter habitat are calculated. See *User's Guide* for more information.
6. Complete field analysis	Vegetation data is collected for each map unit by field technicians. See *Field Data Collection Methods* (Appendix E) for more information.
7. Calculate functional acres using HQT Calculator	Vegetation data and outputs from the desktop analyses are input into the HQT Calculator. Pre-project and post-project functional acres are compared.

Step 1: Determine Project Area

The project area is the area within which functional acres are assessed. For credit projects, the credit project boundary is used. For debit projects, the project area is set based on the type of proposed surface disturbance for debit projects. Table 12 describes the distance from the outermost extent of the proposed surface disturbance for which the debit project area should be set.

Table 12. Distances Used to Determine Debit Project Areas

Disturbance	Subtype	Distance (km)
Oil & Gas Wells	Producing	3
	Non-producing	0
Transmission Lines		3
Mines	Active – Large	3
	Active – Med or small	0
	Inactive – Large	0
	Inactive – Med or small	0
Development	Med – High	6
	Low	3
Roads	Interstate	6
	State Hwy	4
	Unpaved roads	1.5

Note that these results do not reflect distances for siting anthropogenic features around leks, but rather represent spatial impacts of these features on a variety of components of GRSG ecology on the general landscape.

Step 2: Set Map Units

Map units are predefined for all Exchange participants and are the basis for all credit and debit calculations. A systematic grid across the range in Wyoming delineates map units and indicates plot sampling locations within each map unit. Vegetation attributes are measured at each plot sampling location for each map unit to calculate 4th order habitat quality. Map units should be assigned a unique identifier and inputted into the HQT Calculator spreadsheet.

Step 3: Calculate 4th Order Modifiers for Anthropogenic Disturbances

For all projects, existing anthropogenic disturbances are digitized within a GIS. For debit projects, all proposed anthropogenic disturbances are digitized within a GIS. Existing disturbances are used to calculate pre-project condition scores; proposed disturbances are used to calculate post-project condition scores. These 4th order pre-project LDI and post-project LDI modifier values are input into the HQT Calculator. The calculation of this modifier for pre- and post-project condition is described in section 4.2.

Step 4: Calculate 3^{rd} Order Modifiers

Conifer cover, distance to lek, and presence of sagebrush are measured with geospatial layers in a GIS. Each 3^{rd} order modifier applies only to the appropriate seasonal habitat types, as shown in Table 13.

Table 13. 3rd Order Modifiers Applied to Breeding, Summer and Winter Scores

Seasonal Habitat Type	**Local Context (3^{rd} Order) Modifier**
Breeding	Conifer cover Distance to Lek
Summer	Conifer cover Presence of Sagebrush
Winter	Conifer cover

Step 5: Calculate 2^{nd} Order Modifier

The breeding, summer and winter LQI values are calculated for each map unit according to the steps outlined in the *User's Guide.*

At the end of Step 5, all outputs from the desktop analysis for each map unit are inputted into the HQT Calculator. These hypothetical values are depicted in Table 14.

Table 14. Data Inputs from the Desktop Analyses for the Calculation of Functional Acres

Map Unit	Acres	Site Veg Condition Score (4^{th} Order)	**Modifiers**						Functional Acres
			4^{th}		**3^{rd}**			**2^{nd}**	
			Cheat-grass	Pre- or Post-Project LDI	Conifer cover	Distance to Lek	Presence of Sagebrush	LQI	
Breeding	160			1.0	1.0	1.0	N/A	1.0	
Summer	160			.95	1.0	N/A	1.0	1.0	
Winter	160			1.0	1.0	1.0	N/A	1.0	

Step 6: Complete Field Analysis

To complete the field analysis, field technicians will collect field data according to the sampling methodology at the locations provided by the Exchange within each map unit. Field technicians will note anthropogenic disturbances and conifer encroachment and make adjustments to sampling location based on whether or not the sample point is located in non-habitat (e.g. parking lot or building). The process for completing the field analysis is described in Appendix E *Field Data Collection Methods*.

Step 7: Calculate Functional Acres Using HQT Calculator

Field data and outputs from the desktop analyses are inputted into the HQT Calculator and functional acres are calculated automatically. At the end of Step 6, all of the data required to calculate functional acres have been obtained and can be inputted into the HQT Calculator. The vegetation condition score is multiplied by each modifier score in succession to establish the final value score for each map unit (Table 15).

Table 15. Data Inputs for the Calculation of Functional Acres

			Modifiers						
			4th		3rd			2nd	
Map Unit	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Pre- or Post-Project LDI	Conifer cover	Distance to Lek	Presence of Sagebrush	LQI	Functional Acres
Breeding	160	0.85	0.8	1.0	1.0	1.0	N/A	1.0	**108.8**
Summer	160	0.75	0.8	.95	1.0	N/A	1.0	1.0	**91.2**
Winter	160	0.55	1.0	1.0	1.0	1.0	N/A	1.0	**88**

The following section describes the underlying process that takes place within the HQT Calculator to calculate the 4th order site vegetation score.

Decision Triggers

A set of criteria or decision triggers determine whether a location can be considered GRSG seasonal habitat. If vegetation attributes measured within a map unit do not meet the trigger requirements, it will not receive a score for that seasonal habitat type. The triggers used in the HQT are described in Table 16.

Table 16. Decision Triggers Used to Establish the Set of Scoring Curves for the Project Area

Attribute	Trigger	Seasonal Habitat Type
Sagebrush Canopy Cover	≥5% canopy cover required	Breeding and Winter
Mesic Forb Presence	Mesic forb presence required	Summer

Mesic or Arid Scoring Curves

The HQT addresses climatic site variability by using different scoring curves and tables for sites in mesic and xeric conditions. Note that annual precipitation changes (e.g. drought conditions) are different than site conditions. Refer to PRISM Climate Group's "30-yr Normal Precipitation: Annual" for annual precipitation zones at http://prism.oregonstate.edu/normals/.

- **Arid condition**: sites generally in 18-30 cm annual precipitation zone (Winward 2004); *Artemisia tridentata wyomingensis* is a common big sagebrush sub-species for this type of site;

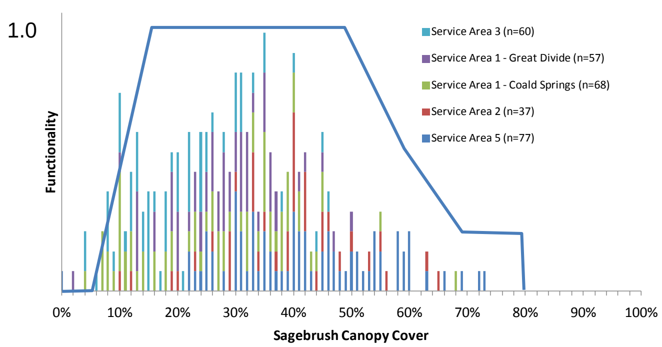
- **Mesic condition**: sites generally in a >30 cm annual precipitation zone (Winward 2004); *Artemisia tridentata vaseyana* is a common big sagebrush sub-species for this type of site

Topography and Aspect for Winter Habitat

The 4th order habitat quality score for winter habitat is based on the topography (percent slope) and aspect of the map unit. There are two scoring curves and tables that correspond to the topography at which the sample point is taken: one scoring curve and table is used for slope greater than 5%, and a different scoring curve and table is used for slope less than 5%.

Vegetation Attributes Translated to Functional Scores Using Scoring Tables

After establishing the specific seasonal habitats being scored and which scoring curves to use, the HQT Calculator scores each vegetation attribute measured at the site based on the appropriate scoring curve and table. For example, Figure 6 is the scoring curve and associated table for sagebrush canopy cover in breeding habitat.



% Cover	< 5	5-14	15-19	20-29	30-39	40-49	50-59	60-69	70-79	>80
Functionality	0	0.5	1	1	1	1	0.5	0.25	0.25	0

Figure 6. Sagebrush Canopy Cover Scoring Curve and Associated Table for Breeding Habitat

Within the HQT Calculator spreadsheet, the field measurement is referenced or "looked up" in the scoring table, which corresponds with a percent performance value for that field measurement. In this case, 10% cover corresponds to 0.5 or 50% functional performance. The score for each habitat attribute is then weighted as established in Table 17.

Table 17. Vegetation Attribute Weighting Values

BREEDING							
Cover / Refugia (50%)					Forage (50%)[A]		
Sagebrush Height 6%	Sagebrush Canopy Cover	Sagebrush Shape 4%	Grass Canopy Cover	Grass Height 12.5%	Forb Cover 16.7%	Forb Species Richness	Presence of Specific Forbs

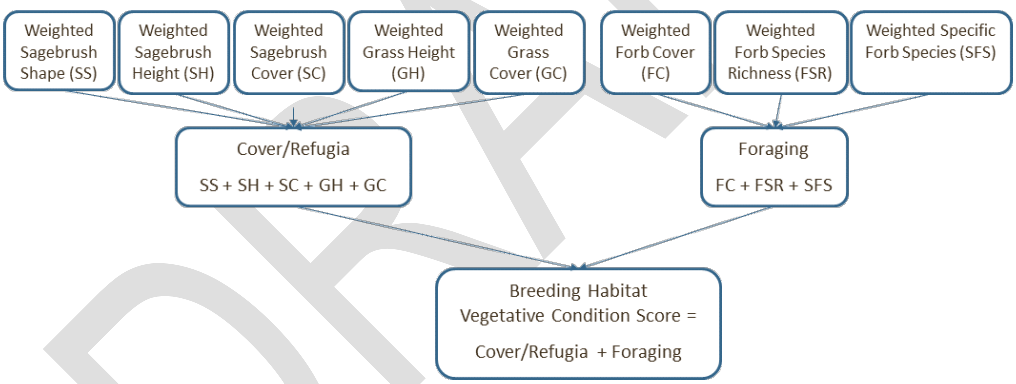
	15%		12.5%			16.7%	16.7%[B]
SUMMER							
Cover / Refugia (30%)			Forage (70%)				
Grass Canopy Cover 15%	Grass Height 15%		Forb Cover 23.3%	Forb Species Richness 23.3%		Presence of Specific Forbs 23.3%	
WINTER							
Sagebrush Height 50%				Sagebrush Canopy Cover 50%			

Each individual attribute score (e.g. 0.5 for sagebrush canopy cover) is multiplied by the weight. Using the breeding sagebrush canopy cover value from above with the weighting from Table 17, the calculation is:

Breeding sagebrush canopy cover: (0.5*0.15) = 0.075

The weighted scores for each attribute by season are then added to generate three seasonal habitat quality scores for a site. Figure 7 depicts how each weighted vegetation attribute in the concept model is combined for each seasonal habitat type.

Breeding Habitat



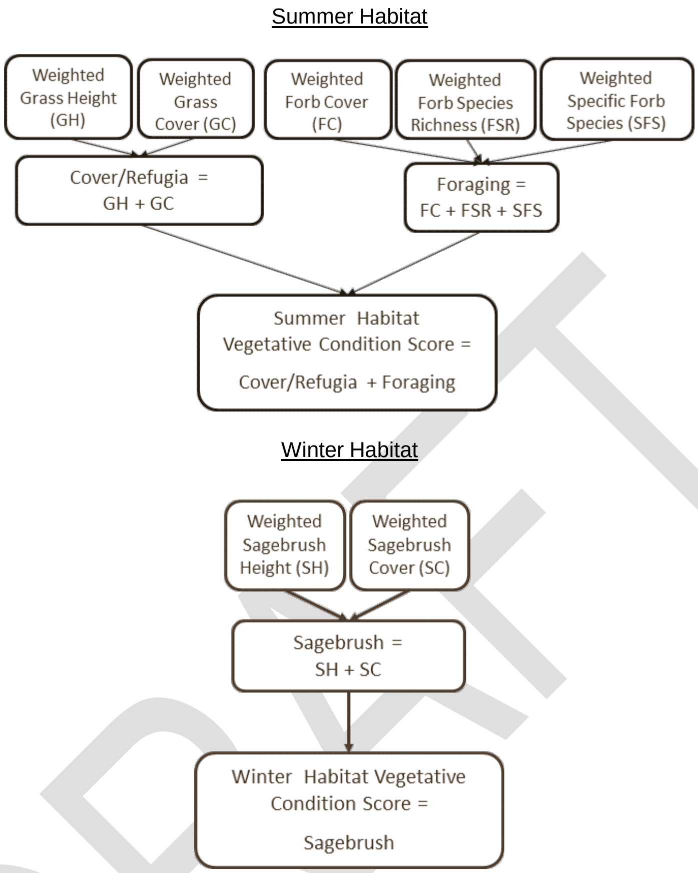


Figure 7. Seasonal habitat scores are derived by adding the weighted vegetation attribute scores for each seasonal habitat type

4.2 Calculation of Functional Acres for Debit Projects

To account for the effect of anthropogenic disturbances, 4th order modifiers based on existing and proposed structures are calculated. As noted above, existing disturbances are used to calculate pre-project condition scores; proposed disturbances are used to calculate post-project condition scores. These values are generated using the raster data that was used to construct the LDI. Exchange participants who generate a Density and Disturbance Calculation Tool (DDCT) assessment area will have digitized existing and proposed disturbances. These rasters can be used to calculate the pre- and post-project LDI values (see the *User's Guide* for detailed steps for calculating pre- and post-project LDI values).

4.2.1 Generate Pre-Project 4^{th} Order Modifier for Existing Structures

This initial process overlays the proposed project area (represented by a shapefile) onto the existing LDI raster and a zonal statistics analysis is performed. This analysis finds the mean value out of the LDI raster for each map unit within the project area. This mean value is the pre-project modifier value for existing structures for each map unit (Table 18).

Table 18. 4^{th} Order Modifier Value for Existing Anthropogenic Disturbances Used in the Calculation of Pre-Project Condition

PRE-PROJECT CONDITION									
			Modifiers						
			4^{th}		**3^{rd}**			**2^{nd}**	
Map Unit	Acres	Site Veg Condition Score (4^{th} Order)	Cheat-grass	Pre-Project LDI	Conifer cover	Distance to Lek	Presence of Sagebrush	LQI	Functional Acres
Breeding	160	0.85	0.8	**1.0**	1.0	1.0	N/A	1.0	**108.8**
Summer	160	0.75	0.8	**.95**	1.0	N/A	1.0	.9	**91.2**
Winter	160	0.55	1.0	**1.0**	1.0	1.0	N/A	1.0	**88**

4.2.2 Generate Post-Project 4^{th} Order Modifier for Proposed Structures

Each type of infrastructure within the landscape is associated with two different disturbance measures. The first of these measures is the maximum distance effect associated with each infrastructure type. For example, an interstate highway has a 6-km maximum distance of influence. The second measure is only relevant within this zone of influence and is represented by a decay curve that shows decreasing impact to habitat quality as distance increases from the source of the disturbance (see figure 6).

The first step is to generate a raster from the two disturbance measures (the distance effect and the decay curve) for each proposed disturbance sub-type. For example, if the project involves the installation of a producing well pad and an unpaved access road, one raster is generated for the producing well pad and a second raster is generated for the unpaved access road. Once generated, each new raster is compared to the original raster for the same disturbance type from the LDI. In other words, the proposed well pad raster is compared to the well pad raster data from the LDI, and the proposed unpaved road raster is compared to the road raster data from the LDI. The comparison of rasters involves overlaying one on top of another and a raster calculator is used to evaluate each set of overlapping 25x25-m cells.

The next step depends on whether the disturbance effect from the proposed structure is less than or greater than the existing disturbance in a given cell. If the disturbance effect from the proposed structure is less than that for the pre-existing disturbance, then the pre-project modifier value is used for that cell. If the disturbance effect from the proposed structure is greater than the existing disturbance, the proportional difference between the new disturbance effect (R1) and the pre-existing disturbance effect (R2) is assessed (R1/R2) and multiplied by the pre-project modifier value to arrive at a newly adjusted post-installation modifier value based on proposed structures.

This process is repeated for each newly proposed disturbance type (well pad, unpaved road, etc…) and the final score for each cell comes from either the LDI (in cases where the new disturbance effect is less than the existing effect) or an iteration of this local LDI modification process (in cases where the new disturbance effect is greater than the existing effect). The final local modified LDI equivalent raster is then used, in conjunction with the delineated map units and the zonal statistics tool, to determine the newly applicable post installation local LDI equivalent score. This score is run through the HQT Calculator to arrive at final post-installation scores for each map unit (Table 19).

Table 19. 4th Order Modifier Value for Proposed Anthropogenic Disturbances Used in the Calculation of Post-Project Condition

POST-PROJECT CONDITION									
			Modifiers						
			4th		3rd			2nd	
Map Unit	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Post-Project LDI	Conifer cover	Distance to Lek	Presence of Sagebrush	LQI	Functional Acres
Breeding	160	0.85	0.8	**0.7**	1.0	1.0	N/A	1.0	**76.16**
Summer	160	0.75	0.8	**0.7**	1.0	N/A	1.0	1.0	**67.2**
Winter	160	0.55	1.0	**0.6**	1.0	1.0	N/A	1.0	**52.8**

Finally, table 20 depicts the comparison of post-project condition and pre-project condition functional acre scores.

Table 20. Comparison of Pre-Project and Post-Project Functional Acres for Debit Project

FUNCTIONAL ACRE CHANGE			
	Post-Project Functional Acres	Pre-Project Functional Acres	Functional Acre Change
Breeding	76.16	108.8	**-32.64**
Summer	67.2	91.2	**-24**
Winter	52.8	88	**-35.2**

4.3 Methodology for Calculating 3rd and 2nd Order Modifiers

Vegetation attributes are measured using transects located within each map unit. In contrast, modifiers at the 3rd and 2nd order are measured in a GIS by 25x25 meter pixel. To modify map unit 4th order vegetation quality scores with 3rd and 2nd order pixel scale measures, the 25×25 m raster grid used in the GIS calculations is laid over the project area, and each raster grid cell – or pixel – that falls within a given map unit is populated with the vegetation quality scores associated with that map unit (Figure 10). This same procedure occurs at the boundary of a project area; if at least half of the pixel lands within the project area, then that pixel is populated by the value of the map unit on which it lands. Conversely if less than half of a pixel lands within the project area, it is not populated with a value and therefore excluded from project area consideration.

5.0 Example Projects

5.1 Example Debit Project

Hypothetical data for three habitat quality scenarios are used to demonstrate the effect of the LDI and LQI modifiers on the score. Average values for each scenario are depicted in Table 21. These values are based on field data only (sagebrush cover and height, grass cover and height, forb cover, number of forb species, percent of forb cover that is noxious weeds, and cheatgrass).

Table 21. Average Field Data Scores for Low, Medium, and High Quality Habitat Scenarios

Scenario	Breeding Field Data Average Score	Summer Field Data Average Score	Winter Field Data Average Score
Low-quality habitat	11%	22%	25%
Medium-quality habitat	45%	66%	46%
High-quality habitat	100%	100%	100%

5.1.1 Project Details

Comment [LH8]: This example will be updated for a location in WY. Because this example uses actual LDI and LQI data, this will be updated once the models are constructed. For now, this example illustrates the way the LDI and LQI affect change in functional acres.

A proposed 4 acre pad will contain two wells.

[INSERT FIGURE THAT SHOWS LOCATION OF WELL PAD]]

The distance effect for a producing oil & gas well pad is 3km, so a 3km buffer is delineated around the well pad. Figure 9 depicts a well pad site, reference area photos, and the 3km buffer.

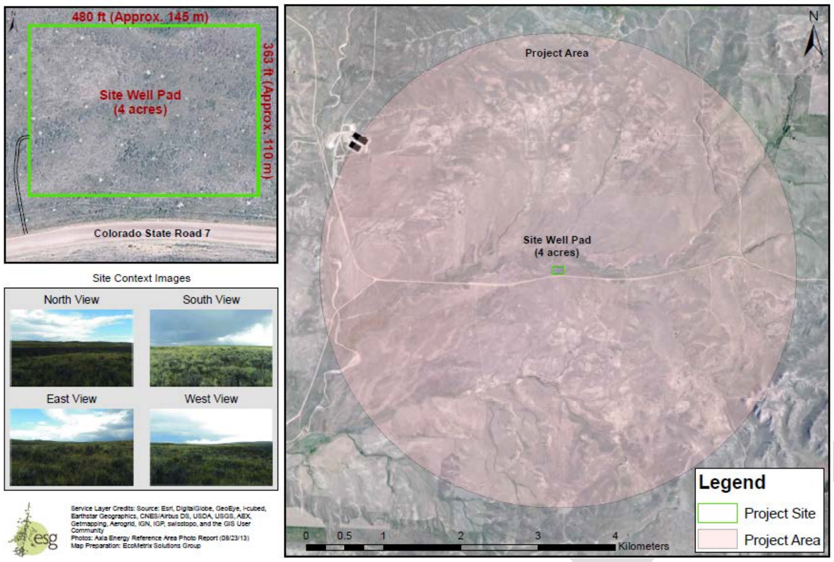


Figure 8. Well Pad Site, Reference Location Photos, and 3km Buffer Around the Well Pad

The predefined grid of map units is overlaid on the project area. Every map unit with a sample point that occurs within the project area is included within the overall project area. In this example, a total of 44 total map units, or 7040 acres, makes up the project area (Figure 10).

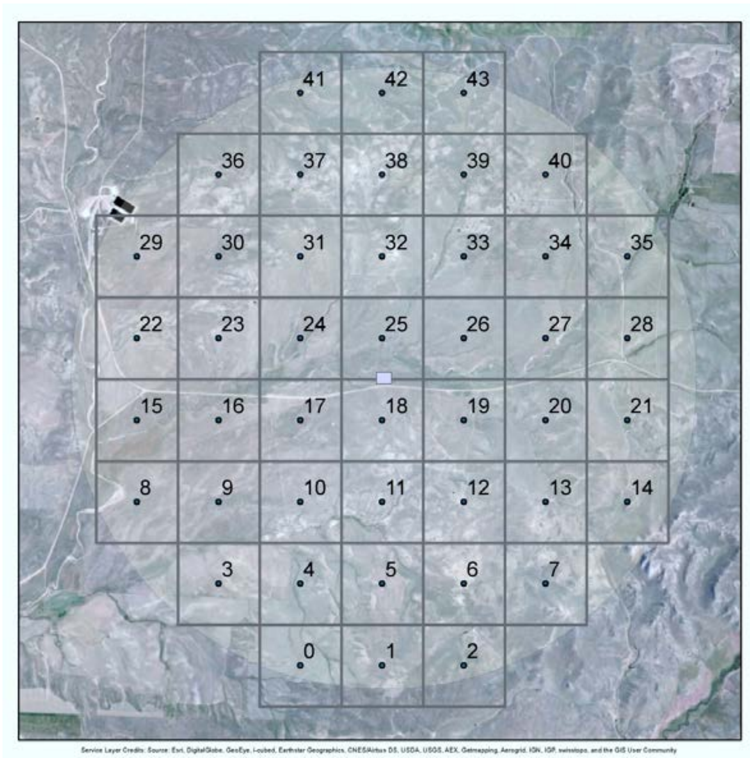


Figure 9. Predefined Map Unit Grid Overlaid on the Project Area

5.1.2 Desktop Data

Hypothetical field data for the three scenarios is entered into the HQT Calculator, which combines vegetation attributes (as described in the previous section) into a site vegetation condition score. Data from the desktop analyses is also input into the HQT Calculator. All 3rd order modifier values (conifer cover, presence of sagebrush, and distance to lek) are 1.0. The actual LQI and pre- and post-project LDI values are depicted in Table 22.

Table 22. Debit Project Example LQI and Pre- and Post-LDI Values per Map Unit

Map Unit	LDI-pre	LDI-post	Breeding LQI	Summer LQI	Winter LQI
0	0.85504	0.84485	0.82088	0.82088	0.43363
1	0.92182	0.91856	0.82475	0.82475	0.43817
2	0.74299	0.74299	0.82899	0.82899	0.44024
3	0.50152	0.48139	0.82680	0.82680	0.43612
4	0.67971	0.59700	0.83178	0.83178	0.44071
5	0.75696	0.65061	0.83660	0.83660	0.44454
6	0.54522	0.53481	0.84188	0.84188	0.44698
7	0.12440	0.12440	0.84843	0.84843	0.44930
8	0.20090	0.19541	0.83303	0.83303	0.44311
9	0.26681	0.21493	0.83876	0.83876	0.44485
10	0.35461	0.15895	0.84431	0.84431	0.44796
11	0.45657	0.14040	0.84952	0.84952	0.45017
12	0.40543	0.22560	0.85556	0.85556	0.45182
13	0.16954	0.16624	0.86320	0.86320	0.45408
14	0.05814	0.05814	0.87035	0.87035	0.45641
15	0.07230	0.06795	0.84676	0.84676	0.45063
16	0.09931	0.05681	0.85209	0.85209	0.45264
17	0.17256	0.02076	0.85693	0.85693	0.45411
18	0.28355	0.00936	0.86161	0.86161	0.45522
19	0.34386	0.04861	0.86824	0.86824	0.45615
20	0.33428	0.23982	0.87575	0.87575	0.45788
21	0.27057	0.27051	0.88182	0.88182	0.45932
22	0.02229	0.02085	0.86117	0.86117	0.45521
23	0.03837	0.02082	0.86500	0.86500	0.45742
24	0.08879	0.00944	0.86855	0.86855	0.45892
25	0.16537	0.00502	0.87266	0.87266	0.45928
26	0.20944	0.02761	0.87878	0.87878	0.45999
27	0.34227	0.20768	0.88482	0.88482	0.46092
28	0.28470	0.27694	0.88915	0.88915	0.46105
29	0.00668	0.00644	0.87229	0.87229	0.45630
30	0.02033	0.01544	0.87560	0.87560	0.45894
31	0.06704	0.02733	0.87857	0.87857	0.46067
32	0.16160	0.04709	0.88323	0.88323	0.46181
33	0.18624	0.08116	0.88850	0.88850	0.46235
34	0.26292	0.20610	0.89250	0.89250	0.46232
35	0.16668	0.16151	0.89451	0.89451	0.46163
36	0.01850	0.01763	0.87978	0.87978	0.45695
37	0.08608	0.07357	0.88387	0.88387	0.45857
38	0.22813	0.18476	0.88961	0.88961	0.46058
39	0.24227	0.21190	0.89463	0.89463	0.46282
40	0.26433	0.25247	0.89673	0.89673	0.46307
41	0.11474	0.11318	0.88217	0.88217	0.45505
42	0.26562	0.26065	0.88720	0.88720	0.45628
43	0.36557	0.36082	0.89128	0.89128	0.45768

5.1.3 Comparison of Final Functional Acre Scores

Table 23 depicts the comparison of pre-project condition and post-project condition functional acre scores for the three scenarios:

Table 23. Comparison of Pre- and Post-Project Functional Acre Scores for the Example Debit Project

FUNCTIONAL ACRE CHANGE				
Pre-Project and Projected Post-Project Final Functional Acre Scores				
Scenario	**Seasonal Habitat**	**Post-Project**	**Pre-Project**	**Difference**
Low-quality habitat	Breeding	84.36	116.93	-32.57
	Summer	167.03	233.53	-66.51
	Winter	231.18	304.57	-73.38
Medium-quality habitat	Breeding	575.54	720.34	-144.8
	Summer	830.64	1042.66	-212.02
	Winter	537.68	673.4	-135.72
High-quality habitat	Breeding	1497.04	1955.85	-458.81
	Summer	1497.04	1955.85	-458.81
	Winter	1497.04	1955.85	-458.81

5.2 Example Credit Project

Comment [LH9]: This example will be updating using Wyoming scoring curves. For now, it illustrates the scoring.

The pre-project site-level condition for an example credit project with 3 map units is depicted in the table below. The Exchange participant's activities are expected to affect site-level conditions only; 2nd and 3rd order modifiers do not change. Table 24 depicts 4th order scores for pre-production condition; Table 25 depicts 4th order scores for post-project condition. **This example is for illustrative purposes only to demonstrate the scoring.**

5.2.1 Results for Pre-Project Condition

Table 24. Pre-Project 4th Order Vegetation Condition Scores

BREEDING Pre-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass		
1	25	18-29	20-29	Spreading	5	10	<2	15-20	No	0-1	0.59	14.75
2	30	18-29	20-29	Spreading	11	>20	5	1-4	No	5-9	0.38	11.4
3	45	10-17	<5	Spreading	4	6	<2	0	No	>15	0	0
										Total Functional Acres		26.15

SUMMER Pre-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass		
1	25	18-29	20-29	Spreading	5	10	<2	15-20	No	0-1	0.73	18.25
2	30	18-29	20-29	Spreading	11	>20	5	1-4	No	5-9	0.40	12
3	45	10-17	<5	Spreading	4	6	<2	0	No	>15	0	0
										Total Functional Acres		30.25

WINTER Pre-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious	Cheatgrass		

									weed cover		Function	
1	25	18-29	20-29	Spreading	5	10	<2	15-20	No	0-1	0.75	18.75
2	30	18-29	20-29	Spreading	11	>20	5	1-4	No	5-9	0.75	22.5
3	45	10-17	<5	Spreading	4	6	<2	0	No	>15	0.25	11.25
											Total Functional Acres	52.5

5.2.2 Results for Post-Project Condition

It is **expected** that the landowner's activities will increase forb cover, increase the number of forb species, and decrease cheatgrass cover. 3rd and 2nd order modifiers did not change as a result of the landowner's activities. Table 25 depicts 4th order scores for post-project condition.

Table 25. Post-Project 4th Order Vegetation Condition Scores

BREEDING Post-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass		
1	25	18-29	20-29	Spreading	5	10	*4*	15-20	No	0-1	0.69	17.25
2	30	18-29	20-29	Spreading	11	>20	*6*	*10-14*	No	*2-4*	0.65	19.5
3	45	10-17	<5	Spreading	4	6	*6*	*10-14*	No	*2-4*	0.37	16.65
											Total Functional Acres	53.4

SUMMER Post-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass		
1	25	18-29	20-29	Spreading	5	10	*4*	15-20	No	0-1	0.87	21.75
2	30	18-29	20-29	Spreading	11	>20	*6*	*10-14*	No	*2-4*	0.74	22.2
3	45	10-17	<5	Spreading	4	6	*6*	*10-14*	No	*2-4*	0.65	29.25
											Total Functional Acres	73.2

WINTER Post-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order	Functional Acres
		Height	%	Shape	Height	%	# of	%	100%	Cheatgrass		

		(cm)	Cover			Cover	Species	Cover	Noxious weed cover		Habitat Function	
1	25	18-29	20-29	Spreading	5	10	*4*	15-20	No	0-1	0.75	18.75
2	30	18-29	20-29	Spreading	11	>20	*6*	*10-14*	No	*2-4*	0.75	22.5
3	45	10-17	<5	Spreading	4	6	*6*	*10-10*	No	*2-4*	0.25	11.25
											Total Functional Acres	52.5

5.2.3 Comparison of Final Functional Acre Scores

Table 26 depicts the comparison of pre-project condition and post-project condition functional acre scores.

Table 26. Comparison of Pre- and Post-Project Functional Acre Scores for the Example Credit Project

FUNCTIONAL ACRE CHANGE			
Pre-Project and Projected Post-Project Final Functional Acre Scores			
Seasonal Habitat	**Post-Project**	**Pre-Project**	**Difference**
Breeding	53.4 functional acres	26.15 functional acres	+27.25 functional acres
Summer	73.2 functional acres	30.25 functional acres	+42.95 functional acres
Winter	52.5 functional acres	52.5 functional acres	No change in functional acres

6.0 Adaptive Management

Adaptive management is a fundamental principle of the HQT and it is vital to the proper functioning of the Exchange overall. When it comes to managing GRSG populations or improving sagebrush habitats, quite a bit is known about the species' habitat preferences, but less is known about the effectiveness of habitat restoration and management techniques in creating positive habitat conditions. For this reason and others, it is necessary that the Exchange implements an adaptive management process that evaluates the effectiveness of practices in meeting desired outcomes.

Adaptive management is defined as the structured dynamic process of addressing uncertainty in management through the incorporation of procedures that seek to periodically revise and update tools, strategies and approaches to management in response to changing conditions or new information. Adaptive management strategies allow for changes to the overall conservation strategy to occur in response to changing conditions or new information, including those identified during monitoring. Adaptive approaches to management recognize that not all of the answers to management questions are known and some management is a process of trial and error. Adaptive management also includes, by definition, a commitment to change management approaches when appropriate for attaining biological goals and objectives of a conservation strategy. The goal of adaptive management for the HQT is to make periodic changes that keep it up to date with the current state of ecological knowledge and apparent functioning of the tool.

A Science Advisory Team will meet periodically to review and evaluate new information including: monitoring data, research on the species biology or ecology, additional or changing threats to the species, recent substantial gains or losses of habitat for the species, the establishment of new protected areas, etc. During the first three years of the Exchange, the Team will meet annually. Beyond that, the Team will meet every other year. These reviews will additionally be used to iteratively evaluate the HQT, specifically: 1) tool functions (scoring tools, GIS applications, etc.); 2) accuracy of the scores in measuring real and expected outcomes; 3) utility (ease of use, efficiency, and cost) across end-users, 4) repeatability of scores from one user to the next and across habitat types, and 5) reliability of scores over time. Previously identified knowledge gaps will be re-evaluated and addressed, as data allows. Modifications to the HQT and the processes by which habitat condition is quantified will be made based on the conclusions the Science Advisory Team reaches during these reviews. The Exchange Manual further describes the role of the Science Advisory Team in implementing and adapting the Exchange.

The Exchange will focus on habitat outcomes, as described by the HQT, while bird population surveys will remain the purview of state and federal agencies. It will be possible, however, to evaluate regional population status and trends over time and relate them to landscape-scale habitat conditions to get an idea of how habitat exchanges are performing in combination with other conservation efforts and to determine whether management practices are yielding net benefits for the species. Verification of project performance should occur on project sites at a minimum 5-year interval. Verification checks will be conducted more frequently at random intervals to confirm that offset projects are holding value and outcomes are on the anticipated trajectory.

There will always be uncertainty about the exact vegetation and bird population responses to habitat manipulations. While much is known about the habitat needs of GRSG, the long-term effects of most available habitat management options are unknown (Sage and Columbian Sharp-tailed Grouse Technical Committee 2009). Caution and discretion must be exercised when proposing habitat treatments, especially on drier sites, sites where cheatgrass may invade, or sites with limited potential to produce sagebrush (e.g., the interface between the Wyoming Basin and the Great Plains). An interdisciplinary group developing grazing management objectives in Wyoming's GRSG habitats (Wyoming Interagency Grazing Management Committee 2009) recommends a small-scale, case-by-case disturbance regime conducted over the long-term. We caution that the Wyoming Conservation Exchange should not be used as justification for wide-scale modification of sagebrush ecosystems as a GRSG management tool. Over time, the adaptive management process should be used to inform habitat treatments that result in the most beneficial outcomes for the species.

7.0 Limitations of the HQT

The HQT is based on the best available science and best professional judgment. However, there are aspects of its content and potential uses that can be improved as it is adaptively managed over time.

First, most of the literature used to estimate the distance effects and relative weights associated with anthropogenic infrastructure is derived from analyses of the response of GRSG on leks (i.e., number of males occupying leks) to that infrastructure (see Appendix C). Since the HQT seeks to quantify vegetation that supports seasonal needs of GRSG (i.e., breeding, summer and winter), and credits and debits are based on these assessments of seasonal habitat value, the LDI will be developed as more information pertaining to GRSG seasonal response to anthropogenic activity becomes available.

Second, the HQT currently relies on a standardized, site-specific vegetation sampling protocol to establish vegetation conditions and monitor vegetation changes. However, standardizing vegetation sampling protocols over space and time has its challenges, which could be problematic in situations where quantifying vegetation change is the objective of monitoring (Seefeldt and Booth 2006). Aerial imagery and other remotely-sensed information offer the opportunity for objective measurement of vegetation across space and time, but in most instances the products derived from these data are too coarse to effectively detect small-scale changes in the vegetation (Seefeldt and Booth 2006). As remote-sensing platforms and sensors mature, spatial and temporal resolution are expected to improve and costs decrease, making it easier to effectively quantify change in relevant vegetation attributes. The Science Advisory Team will stay abreast of advances in remote-sensing and image analysis software so that GIS-based monitoring protocols can be incorporated into the HQT as suitable to address the HQT objectives.

Third, the HQT alone is not an effective tool for assessing how changes in habitat condition contribute to population viability. As described earlier in this document, the HQT is focused on actions that occur at the site level, and the methods required to accurately measure conditions at that scale (e.g., vegetation plots) are not conducive to large-scale assessments. However, additional research could contribute to a greater understanding of how cumulative habitat changes contribute to population viability. Furthermore, as long as debits are offset by credits, and as credits accumulate beyond debits, the Exchange will contribute to net increases in high quality habitat that we believe to be likely to sustain resilient GRSG populations over time.

Fourth, the HQT uses the proportion of each seasonal range available to GRSG on the landscape surrounding a project site as a modifier of habitat quality. However, the interspersion, juxtaposition and availability of the differing cover types used by GRSG during an annual cycle influence the effectiveness of a given landscape to provide GRSG with useable and high quality habitat (Connelly et al. 2011c). Future iterations of the HQT could explore how to integrate interspersion and juxtaposition as modifiers.

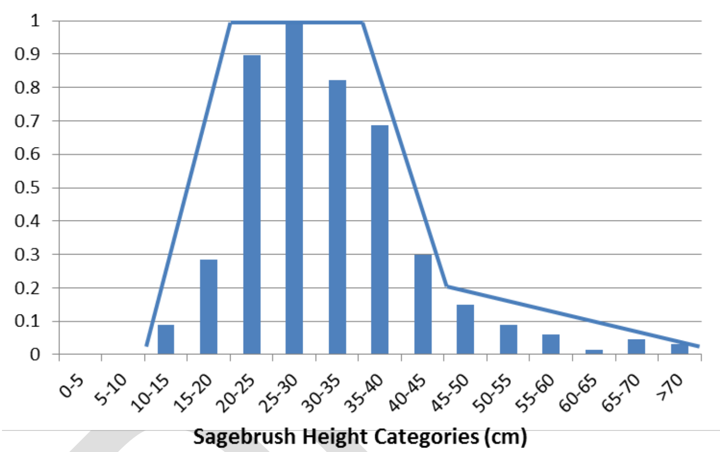
Finally, the scoring approach used in the HQT does not include a short-term temporal aspect. Thus, it cannot detect short-term changes in impacts resulting from infrastructure. For example, a drilling rig may have more impact than an active producing well. Due to this limitation, it scores the impact based on the primary level of activity the majority of the time the disturbance is present. In this example, it scores based on the impact of the active production phase, rather than the drilling rig phase, which may only last 60 days.

Appendix A. Scoring Curves and Tables

Scoring response curves for each attribute were developed by the Science Team. Data provided by A. Wuenschel were used to develop and/or inform the relationships based on locations in the Upper Green River Basin, Sublette County, Wyoming from 1998 – 2010. The Science Team did not use habitat measurements from outside Wyoming.

[[As of this writing the scoring curves for summer and winter habitat have yet to be developed. In addition, the scoring curves for breeding habitat in mesic conditions have yet to be developed.]]

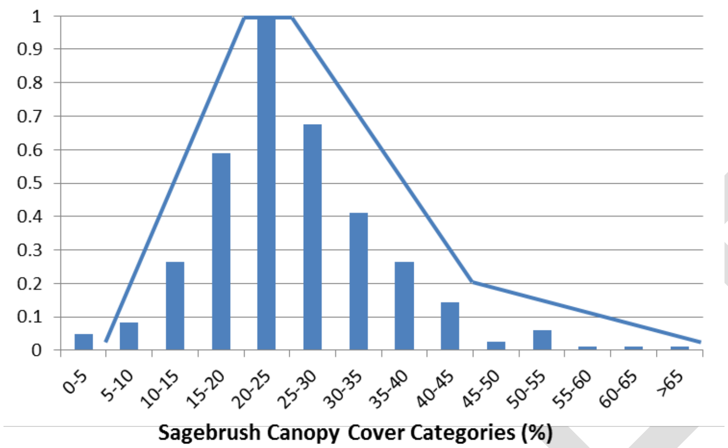
Breeding Habitat: Sagebrush Height, Arid Sites in the Upper Green River Basin



Reference: Wuenschel, Amarina. 2014. *Ecological and Fine-Scale Spatial variation in Vegetation at Sage-grouse Nests in western Wyoming*. Thesis, Department of Ecosystem Science and Management, University of Wyoming, Laramie, USA.

Frequency distribution of mean sagebrush height (cm), measured as maximum height excluding flowering stalks of sagebrush plants intersected along 2 perpendicular 30 m transects crossing at sage-grouse nest (n=234) and early brood-rearing (n=65) locations in the Upper Green River Basin, Sublette County, Wyoming 1998-2010. Frequencies were normalized to 1 by dividing the number of sage-grouse locations in each category by the number of locations in the category with the largest number of locations (25-30 cm).

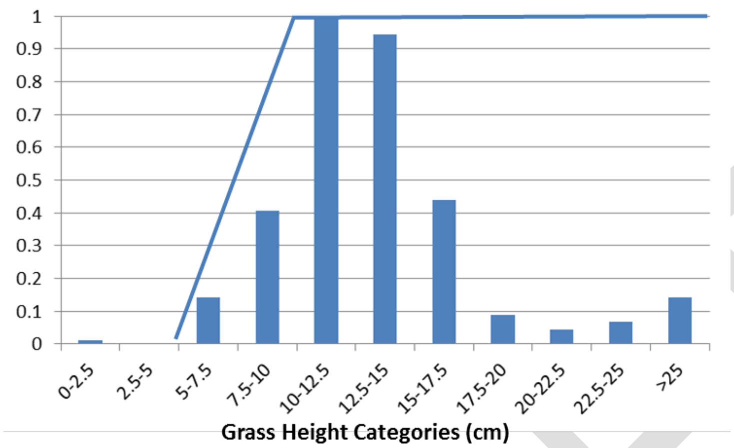
Breeding Habitat: Sagebrush Canopy Cover; Arid Sites in the Upper Green River Basin



Reference: Wuenschel, Amarina. 2014. *Ecological and Fine-Scale Spatial variation in Vegetation at Sage-grouse Nests in western Wyoming*. Thesis, Department of Ecosystem Science and Management, University of Wyoming, Laramie, USA.

Frequency distribution of sagebrush canopy cover (%), measured using the line intercept method (Canfield 1941) along 2 perpendicular 30 m transects crossing at sage-grouse nest (n=234) and early brood-rearing (n=65) locations in the Upper Green River Basin, Sublette County, Wyoming 1998-2010. Frequencies were normalized to 1 by dividing the number of sage-grouse locations in each category by the number of locations in the category with the largest number of locations (20 – 25%).

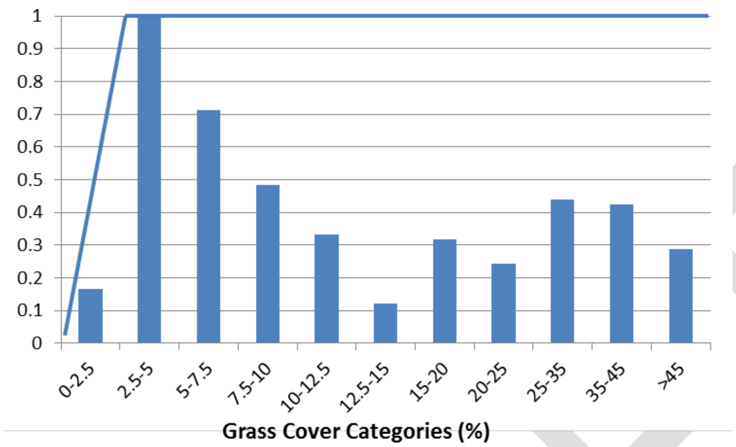
Breeding Habitat: Grass Height, Arid Sites in the Upper Green River Basin



Reference: Wuenschel, Amarina. 2014. *Ecological and Fine-Scale Spatial variation in Vegetation at Sage-grouse Nests in western Wyoming*. Thesis, Department of Ecosystem Science and Management, University of Wyoming, Laramie, USA.

Frequency distribution of mean grass height (cm), measured as average maximum droop height (i.e., the highest naturally growing portion of the plant excluding flowering stalks) of grass plants occurring in Daubenmire (1959) frames within 2.5 m of sage-grouse nest (n=234) and early brood-rearing (n=65) locations in the Upper Green River Basin, Sublette County, Wyoming 1998-2010. Frequencies were normalized to 1 by dividing the number of sage-grouse locations in each category by the number of locations in the category with the largest number of locations (10 – 12.5 cm). The shape of the resulting curve reflects the relationship between grass height and sage-grouse breeding habitat quality, where taller grasses are correlated with increased habitat quality in terms of success (i.e., the relationship is not quadratic; Holloran et al. 2005, Thompson et al. 2006, Doherty et al. 2014).

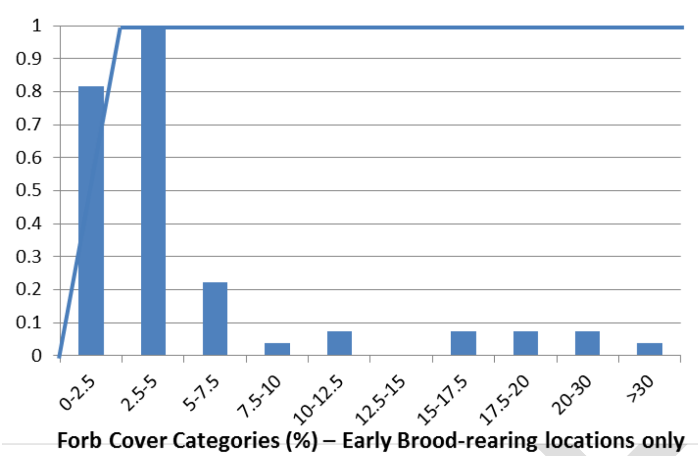
Breeding Habitat: Grass Canopy Cover, Arid Sites in the Upper Green River Basin



Reference: Wuenschel, Amarina. 2014. *Ecological and Fine-Scale Spatial variation in Vegetation at Sage-grouse Nests in western Wyoming*. Thesis, Department of Ecosystem Science and Management, University of Wyoming, Laramie, USA.

Frequency distribution of mean grass cover (%), estimated using the Daubenmire (1959) method and averaged across 12 frames within 2.5 m of sage-grouse nest (n=234) and early brood-rearing (n=65) locations in the Upper Green River Basin, Sublette County, Wyoming 1998-2010. Frequencies were normalized to 1 by dividing the number of sage-grouse locations in each category by the number of locations in the category with the largest number of locations (2.5 – 5%). The shape of the resulting curve reflects the relationship between grass cover and sage-grouse breeding habitat quality, where increased grass cover is correlated with increased habitat quality in terms of success (i.e., the relationship is not quadratic; Holloran et al. 2005, Thompson et al. 2006).

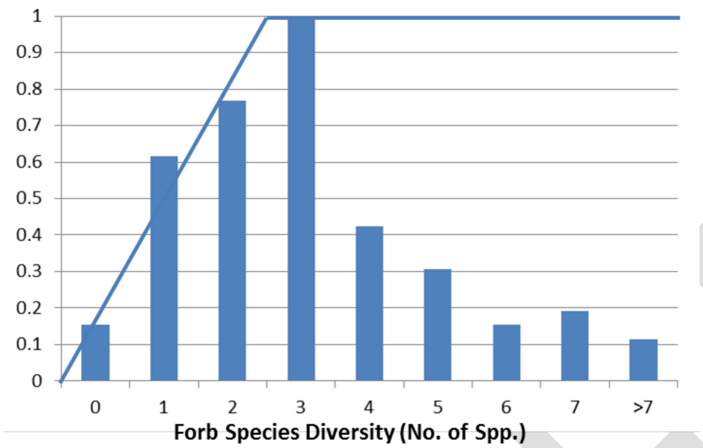
Breeding Habitat: Forb Cover, Arid Sites in the Upper Green River Basin



Reference: Wuenschel, Amarina. 2014. *Ecological and Fine-Scale Spatial variation in Vegetation at Sage-grouse Nests in western Wyoming*. Thesis, Department of Ecosystem Science and Management, University of Wyoming, Laramie, USA.

Frequency distribution of mean forb cover (%), estimated using the Daubenmire (1959) method and averaged across 12 frames within 2.5 m of sage-grouse early brood-rearing (n=65) locations in the Upper Green River Basin, Sublette County, Wyoming 1998-2003. Frequencies were normalized to 1 by dividing the number of sage-grouse locations in each category by the number of locations in the category with the largest number of locations (2.5 – 5%). The shape of the resulting curve reflects the relationship between for cover and sage-grouse breeding habitat quality, where increased forb cover is correlated with increased habitat quality in terms of success (i.e., the relationship is not quadratic; Johnson and Boyce 1990).

Breeding Habitat: Forb Species Richness, Arid Site in the Upper Green River Basin



Reference: Wuenschel, Amarina. 2014. *Ecological and Fine-Scale Spatial variation in Vegetation at Sage-grouse Nests in western Wyoming*. Thesis, Department of Ecosystem Science and Management, University of Wyoming, Laramie, USA.

Frequency distribution of forb species diversity (No. of species), estimated using the line-point intercept method (Herrick et al. 2009) along 2 perpendicular 30 m transects crossing at sage-grouse nest (n=97) locations in the Upper Green River Basin, Sublette County, Wyoming 2009-2010. Frequencies were normalized to 1 by dividing the number of sage-grouse locations in each category by the number of locations in the category with the largest number of locations (3 species). The shape of the resulting curve reflects the relationship between forb diversity and sage-grouse breeding habitat quality, where increased diversity is correlated with increased habitat quality in terms of success (i.e., the relationship is not quadratic; Connelly et al. 2000).

Appendix B. Landscape Quality Index

[[If a Landscape Quality Index is built for this Exchange, this appendix will describe the methods used to construct the model.]]

Appendix C. Sage-Grouse Response to Anthropogenic Disturbance – A Literature Review

Distance to Energy Development

Researchers have reported a "distance-effect" associated with the infrastructure of energy fields whereby GRSG on leks are negatively influenced to a greater extent if infrastructure is placed near the lek, with the response diminishing as distances from lek to infrastructure increase (Manier et al. 2013). Additionally, the distance-effect of infrastructure with higher levels of human activity may be larger than that of infrastructure with lower levels of activity. Harju et al. (2010) reported that impacts to lekking GRSG of well pads located at shorter distances to leks were more consistently observed across energy fields compared to well pads at longer distances. There was a consistent pattern whereby the presence of well pads within smaller radii buffers (<1.6 - 2 km) around leks in extensively developed areas was associated with 35-76% fewer GRSG males on leks compared to leks with no well pads within these radii (Harju et al. 2010). Walker et al. (2007) found a strong negative effect of infrastructure within 0.8 and 3.2 km of leks on lek persistence, with lesser impacts to lek persistence apparent at 6.4 km. Holloran (2005) reported that impacts of development to the number of males occupying leks were greatest when infrastructure was located near the lek, but that impacts were discernable to 3 km for lower activity sites (producing well pads) and 6 km for higher activity sites (drilling rigs). Johnson et al. (2011) reported negative lek trends for leks within approximately 4 km of a producing well pad across the range of the species. Additionally, distance effects of infrastructure have been noted for other seasonal periods. Carpenter et al. (2010) found that GRSG avoided habitats within 1.9 km of infrastructure during the winter. Holloran et al. (2010) reported that yearling females avoided nesting within 950 m of well pads. Annual survival of GRSG chicks reared near gas field infrastructure was lower than those reared away from infrastructure, and the probability of male chicks reared near infrastructure establishing a breeding territory as a yearling was half that of male chicks reared away from infrastructure (Holloran et al. 2010). Dzialak et al. (2011) reported that the closer a nest was to a natural gas well (that existed or was installed in the previous year), the more likely it was to fail. LeBeau et al. (*In Press*) reported that the risk of a nest or a brood failing decreased by 7.1% and 38.1%, respectively, with every 1-km increase in distance from the nearest wind turbine; however, no variation in female survival was detected relative to wind energy infrastructure.

Density of Energy Development

Substantial amounts of research suggest that increased infrastructure densities around leks will negatively influence GRSG. Harju et al. (2010) reported that well pad densities of 4 and 8 pads/section (square mile) within 8.5 km of leks were associated with lek count declines ranging from 13-74% and 77-

79%, respectively. Doherty et al. (2010a) reported that impacts to leks were indiscernible at well pad densities at or below 1 pad/section within 3.2 km of leks, but that lek loss and declines in numbers of males on leks increased at greater pad densities. Holloran (2005) reported that well densities exceeding 1 well/section within 3 km of leks negatively influenced male lek attendance. Hess and Beck (2012) reported 0% probability of lek occurrence in areas with well pad densities exceeding 6.5 pads/section within 1 km. Tack (2009) reported that larger leks (>25 males) did not occur in areas where well pad densities exceeded 2.5 pads/section within 12.3 km of a lek. Johnson et al. (2011) found a generally negative trend in lek counts as numbers of producing wells increased within 5 and 18 km of leks. Kirol (2012) reported that females avoided nesting and rearing broods in areas with increased numbers of visible wells within a 1-km^2 area. Aldridge and Boyce (2007) reported that chick survival decreased with increasing numbers of visible wells within 1 km of brood-rearing locations. Doherty et al. (2008) found that GRSG were 1.3 times more likely to occupy suitable winter habitats with no gas field infrastructure within a 4-km^2 area compared to areas with 12.3 pads (8 pads/section).

Mining

Coal mining has been a major activity within GRSG habitat (Braun 1998). Yet, the magnitude of the impacts of mining activities on GRSG and sagebrush habitats is largely un-quantified (Braun 1998). Development of surface mines and associated infrastructure (e.g., roads and power lines), noise and human activity negatively impact GRSG numbers in the short term (Braun 1998). The number of displaying GRSG on two leks within 2 km of active coal mines in northern Colorado declined by approximately 94% over a 5-year period following an increase in mining activity (Remington and Braun 1991). However, Braun (1998) reports that studies in Montana, Wyoming and Colorado suggest that some recovery of populations occurred after initial development and subsequent reclamation of mine sites, although populations did not recover to pre-development sizes. Additionally, population re-establishment may take upwards of 30 years (Braun 1998).

Comment [LH10]: This section will be revised with new literature.

Noise

Blickley et al. (2012) report that peak male attendance (i.e., abundance) at leks experimentally treated with noise recorded at roads in a natural gas field decreased 73% relative to paired controls. The authors reported that the intermittent nature of noise from roads impacted male GRSG to a greater degree than more constant noise as that from a drilling rig; peak male attendance at leks treated with noise from natural gas drilling rigs decreased 29% relative to paired controls (Blickley et al. 2012).

Noise is not directly addressed in the HQT. However, the potential differential effects of noise on GRSG relative to activity levels associated with infrastructure are accounted for in the indirect effects, and associated response curves, used to establish the LDI.

Roads

GRSG avoidance of high-activity roads is well documented. Connelly et al. (2004) found that no leks occurred within 2 km of interstate 80, there were fewer leks within 7.5 km than within 15 km of the interstate, and there were higher rates of decline in lek counts between 1970 and 2003 on leks located within 7.5 km compared to beyond 7.5 km of the interstate. Knick et al. (2013) reported that high habitat suitability was associated with <1.0 km/km^2 of secondary roads, 0.05 km/km^2 of highways, and 0.01 km/km^2 of interstate highways within 5-km radius areas. LeBeau (2012) found that GRSG avoided nesting and summering near major roads (e.g., paved secondary highways). Tack (2009) found negative relationships with more roads around leks at all levels of lek attendance, but impacts were greatest for larger leks (>25 males); the probability of occurrence of a large lek was 50% with road densities of approximately 25 km of road within 3.2 km of a lek. Dzialak et al. (2012) documented GRSG during the winter avoiding haul roads associated with natural gas development. In contrast, Johnson et al. (2011) found negative trends in counts of males on leks throughout the range of the species with increasing distance to interstate highway—although few leks occurred near interstates; relatively consistent slight negative trends in lek counts with distance to highways; and no relationship between distance to secondary roads and lek trends. Road densities within 5-km radii of leks suggested similar relationships by road category (Johnson et al. 2011).

Traffic

Remington and Braun (1991) reported that the upgrade of a haul road accessing a coal mine was correlated with a 94% decline in the number of GRSG on leks <2 km from the road over a 5-year period; traffic speed was not measured but the potential for increased speed was inferred from upgraded road surface. Holloran (2005) reported that declines in lek counts on leks within 3 km of roads were positively correlated with increased traffic volumes and that vehicle activity on roads within 3 km of leks during the time of day GRSG were present on leks influenced the number of males on leks more negatively than leks where roads within 3 km had no vehicle activity during the strutting period. Lyon and Anderson (2003) reported that traffic disturbance (1 to 12 vehicles/day) within 3 km of leks during the breeding season reduced nest-initiation rates and increased distances moved from leks during nest site selection of female GRSG breeding on those leks. Blickley et al. (2012) report that peak male attendance (i.e., abundance) at leks experimentally treated with noise recorded at roads in a natural gas field decreased

73% relative to paired controls; the authors found that the intermittent nature of noise from roads impacted male GRSG to a greater degree than more constant noise, such as that from a drilling rig.

Transmission and Power Lines

Research investigating the impacts of transmission and power lines on GRSG is not conclusive, but could be considered suggestive in that these structures may negatively influence GRSG habitat selection and survival. Knick et al. (2013) reported that leks were absent from 5-km radius areas where transmission line and major power line densities exceeded 0.20 km/km^2. LeBeau (2012) reported that GRSG avoided habitats within 4.7 km of transmission lines during brood-rearing, and that the probability of nest success and probability of female survival increased as distance to transmission line increased; but it is worth noting that the author found that brood-rearing and nesting GRSG selected habitats nearer transmission lines in the control study area. Walker et al. (2007) reported that the probability of lek persistence decreased with proximity to power lines and with increasing proportion of power lines within a 6.4 km window around leks; but it is worth noting that distances to power line and power line densities as covariates were highly correlated with other gas development infrastructure covariates examined on the study site, and were not as good as predictors as gas wells. Other often cited studies that may provide evidence of impacts of tall structures on GRSG include the following: Beck et al. (2006) reported that collisions with power lines accounted for 33% of juvenile GRSG winter mortality, but only 2 juvenile grouse were killed by running into power lines.

Towers

Despite low numbers of communication towers across the sagebrush biome, GRSG lek trends across the range of the species generally decreased with distance to nearest communication tower and generally decreased with increasing numbers of towers within 5 km and 18 km of leks (Johnson et al. 2011). The authors surmised that the response of GRSG to communication towers may be correlative with human development in general as these types of towers tend to be concentrated along major roadways and near urban centers; however, with the increase in these types of structures throughout the sagebrush biome (e.g., meteorological towers at proposed wind developments), it is worth considering the documented effects.

Urban Development

Urban areas by themselves remove habitat and present inhospitable environments for GRSG, but the physical boundaries of cities are small relative to the total sagebrush area. However, people in cities require resources from surrounding areas, and the connecting roads, railways, power lines and communications corridors exert a greater influence on sagebrush habitats (Connelly et al. 2004). Additionally, recreation, including hiking, hunting and fishing, and off-highway vehicle use in areas surrounding urban centers can negatively influence GRSG through habitat loss and fragmentation, facilitation of exotic plant spread, animal displacement or avoidance, establishment of population barriers, or increased human-wildlife encounters that increase wildlife mortality (Connelly et al. 2004). Across the GRSG range, lek count trends were lower when human-footprint scores exceeded 2 at leks, or when median scores exceeded 3 within either 5 km or 18 km of a lek (Johnson et al. 2011). The human-footprint index was a measure of the totality of direct anthropogenic features – including human habitation, highways and roads, railroads, power lines, agricultural lands, campgrounds, rest stops, landfills, oil and gas developments, and human-induced fires – on a landscape expressed on a 1 to 10 scale (Johnson et al. 2011). Wisdom et al. (2011) reported that human density was 26 times lower in occupied GRSG range compared to historically occupied but currently extirpated range. Aldridge and Boyce (2007) found that brood-rearing females avoided habitats associated with a high density of urban developments; it is worth noting that "urban" was defined as towns, farmsteads, and energy infrastructure in this study.

Landscape Disturbance Index Methods

[[This section will describe the methods used to construct the LDI once a model has been constructed for this Exchange.]]

Appendix D. Forb and Grass Species List

Information compiled by Alan Sands and Kerry Reese. Modified from a list compiled by Scott Lambert for the northern Great Basin with additions to reflect conditions across the species range.

Species Name	Common Name	Species Name	Common Name
Achillea lanulosa	Yarrow	Lithophragma parvifolia	Woodland star
Agoseris glauca	False dandelion	L. bulbifera	Woodland star
Allium spp.	Wild onion	Lithospermum ruderale	Western stoneseed
Androsace septentrionalis	Northern rock jasmine	Lomatium dissectum	Fernleaf biscuitroot
Antennaria spp.	Pussytoes	L. triternatum	Nineleaf biscuitroot
Arabis cobrensis	Sagebrush rockcress	L. nevadense	Nevada biscuitroot
Arnica spp.	Arnica	Lupinus spp.	Lupine
Aster occidentalis	Western aster	Medicago sativa	Alfalfa
Astragalus spp.	Milkvetch (native aridland ecotypes)	Melilotus officinalis	Yellow sweetclover
Balsamorhiza sagittata	Arrowleaf balsamroot	Mertensia oblongifolia	Oblongleaf bluebells
B. hookeri	Rock balsamroot	Microseris nutans	Nodding microceris
Calochortus macrocarpus	Sagebrush mariposa lily	Oenothera spp.	Evening-primrose
C. nuttallii	Sego lily	Onobrychis viciifolia	Sainfoin
C. gunnisoni	Gunnison’s mariposa lily	Penstemon strictus	Rocky mountain penstemon
Castilleja spp.	Indian paintbrush	Phlox hoodii	Hoods phlox
Cleome lutea	Yellow spikeflower	P. gracilis	Slender phlox
C. serrulata	Rocky mountain beeplant	P. longfolia	Longleaf phlox
Collinsia parviflora	Maiden blue eyed Mary	Polygonum spp.	Knotweed
Crepis acuminata	Tapertip hawksbeard	Sanguisorba minor	Small burnet
C. occidentalis	Largeflower hawksbeard	Sphaeralcea munroana	Globemallow
C. intermedia	Limestone hawksbeard	Taraxicum officinale	Dandelion
Erigeron spp.	Fleabane	Townsendia hookeri	Hooker’s townsend daisy
Eriogonum umbellatum	Sulphur-flower buckwheat	Tragopogon dubius	Yellow salsify
Grindelia squarrosa	Curlcup gumweed	Trifolium macrocephalum	Largehead clover
Hydrophyllum capitatum	Ballhead waterleaf	T. variegatum	Whitetip clover
Lactuca serriola	Prickly lettuce	T. gymnocarpon	Hollyleaf clover
Lepidium densiflorum	Common pepperweed	Vicia spp.	Vetch
Linum lewisii	Prairie flax		
L. perenne	Blue flax		

Appendix E. Field Data Collection Methods

The methods outlined below are for field data collection of attributes associated with the 4th order scale, which defines habitat conditions at the site of proposed activities. The attributes in Table 32 collected for the habitat model result in functional acre scores for specified habitat areas.

Table 27. Methods for Data Collection of Field Attributes

ATTRIBUTE	RESOURCE	GRSG SEASON	ATTRIBUTE DATA COLLECTION SUMMARY
Sagebrush Height	Cover / Refugia	Breeding	The sagebrush height is measured for plants intersecting transect line (see also sagebrush canopy cover).
Sagebrush Canopy Cover		Breeding	The percent canopy cover is estimated with line intercept (% of shrub canopy intersecting transect line).
Sagebrush Shape		Breeding	This measures the growth-form of sagebrush for plants intersecting transect line.
Perennial Grass Height		Breeding, Summer	The grass height is measured for plants intersecting transect line (see also grass canopy cover).
Perennial Grass Cover		Breeding, Summer	Percent cover of perennial grasses is determined from sampling over a standard-sized area of 1 m^2. Percent cover of perennial grasses is estimated within 1 m^2 quadrats at 10 meter increments along a 50 m transect.
Forb Cover	Foraging	Breeding, Summer	Percent cover of forbs is determined from sampling over a standard-sized area of 1 m^2. Percent cover of forbs is estimated within 1 m^2 quadrats at 10 meter increments along a 50 m transect.
Forb Species Richness		Breeding, Summer	Presence of forbs is determined from sampling over a standard-sized area of 1m^2. Species are tallied using a 1 m^2 quadrat at 10 meter increments along a 50 m transect.
Specific Forb Species Presence		Breeding, Summer	Presence of forbs is determined from sampling over a standard-sized area of 1m^2. Species are tallied using a 1 m^2 quadrat at 10 meter increments along a 50 m transect.
Sagebrush Height	Cover / Refugia and Foraging	Winter	The sagebrush height is measured for plants intersecting transect line (see also sagebrush canopy cover).
Sagebrush Canopy Cover		Winter	The percent canopy cover is estimated with line intercept (% of shrub canopy intersecting transect line).
Invasive Grass Canopy Cover			Percent cover of invasive grasses is determined from sampling over a standard-sized area of 1 m^2. Percent cover of invasive grasses is estimated within 1 m^2 quadrats at 10 meter increments along a 50 m transect.
Presence of Mesic Forb Species			Presence of mesic forbs is measured for plants intersecting transect line.

Materials Needed

Hand-held GPS unit, preloaded with sample points
Field maps, using aerial photos as background
Tripod-mounted laser pointer (or pin flag if laser not available)
Two 50-meter tapes or one 100-meter tape
PVC or wooden 1 m^2 quadrat
1 meter ruler
Plant field guides for the area
1 meter tape

Map Unit Delineation and Sampling Intensity

In order to properly assess functional acreage, the site and its map units must be clearly defined. This step is essential because the "currency" of this evaluation, functional acres, is tied to a unit of area. The site is defined as the area being evaluated and includes all habitats within a maximum zone of influence surrounding existing and proposed installations. Map units are predefined for all Exchange participants using a systematic grid with each grid cell measuring 160 acres. Within each map unit, a specific sampling location at the center of the map unit is also predesignated. Vegetation attributes are measured at each plot sampling location within each map unit.

Modifying Sampling Location Based on Field Observations

As noted above, plot sampling locations are predesignated for all habitats within the Exchange. However, if it is determined during field work that the sampling location is located in non-habitat such as a building or road, the field technician should move at least 200 feet from the area, throw a Frisbee or other identifiable object a short direction and use that as the center stake of the transect line.

Although the HQT generally describes seasonal habitat use by GRSG, by no means is the HQT a comprehensive review of the available literature on GRSG habitat use. Practitioners of the HQT should have a working knowledge of GRSG ecology and habitat use. This can be accomplished by conducting a comprehensive review of the literature or consulting closely with GRSG experts or local agency biologists.

Timing of Transect Data Collection

To best equate and compare data collection in map units with breeding, summer, and winter habitat attributes, every effort should be made to collect data during those seasons (with the exception of winter; winter data can be collected any time of year). Data collection should be season specific because of the temporal changes that occur in herbaceous heights and plant species presence and identification. However, it may not be possible to conduct more than one visit to a given project. Thus, data collection for the vegetation attributes for the breeding season may occur in May through mid-July. Because vegetation phenology varies during this time period, for repeated measurements at a given site, if possible field data should be collected within the same three week period or under similar phonological conditions. Data collection for the summer season vegetation attributes may occur June through mid-September. Data collection for the winter season vegetation attributes can occur anytime of the year because sagebrush height does not vary significantly. Topographic measurements can occur at any time. A useful manuscript to consult that describes how GRSG habitat measurements are collected is Connelly et al. (2003).

In some cases Exchange participants may have very limited or no access to habitats within the project area or they may not be able to collect field data during the appropriate seasons. In these situations, Exchange participants would input all data from desktop analyses (Steps 1-5 as described in section 4.1), and field data inputs would be assigned maximum habitat value (1.0). This is similar to the high quality habitat scenario from the debit project example in section 5.2. The HQT Calculator includes this option for maximizing values for all field measurements for debit projects only.

Sampling Location Quality Check / Site Reconnaissance

Upon arrival at the site, field crews should walk the site together to confirm that the predesignated plot sampling locations are not located in non-habitat areas. Crews should be prepared to modify the plot sampling location in the field based on observations, and should also come to a common understanding of the plants present, and the protocol that follows. The sampling location should be recorded once it becomes final.

Transect Layout and Initial Measurements

The core layout for the measurements that follow will be a 50-meter transect. Field crews should navigate to the sample point via hand-held GPS. Select a random direction by blindly spinning a compass wheel, flipping a pen in the air, or other commonly used method. Insert a stake in the ground, and lay out a 50-meter transect along the direction chosen, taking care to lay it over any shrubs along the transect.

Fill in all fields at the top of the data sheet, with the date, observer initials, site name (a unique identifier assigned by the workers), the site UTMs (including UTM Zone and Datum), and whether the site is arid or mesic. Be sure to record all photo numbers and the camera used throughout data collection. At the midpoint of the transect (25 meters) record the slope and aspect of the map unit.

NOTE: During the course of sampling, a 1 m^2 quadrat and tripod-mounted laser may be used to sample cover, vegetation composition, and other attributes. (If a laser is not available or is difficult to use because of the thickness and/or height of sagebrush, crews should use standard point intercept methods, e.g. with a pin flag or using the thin metal edge of a meter stick. It should be decided a-priori on which side of the transect the sampling will occur (e.g. the right side as seen from 0 to 50 meters), and all unnecessary foot traffic should occur on the other (e.g. left) side of the transect line so as not to trample vegetation.

Grass, Forb, and Shrub Measurements with Quadrat

Using a $1m^2$ quadrat, take the following measurements on the right side of the transect line, by placing the quadrat every 10 meters from 10 to 50 (five measurements total).

- Grass height. Height is the estimate of the height above the ground at which the preponderance of grass biomass is present (this is important for both forage and hiding cover for GRSG) (Connelly et al. 2003). It is NOT necessarily the total height of the grass. Grasses with different morphologies will have different bulk heights. For example, grasses with large and diffuse seed heads (such as Indian ricegrass) will likely have the bulk height near the top of the plant; bunch grasses with small seed heads will likely have it near the bottom. Measure this in centimeters with a wooden ruler.
- Grass Cover. Estimate the percent cover of perennial grass species present inside the quadrat; grass cover should be measured by overall grass cover (aerial cover), as opposed to the root cover only.
- Invasive Grass Cover. Estimate the percent cover of cheatgrass (*Bromus tectorum*) present inside the quadrat.
- Number of Forb Species Present. Tally the number of different annual and perennial forb species present inside the quadrat.
- Forb Cover. Estimate the percent cover of perennial forbs species present inside the quadrat.
- Height of Sagebrush. Measure the height (excluding the flower inflorescence) of the nearest sagebrush plant within one meter of the meter mark where the quadrat is located (5, 10, 15, etc.). If there is NO sagebrush plant within one meter of the mark, put a dash in this field.
- Height of Other Shrubs. If another non-sage shrub is within one meter of the meter mark, note the species and the height of the plant.

Sagebrush Cover via Line-Intercept

Using a one-meter tape or stick, record the “lengths” of sagebrush cover at all places where sagebrush intersect the transect. Consider a length of sagebrush unbroken if there is no more than a 5.0 cm. gap. The total of all the lengths over the 50 meters will enable an easy calculation of percent canopy cover of sagebrush. (If you do not have a one-meter tape, record the start of stop points of the sage along the transect, but the above method is much more rapid).

- Each unique shrub is counted, even if the transect crosses multiple shrubs in a cluster.
- Completely dead shrubs do not get counted.
- Cover lengths of live shrubs are measured along a 50m transect for every span of live vegetation less than 5 cm. Spans that are less than 5cm between live vegetation are not measured. Multiple measurements may be taken for single clusters.

Anthropogenic Disturbance Measurements

All of the measurements in the datasheet related to anthropogenic disturbance will be accomplished with GIS.

Food and Cover Abundance

On the data sheet, record the abundance of the plants listed. A pre-study analysis of the study area will determine if all of these species listed in Appendix D are applicable. Without taking too much time, record a qualitative estimate of the relative abundance of the plants over the entire map unit, not just what may or may not have fallen in the quads or along the transect.

Appendix F. Field Datasheet

EcoMetrix

SAGE-GROUSE Attribute Measurements

Revised 12-07-14 (JKo)

Site Name:

Map Unit ID: | Date: | Observers:

Transect #: | Transect UTM E: | Transect UTM N:

Transect Sample Bearing (°): | Camera / Photo #'s:

Site is: ARID or MESIC (circle one) | % Slope: <5% or >5% (Circle one) | Aspect (°):

LINE INTERCEPT (SHRUB COVER)

Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading	Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading
1					11				
2					12				
3					13				
4					14				
5					15				
6					16				
7					17				
8					18				
9					19				
10					20				

Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading	Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading
21					31				
22					32				
23					33				
24					34				
25					35				
26					36				
27					37				
28					38				
29					39				
30					40				

Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading	Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading
41					51				
42					52				
43					53				
44					54				
45					55				
46					56				
47					57				
48					58				
49					59				
50					60				

Notes for Line Transect:

DAUBENMIRE PLOTS (HERBACEOUS COVER)

Record percent cover

Plot #	Presence of Facultative Species*	Grass Height (cm)	% Grass Cover	% BROTEC Cover	# of Forb Species	% Forb Cover	100% Noxious Weed Cover? (Y/N)	Comments
1								
2								
3								
4								
5								

Total number of unique forb species along transect:

Sum total number of unique forb species found across all plots within this transect:

Notes for Daubenmire plots and unknown species codes/descriptions:

Appendix G. Literature Referenced

Aldridge, C.L., S.E. Nielsen, H.L. Beyer, M.S. Boyce, J.W. Connelly, S.T. Knick, and M.A. Schroeder. 2008. Range-wide patterns of greater sage-grouse persistence. Diversity and Distributions 14(6):983-994.

Aldridge, C.L. and M.S. Boyce. 2007. Linking occurrence and fitness to persistence: Habitat-based approach for endangered greater sage-grouse. Ecological Applications 17:508-526.

Antle, J., S. Capalbo, S. Mooney, E. Elliott, K. Pautian. 2003. Spatial heterogeneity, contract design and the efficiency of carbon sequestration policies for agriculture. Journal of Environmental Economics and Management. 46: 231-250.

Balch, J., B. Bradley, C. D'Antonio, and J. Gomesdans. 2013. Introduced annual grass increases regional fire activity across the arid western USA (1980-2009). Global Change Biology 19:173-183.

Barnett, J.K. and J.A. Crawford. 1994. Pre-laying nutrition of sage grouse hens inOregon. Journal of Range Management 47:114–118.

Baruch-Mordo, S., J.S. Evans, J.P. Severson, D.E. Naugle, J.D. Maestas, J.M. Kiesecker, M.J. Falkowski, C.A. Hagen, and K.P. Reese. 2013. Saving sage-grouse from the trees: A proactive solution to reducing a key threat to candidate species. Biological Conservation 167: 233-241.

Beck, T.D.I. 1977. Sage grouse flock characteristics and habitat selection during winter. Journal of Wildlife Management 41:18-26.

Beck, J.L, K.P. Reese, J.W. Connelly, and M.B. Lucia. 2006. Movements and survival of juvenile greater sage-grouse in southeastern Idaho. Wildlife Society Bulletin 34(4): 1070-1078.

Benitez-Lopez, A., R. Alkemade, P.A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biological Conservation 143: 1307-1316.

Blickley, J.L., D. Blackwood, and G. Patricelli. 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. Conservation Biology 26 (3): 461-471.

Blomberg, E.J.,J.S. Sedinger, M.T. Atamian, and D.V. Nonne. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. Ecosphere 3:art55.

Boarman, W. I., and M. Sazaki. 2006. A highway's road-effect zone for desert tortoises (*Gopherus agassizii*).Journal of Arid Environments 65:94-101.

Brown, M.T., and M.B. Vivas. 2005. Landscape development intensity index. Environmental Monitoring and Assessment 101:289-309.

Bureau of Land Management. 1999. Draft EIS for the Pinedale Anticline Oil and Gas Exploration and Development Project, Sublette County, WY. U.S.D.I., BLM, Pinedale Field Office, Pinedale, WY.

Carpenter, J. E., C. L. Aldridge, and M. S. Boyce. 2010. Sage-grouse habitat selection during winter in Alberta. Journal of Wildlife Management 74:1806–1814.

Cody, M.L., ed. 1985. Habitat selection in birds. Academic Press, Orlando, FL.

Colorado Greater Sage-grouse Steering Committee. 2008. Colorado greater sage-grouse conservation plan. Colorado Division of Wildlife, Denver, Colorado, USA.Connelly, J.W., E.T. Rinkes, and C.E. Braun. 2011. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macroscales. pp. 69-83 in S.T. Knick and J.W. Connelly (editors). Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38). University of California Press, Berkeley, CA.

Connelly, J. W., 1982. An ecological study of sage grouse in southeastern Idaho. Ph.D. Dissertation, Washington State University, Pullman. 84pp.

Connelly, J.W., H.W. Browers, and R.J. Gates. 1988. Seasonal movements of sage grouse in southeastern Idaho. Journal of Wildlife Management 52:116-122.

Connelly, J.W., A. D. Apa, R. B. Smith and K. P. Reese. 2000. Effects of predation and hunting on adult sage-grouse Centrocercus urophasianus in Idaho. Wildlife Biology 6:227–32.

Connelly, J.W., K.P. Reese and M.A. Schroeder. 2003. Monitoring of Greater Sage-Grouse Habitats and Populations. University of Idaho, College of Natural Resources Experiment Station Bulletin 80. Moscow, ID.

Connelly, J.W, S.T. Knick, M.A. Schroeder and S.J. Stiver. 2004. Conservation Assessment of Greater Sage-Grouse and Sagebrush Habitat. Western Association of Fish and Wildlife Agencies, Cheyenne, WY. Available at http://www.sagebrushsea.org/WAFWA_page.htm.

Connelly, J.W., C.A. Hagen, and M. . Schroeder. 2011a. Characteristics and dynamics of greater sage-grouse populations. pp. 53-67 in S.T. Knick and J.W. Connelly (editors). Greater Sage-Grouse:

ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA, USA.

Connelly, J.W., S.T. Knick, C.E. Braun, W.L. Baker, E.A. Beever, T. Christiansen, K.E. Doherty, E.O. Garton, S.E. Hanser, D.H. Johnson, M. Leu, R.F. Miller, D.E. Naugle, S.J. Oyler-McCance, D.A. Pyke, K.P. Reese, M.A. Schroeder, S.J. Stiver, B.L. Walker, and M.J. Wisdom. 2011b. Conservation of greater sage-grouse: a synthesis of current trends and future management. pp. 549-563 in S.T. Knick and J.W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA, USA.

Connelly, J.W., E.T. Rinkes, and C.E. Braun. 2011c. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macroscales. pp. 69-83 in S.T. Knick and J.W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA, USA.

Crawford, J.A., R.A. Olson, N.E. West, J.C. Mosley, M.A. Schroeder, T.D. Witson, R.F. Miller, M.A. Gregg, and C.S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management 57: 2-19.

Cushman, S.A., K. McGarigal, and M.C. Neel. 2008. Parsimony in Landscape Metrics: Strength, Universality, and Consistency. Ecological Indicators 8:691-703.

Davis, B.N.K., K.H. Lakhani, T.J. Yates, A.J. Frost, and R.A. Plant. 1993. Insecticide drift from ground-based, dydraulic spraying of peas and brussels sprouts: bioassays for determining buffer zones. Agriculture. Ecosystems and Environment 43:93-108.

de Jong, F.M.W., G.R. de Snoo, and J.C. van de Zande. 2008. Estimated nationwide effects of pesticide spray drift on terrestrial habitats in the Netherlands. Journal of Environmental Management 86(4):721-730.

Decker, K. and M. Fink. 2008. Modeling landscape integrity in Colorado. Poster session presented at GIS day, November 2008, Colorado State University, Fort Collins, Colorado.

Doherty, K.E., D.E. Naugle, B.L. Walker and J.M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72(1): 187-195.

Doherty, K.E., D.E. Naugle, and J.S. Evans. 2010a. A Currency for offsetting energy development impacts: horse-trading sage-grouse on the open market. Plos One 5: e10339. doi:10.1371/journal.pone.0010339

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

Doherty, K.E., D.E. Naugle, H. Copeland, A. Pocewicz, and J. Kiesecker. 2011. Energy development and conservation tradeoffs: systematic planning for greater sage-grouse in their eastern range. pp 505-516 in S. T. Knick and J. W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA, USA.

Drut, M.S., W.H. Pyle, and J.A. Crawford. 1994. Diets and food selection of sage grouse chicks in Oregon. Journal of Range Management 47:90-93.

Dzialak, M.R., C.V. Olson, S.M. Harju, S.L. Webb, J.P. Mudd, J.B. Winstead and L.D. Hayden-Wing. 2011. Identifying and prioritizing greater sage-grouse nesting and brood-rearing habitat for conservation in human-modified landscapes. PLoS ONE 6(10): e26273. doi:10.1371/journal.pone.0026273

Dzialak, M.R., C.V. Olson, S.M. Harju, S.L. Webb, and J.B. Winstead. 2012. Temporal and hierarchical spatial components of animal occurrence: conserving seasonal habitat for greater sage-grouse. Ecosphere 3:30. http://dx.doi.org/10.1890/ES11-00315.1.

Eigenbrod, F., S.J. Hecnar, and L. Fahrig. 2009. Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. Ecology and Society 14(1): 24

Epanchin-Niell, R., J.Englin, and D. Nalle. 2009. Investing in rangeland restoration in the Arid West, USA: Countering the effects of an invasive weed on the long-term fire cycle. Journal of Environmental Management 91(2):370-379.

Fahrig, L. and T.Rytwinski. 2009. Effects of roads onanimal abindance: an empirical review and synthesis. Ecology and Society 14;21.

Fedy, B. C., C.L. Aldridge, K.E. Doherty, M. O'Donnell, J.L. Beck, B. Bedrosian, M.J. Holloran, G.D. Johnson, N.W. Kaczor, C.P. Kirol, C.A. Mandich, D. Marshall, G. McKee, C. Olson, C.C. Swanson, and B.L. Walker. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. Journal of Wildlife Management 76:1062-1071.

Fischer, R.A., K.P. Reese, and J.W. Connelly. 1996a. An investigation on fire effects within xeric sage-grouse brood habitat. Journal of Range Management 49:194–198.

Fischer, R.A., K.P. Reese, and J.W. Connelly. 1996b. Influence of vegetal moisture content and nest fate on timing of female sage grouse migration. Condor 98:868–872.

Fischer, R.A., K.P. Reese, and J.W. Connelly. 1997. Effects of prescribed fire on movements of female sage grouse from breeding to summer ranges. Wilson Bulletin 109:82-91.

Fuhlendorf, S.D., A.J.W. Woodard, D.M. Leslie Jr and J.S. Shackford. 2002. Multi-scale effects of habitat loss and fragmentation on lesser prairie-chicken populations of the US Southern Great Plains.Landscape Ecology 17: 617-628.

Fuhlendorf, S.D. and F.E. Smeins. 1996. Spatial scale influence on longterm temporal patterns of a semi-arid grassland. Landscape Ecology 11:107–113.

Gibson, R.M. 1996. A re-evaluation of hotspot settlement in lekking sage-grouse. Animal Behavior 52:993-1005.

Gill, R..B. 1965. Distribution and abundance of a population of sage grouse in North Park, Colorado. Thesis, Colorado State University, Fort Collins.

Greer, R. 1990. Sage grouse habitat requirements and development. Habitat Extension Bulletin Number 31. Habitat Extension Services, Wyoming Game and Fish Department, Laramie, WY, USA.

Hagen, C.A., J.W. Connelly and M.A. Schroeder. 2007. A meta-analysis of greater sage-grouse Centrocercus urophasianus nesting and brood-rearing habitats. Wildlife Biology 13(Suppl. 1): 27-35.

Hansen, A.J., R.L Knight, J.M. Marzluff, S. Powell, K. Brown, P.H. Gude, and K. Jones. 2005. Effects of exurban development on biodiversity: Patterns, mechanisms, and research needs. Ecological Applications 15(6):1893-1905.

Harju S.M., M.R. Dzialak, R.C. Taylor, L.D. Hayden-Wing and J.B. Winstead. 2010. Thresholds and time lags in effects of energy development on Greater Sage-Grouse Populations. Journal of Wildlife Management 73: 437–448.

Hess, J.E. and J.L Beck. 2012. Disturbance factors influencing greater sage-grouse lek abandonment in north-central Wyoming. The Journal of Wildlife Management 76(8): 1625-1634.

Hilden, O. 1965. Habitat selection in birds: a review. Annales Zoologici Fennici 2: 53-75.

Holloran, M. J. 2005. Greater sage-grouse (Centrocercus urophasianus) population response to natural gas field development in western Wyoming. Dissertation, University of Wyoming, Laramie, WY.

Holloran, M.L. and S.H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. The Condor 107(4): 742-752.

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

Holloran, M.J., R.C. Kaiser and W.A. Hubert. 2010. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74: 65-72.

Huffman, D.W., M.T. Stoddard, J.D. Springer, J.E. Crouse and W.W. Chancellor. 2013. Understory plant community responses to hazardous fuels reduction treatments in pinyon-juniper woodlands of Arizona, USA. For. Ecol. Manage. 289: 478-488.

Hupp J.W. 1987. Sage grouse resource exploitation and endogenous reserves in Colorado. Dissertation, Colorado State University, Fort Collins, CO.

Hupp, J.W. and C.E. Braun. 1989. Topographic distribution of sage grouse foraging in winter. Journal of Wildlife Management. 53 (3): 823-829.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Johnson, G.D., and M.S. Boyce. 1990. Feeding trials with insects in the diet of sage grouse chicks. Journal of Wildlife Management 54:89–91.

Johnson, D.H., M.J. Holloran, J.W. Connelly, S.E. Hanser, C.L. Amundson and S.T. Knick. 2011. Influences of of environmental and anthropogenic features on greater sage-grouse populations. Pages 407-450 in S.T. Knick and J.W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. University of California Press, Berkeley, CA, USA.

Just, R.E. and J.M. Antle 1990 Interactions between agricultural and environmental policies: A conceptual framework. The American Economic Review. 80: 197-202.

Kindlmann, P. and F. Burel. 2008. Connectivity measures: a review. Landscape Ecology 23:879–890.

Kirol, C. P. 2012. Quantifying habitat importance for greater sage-grouse (*Centrocercus urophasianus*) population persistence in an energy development landscape. Thesis, University of Wyoming, Laramie, WY.

Knick, S.T., S.E. Hanser and K.L. Preston. 2013. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: implications for population connectivity across their western range, U.S.A. Ecology and Evolution 3(6): 1539-1551.

Knick, S.T., S.E. Hanser, R.F. Miller, D.A. Pyke, M.J. Wisdom, S.P. Finn, E.T. Rinkis, and C.J. Henny. 2011. Ecological influence and pathways of land use in sagebrush. pp. 203-251 in S.T. Knick and J.W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA, USA.

Lambertucci, S.A., K.L. Speziale, T.E. Rogers, and J.M. Morales. 2009. How do roads affect the habitat use of an assemblage of scavenging raptors? Biodiversity Conservation 18:2063-2074.

LeBeau, C.W. 2012. Evaluation of greater sage-grouse reproductive habitat and response to wind energy development in south-central Wyoming. Masters thesis. Department of Ecosystem Science and Management, University of Wyoming.

LeBeau, C.W., J.L. Beck, G.D. Johnson, and M.J. Holloran. In Press. Short-term impacts of wind energy development on greater sage-grouse fitness. Journal of Wildlife Management.

Leonard, K.M., K.P. Reese, and J.W. Connelly. 2000. Distribution, movements, and habitats of sage grouse *Centrocercus urophasianus* on the Upper Snake River Plain of Idaho: changes from the 1950's to the 1990's. Wildlife Biology 6(4):265-270

Lovich, J.E. and J.R. Ennen. 2011. Wildlife conservation and solar energy development in the Desert Southwest, United States. BioScience 61:982-992.

Lyon, A.G. and S.H. Anderson 2003. Potential gas development impacts on sage-grouse nest initiation and movement. Wildlife Society Bulletin 31:486–491.

Manier, D.J, D.J.A. Wood, Z.H. Bowen, R.M. Donovan, M.J. Holloran, L.M. Juliusson, K.S. Mayne, S.J. Oyler-McCance, F.R. Quamen, D.J. Saher and A.J. Titolo. 2013. Summary of science, activities, programs, and policies that influence the rangewide conservation of Greater Sage-Grouse (*Centrocercus urophasianus*): U.S. Geological Survey Open-File Report 2013–1098, 170 p., http://pubs.usgs.gov/of/2013/1098/

Manier, D.J., Bowen, Z.H., Brooks, M.L., Casazza, M.L., Coates, P.S., Deibert, P.A., Hanser, S.E., and Johnson, D.H. 2014. Conservation buffer distance estimates for Greater Sage-Grouse: a review: U.S. Geological Survey Open-File Report 2014–1239, 14 p., http://dx.doi.org/10.3133/ofr20141239.

McDonald, R.I., R.T.T. Forman, P. Kareiva, R. Neugarten, D. Salzer, and J. Fisher. 2009. Urban effects, distance, and protected areas in an urbanizing world. Landscape and Urban Planning 93:63–75.

McKenney, B.A. and J.M. Kiesecker 2010. Policy development for biodiversity offsets: A review of offset frameworks. Environmental Management 45: 165-176.

Miller, R.F, S.T. Knick, D.A. Pyke, C.W. Meinke, S.E. Hanser, M.J. Wisdom and A.L. Hild. 2011. Characteristics of sagebrush habitat and limitations to long-term conservation. Greater Sage-Grouse: Ecology and Conservation of a Landscape Species and its Habitats. Studies in Avian Biology, Volume 38 (eds. S.T. Knick and J.W. Connelly), pp. 145-184, University of California Press, Berkeley, CA

Miller, R.F., J.D. Bates, T.J. Svejcar, F.B. Pierson and L.E. Eddleman. 2005. Biology, ecology, and management of western juniper (Juniperus occidentalis): Oregon State University Agricultural Experiment Station.Miller, R. F., T. J. Svejcar, and J. A. Rose. 2000. Impacts of western juniper on plant community composition and structure. J. Range Manage. 53: 574-585.

Miller, R.F., Svejcar, T.J., Rose, J.A. 2000. Impacts of western juniper on plant community composition and structure. Journal of Rangeland Management 53:574–585.

Monsen, S.B. 2005. Restoration manual for Colorado sagebrush and associated shrubland communities. Colorado Division of Wildlife Department of Natural Resources.

Mooney, H.A. and E.E. Cleland 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Science 98:5446-5451.

Morrison, M.L., B.G. Marcot and R.W. Mannan. 2006. Wildlife-Habitat Relationships: Concepts and Applications (3rd ed.). University of Wisconsin Press, Madison, WI.

Nasen, L.C. 2009. Environmental effects assessment of oil and gas development on a grassland ecosystem. M.S. Thesis. Department of Geography and Planning, University of Saskatchewan, Saskatoon.

Naugle, D.E., K.E. Doherty, B.L. Walker, H.E. Copeland, M.J. Holloran, and J.D. Tack. 2011. Sage-grouse and cumulative impacts of energy development. pp. 55-70 in D. E. Naugle (editor). Energy development and wildlife conservation in western North America. Island Press, Washington, DC, USA. Neel, L.A. 1980. Sage grouse response to grazing management in Nevada. Masters thesis, University of Nevada, Reno.

Neel, L.A. 1980. Sage grouse response to grazing management in Nevada. MS Thesis, University of Nevada, Reno, NV, USA.

Neely, B., S. Kettler, J. Horsman, C. Pague, R. Rondeau, R. Smith, L. Grunau, P. Comer, G. Belew, F. Pusateri, B. Rosenlund, D. Runner, K. Sochi, J. Sovell, D. Anderson, T. Jackson and M. Klavetter. 2006. Central Shortgrass Prairie Ecoregional Assessment and Partnership Initiative. The Nature Conservancy of Colorado and the Shortgrass Prairie Partnership. 124 pp. and Appendices.

Odell, E.A. and R.L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology 15(4):1143-1150.

Orians, G.H. and J.F. Wittenberger. 1991. Spatial and temporal scales in habitat selection. American Naturalist 137:29–49.

Owen, S.M., C.H. Sieg, C.A. Gehring and M.A. Bowker. 2009. Above- and belowground responses to tree thinning depend on the treatment of tree debris. For. Ecol. Manage. 259: 71-80.

Palomino, D. and L.M. Carrascal. 2007. Threshold distances to nearby cities and roads influence the bird community of a mosaic landscape. Biological Conservation 140:100-109.

Parris, K.M. and A. Schneider. 2008. Impacts of traffic noise and traffic volume on birds of roadside habitats. Ecology and Society 14(1):29

Patten, M.A., D.H. Wolfe, E. Shocat and S.K. Sherrod. 2005. Habitat fragmentation, rapid evolution and population persistence. Evolutionary Ecology Research 7: 1-15.

Patterson, R.L. 1952. The sage grouse in Wyoming. The Wyoming Game and Fish Commission and Sage Books. Denver, Colorado.

Petersen, S. L., T. K. Stringham, and B. A. Roundy. 2009. A process-based application of state-and-transition models: a case study of western juniper (*Juniperus occidentalis*) encroachment. Rangeland Ecology & Management 62:186–192.

Peterson, J.G. 1970. The food habits and summer distribution of juvenile sage grouse in central Montana. Journal of Wildlife Management 34:147-155.

Remington, T.E. and C.E. Braun. 1985. Sage grouse food selection in winter, North Park, Colorado. Journal of Wildlife Management 49:1055-1066.

Remington, T.E. and C.E. Braun. 1991. How surface coal mining affects sage grouse, North Park, Colorado. Proceedings, Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute 5:128-132.

Rice, M.B, A.D. Apa, M.L Phillips, J.H. Gammonley, B.B. Petch, and K. Eichhoff. 2013. Analysis of Regional Species Distribution Models Based on Radio-Telemetry Datasets From Multiple Small-Scale Studies. Journal of Wildlife Management 77(4): 821-831.

Ricklefs, R.E. 1979. Ecology. Second Edition. Chiron Press, Inc. New York.

Robertson, M.D. 1991. Winter ecology of migratory sage grouse and associated effects of prescribed fire in southeastern Idaho. Thesis, University of Idaho, Moscow.

Romme, W.H., C.D. Allen, J.D. Balley, W.L. Baker, B.T. Bestelmeyer, P.M. Brown, K.S. Eisenhart, M.L. Floyd, D.W. Huffman, B.F. Jacobs, R.F. Miller, E.H. Muldavin, T.W. Swetnam, R.J. Tausch and P.J. Weisberg. 2009. Historical and Modern Disturbance Regimes, Stand Structures, and Landscape Dynamics in Pinon-Juniper Vegetation of the Western United States. Rangeland Ecology & Management 62: 203-222.

Rondeau, R., K. Decker, J. Handwerk, J. Siemers, L. Grunau, and C. Pague. 2011. The state of Colorado's biodiversity 2011. Prepared for The Nature Conservancy. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Rosenzweig, M. L. 1995. Species Diversity in Space and Time Cambridge: Cambridge University Press.

Ross, M.R., S.C. Castle and N.N. Barger. 2012. Effects of fuels reductions on plant communities and soils in a Pinon-juniper woodland. Journal of Arid Environments 79: 84-92.

Rowland, M.M., L.H. Suring, and M.J. Wisdom. 2010. Assessment of Habitat Threats to Shrublands in the Great Basin: A Case Study. Pages 673-685 in J. M. Pye, H. M. Rauscher, Y. Sands, D. C. Lee, and J. S. Beatty, editors. Environmental Threat Assessment and Application to Forest and Rangeland Management. U S Forest Service, General Technical Report, PNW, Bozeman, MT.

Sage and Columbian sharp-tailed grouse technical committee. 2009. Prescribed fire as a management tool in xeric sagebrush ecosystems: is it worth the risk to sage-grouse? Unpublished Report, Western Association of Fish and Wildlife Agencies, Cheyenne, WY, USA.

Schindler, S., K. Poirazidis, and T. Wrbka. 2008. Towards a core set of landscape metrics for biodiversity assessments: A case study from Dadia National Park, Greece. Ecological Indicators 8(5):502–514.

Schroeder, M.A., J.R. Young and C.E. Braun. 1999. Sage Grouse (Centrocercus urophasianus). In The Birds of North America, No. 425 (A. Poole and F. Gill, eds.) The Birds of North America, Inc., Philadelphia, PA.

Seefeldt, S. S., and D. T. Booth. 2006. Measuring plant cover in sagebrush steppe rangelands: a comparison of methods. Environmental Management 37:703-711.

Shepherd, J. 2006. Landscape-scale habitat use by greater sage-grouse (*Centrocercus urophasianus)* in southern Idaho. PhD Dissertation, University of Idaho, Moscow.

Stiver, S.J., E.T. Rinkes and D.E. Naugle. 2010. Sage-grouse Habitat Assessment Framework. U.S. Bureau of Land Management. Unpublished Report. U.S. Bureau of Land Management, Idaho State Office, Boise, Idaho.

Tack, J.D. 2009. Sage-grouse and the human footprint: implications for conservation of small and declining populations. Thesis, University of Montana, Missoula.

Tausch,R.L. and P.T. Tueller 1990. Foliage biomass and cover relationships between tree- and shrub-dominated communities in pinyon-juniper woodlands. Great Basin Naturalist 50:121-134.

Theobald, D., J. Miller, and N.T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39:25–36.

Thompson, T.R. 2012. Dispersal ecology of greater sage-grouse in northwestern Colorado: evidence from demographic and genetic methods. Ph.D. Dissertation, University of Idaho, Moscow, Idaho.

Thompson, K.M., M.J. Holloran, S.J. Slater, J.L. Kuipers, and S.H. Anderson. 2006. Early brood-rearing habitat use and productivity of greater sage-grouse in Wyoming. Western North American Naturalist 66:332–342.

Tuffly, M. and P. Comer. 2005. Calculating landscape integrity: A working model. Internal report for NatureServe Vista decision support software engineering, prepared by NatureServe, Boulder CO.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893-901.

Vance, L.K. 2009. Assessing wetland condition with GIS: A landscape integrity model for Montana. A report to the Montana Department of Environmental Quality and The Environmental Protection Agency. Montana Natural Heritage Program, Helena, MT.

Vitousek PM. 1990. Biological invasions and ecosystem processes: Toward an integration of population biology and ecosystem studies. Oikos 57:7–13.

Walker, B.L. 2013. Assessment of greater sage-grouse response to pinyon-juniper removal in the Parachute-Piceance-Roan population of northwestern Colorado. Wildlife research report, Colorado Division of Parks and Wildlife.

Walker, B.L., D.E. Naugle and K.E. Doherty. 2007. Greater sage-grouse population response to energy development and habitat loss. Journal of Wildlife Management 71:2644-2654.

Wallestad, R.O. 1971. Summer movements and habitat use by sage grouse broods in central Montana. Journal of Wildlife Management 35:129-136.

Wuenschel, A. 2014. Ecological and Fine-Scale Spatial variation in Vegetation at Sage-grouse Nests in western Wyoming. Thesis, Department of Ecosystem Science and Management, University of Wyoming, Laramie, USA.

Wiens, J.A. 1989. Spatial scaling in ecology. Functional Ecology 3(4): 385-397.

Wiens, J. A., J.T. Rotenberry and B.V. Horne. 1987. Habitat occupancy patterns of North American shrubsteppe birds: the effects of spatial scale. Oikos 48:132–147.

Wilbert, M., J. Thomson, and N. Wolff Culver. 2008. Analysis of habitat fragmentation from oil and gas development and its impact on wildlife: A framework for public land management planning. The Wilderness Society, Washington, D.C.

Winward, A.H. 2004. Sagebrush of Colorado: taxonomy, distribution, ecology and management. CO Division of Wildlife. Denver, CO.

Wisdom, M.J., C.W. Meinke, S.T. Knick and M.A. Schroeder. 2011. Factors associated with extirpation of sage-grouse. pp. 451-472 in S. T. Knick and J. W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA, USA.

Wyoming Interagency Grazing Management Committee. 2009. Grazing influence, management, and objective development in Wyoming's greater sage-grouse habitat: with emphasis on nesting and early brood rearing. Unpublished Report, Wyoming Game and Fish Department, Cheyenne, WY, USA.