Sagebrush Ecosystem Conservation and Management:

Ecoregional Assessment Tools and Models for the Wyoming Basins

The Wyoming Basins are one of the remaining strongholds of the sagebrush ecosystem. However, like most sagebrush habitats, threats to this region are numerous. This book adds to current knowledge about the regional status of the sagebrush ecosystem, the distribution of habitats, the threats to the ecosystem, and the influence of threats and habitat conditions on occurrence and abundance of sagebrush associated fauna and flora in the Wyoming Basins. Comprehensive methods are outlined for use in data collection and monitoring of wildlife and plant populations. Field and spatial data are integrated into a spatially explicit analytical framework to develop models of species occurrence and abundance for the region. This book provides significant new information on distributions, abundances, and habitat relationships for a number of species of conservation concern that depend on sagebrush in the region. The tools and models presented in this book increase our understanding of impacts from land uses and can contribute to the development of comprehensive management and conservation strategies.

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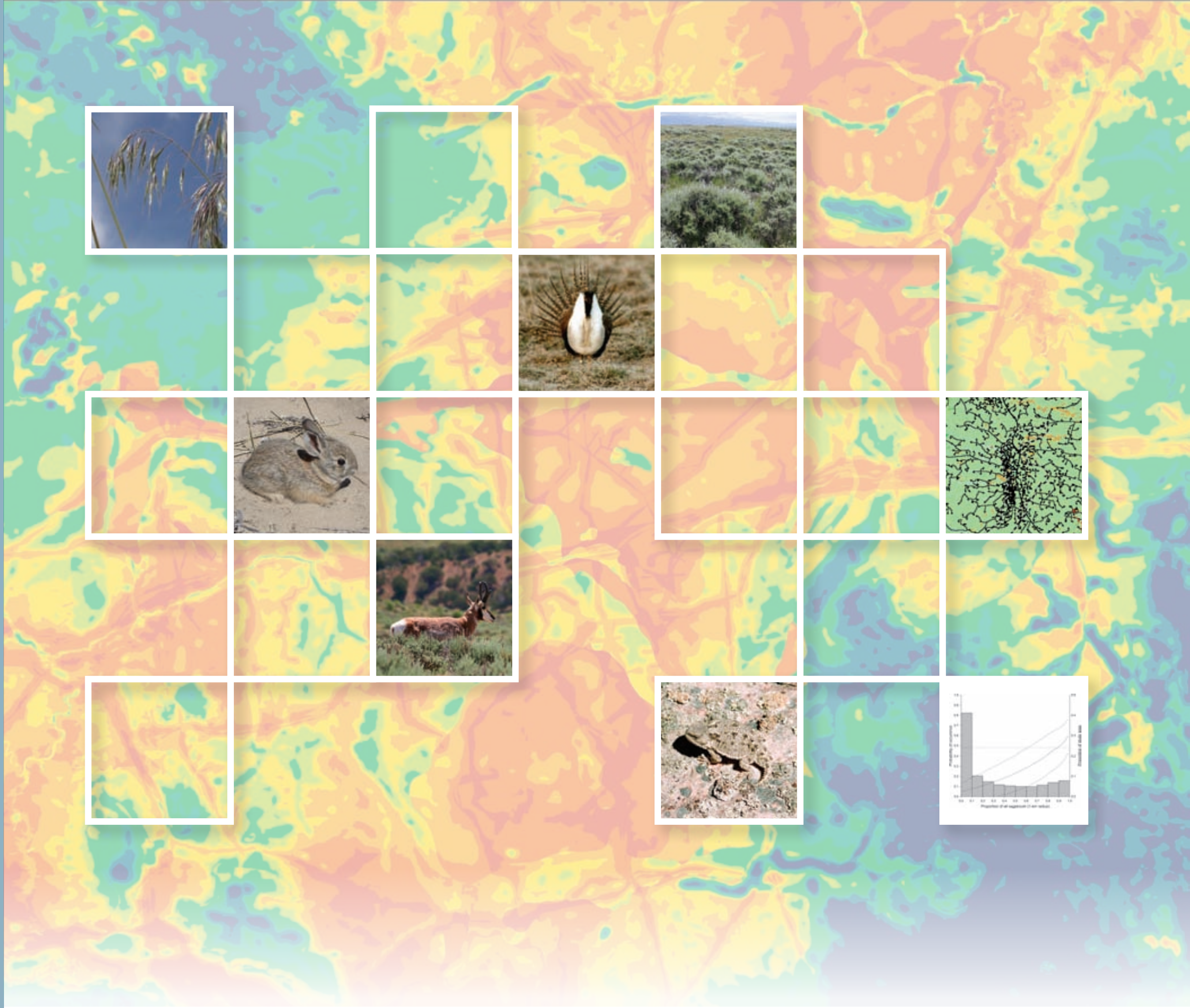
Sagebrush Ecosystem Conservation and Management



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Edited by STEVEN E. HANSER, MATTHIAS LEU, STEVEN T. KNICK, and CAMERON L. ALDRIDGE

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Preface

The perception of the average traveler while driving through the sagebrush (*Artemisia* spp.) ecosystem of western North America is one of a vast expanse of empty desert. This view does not capture the importance of this landscape for numerous wildlife and plant species that make up this ecosystem covering >250,000 km^2. The sagebrush ecosystem provides crucial resources to our nation in the form of land for livestock grazing, areas to recreate, and rich deposits of renewable and non-renewable energy. Land management agencies tasked with managing ecosystems for multiple use are faced with the difficult challenge of balancing the needs for biodiversity and habitat conservation with human demands for resources contained in these ecosystems.

The Wyoming Basins are one of the remaining strongholds of the sagebrush ecosystem. However, like most sagebrush habitats, threats to this region are numerous. While no single threat can be attributed as the main cause of habitat loss and degradation, human land use is a common factor associated with the decline of the ecosystem. In the Wyoming Basins, energy development is an example of a disturbance that has grown rapidly over the past decade with increased demand for domestic energy production. The region contains ~41% of known domestic natural gas reserves, and a 50% increase in energy demand is predicted over the next 20 years. Within this context, our assessment was developed to provide an integrated process to delineate and quantify the level of threats to the sagebrush ecosystem and associated species of conservation concern in the Wyoming Basins and to produce information necessary for broad-scale natural resource management and planning to meet future development and energy demands.

The Wyoming Basins Ecoregional Assessment was a collaborative effort between the U.S. Geological Survey and the U.S. Forest Service and was conducted at the request of the U.S. Bureau of Land Management. We present this volume in separate chapters that largely are self-contained. In arranging these chapters, we followed the approximate order of analytical steps described by Wisdom et al. (2005. Habitat Threats in the Sagebrush Ecosystem: Methods of Regional Assessment and Applications in the Great Basin, Alliance Communications Group, Lawrence, KS) for regional assessment of habitats of species of concern in the sagebrush ecosystem.

We begin by providing background and context for ecoregional assessments in the Introduction. In Chapters 1–3 we introduce the region, identify the regional sagebrush-associated species of conservation concern, and examine the impact of oil and gas development on the landscape configuration. We then present, in Chapter 4, a sampling approach to collect multi-taxa field data and an analytical approach to develop spatially-explicit species models based on field data, land cover, climate, topography, and human disturbance variables derived from geographic information system (GIS) data. We implemented this field sampling approach to allow us to develop occurrence and abundance models for multiple species, including sage-grouse (*Centrocercus urophasianus*) (Chapter 5), songbirds (Chapter 6), other wildlife species (Chapter 7), pronghorn (*Antilocapra americana*) (Chapter 8), small mammals (Chapter 9), and exotic plants (Chapter 10). We conclude by discussing management considerations and the assumptions and limitations of our approach (Chapter 11).

This book adds to current knowledge about the regional status of the sagebrush ecosystem, the distribution of habitats, the threats to the ecosystem, and the influence of threats and habitat conditions on occurrence and abundance of sagebrush-associated fauna and flora in the Wyoming Basins. We have built upon the framework outlined in the Great Basin Ecoregional Assessment, adding field surveys and developing empirical models of species and environmental relationships. We developed a large database of spatial data for use in our analyses as well as future planning processes. We also developed and implemented a field data collection protocol which may be used for future data collection and monitoring of wildlife populations. We further integrated field and spatial data into a spatially explicit analytical framework to develop new models of species occurrence and abundance for the region. As federal management agencies move toward management at regional scales through efforts such as U.S. Bureau of Land Management Rapid Ecoregional Assessments and U.S. Department of Interior Landscape Conservation Cooperatives, our ecoregional assessment approach and results for the Wyoming Basins can further advance a cohesive approach to management of the sagebrush ecosystem.

Steven E. Hanser,
Matthias Leu,
Steven T. Knick, and
Cameron L. Aldridge
Editors
August 30, 2011

Sagebrush Ecosystem Conservation and Management: xiii–xvi, 2011

Foreword

Somehow the editors of this volume got wind of the fact that I love sagebrush and would not be able to resist an invitation to compose a Foreword to a book on the sagebrush ecosystem. When I lived with my family in western Oregon, we regularly hopped over the Cascades, sometimes crossing the high passes during blinding blizzards, to spend time in the High Desert, also known as the Sagebrush Steppe. In the summers we ran Breeding Bird Survey routes, surveyed Breeding Bird Atlas units, hiked, camped, caught lizards, and just hung out in some of the wildest areas of the West. My kids spent a good part of their early years sleeping under the High Desert's brilliant stars. There is unspeakable beauty in these lonesome landscapes, which can roast you by day and freeze you that same night, where the clarity of the air and the vastness of space create a freedom of mind that is difficult to attain in more confined places.

The Sagebrush Steppe, as mapped by geographer A.W. Küchler, covers most of central and eastern Oregon, southeastern Washington, northern Nevada, southern Idaho, southern Wyoming, and portions of adjacent Utah, Montana, and Colorado. The Wyoming Basins study area for this book covers the Wyoming portion of the Sagebrush Steppe, expanded to encompass the entire Wyoming Basins and Utah-Wyoming Rocky Mountains ecoregions, which include the 'Greater Yellowstone Ecosystem,' plus portions of adjacent ecoregions (see Introduction). My colleagues and I conducted conservation assessments for the Greater Yellowstone Coalition and The Nature Conservancy for much of this same area in the early 1990s and again in 1999–2001. We confirmed many sites and landscapes of high conservation value and scientific interest. This book brings back some of my fondest memories of those precious places.

The Wyoming Basins, as defined in this book, constitutes some of the most remote country south of Canada. The farthest you can get from a road in the lower 48 states is in this region, in the southeastern corner of Yellowstone National Park. Remoteness, however, should not feed complacency. This region has suffered more than its share of wounds. These include overhunting that led to near extinction of the bison; relentless persecution of large carnivores, resulting in regional extinction of the gray wolf and severe range contraction of the grizzly bear and lynx; overgrazing by cows and sheep; some of the worst problems with invasive non-native plants, such as cheatgrass and Russian thistle, anywhere on the continent; and ever-increasing impacts and threats from energy development. Even my favorite ungulate and one of the most taxonomically distinct vertebrates in the New World, the American pronghorn, suffered a huge decline and is still far from recovered. Rapid climate change now poses a menace to all of the region's ecosystems, with uncertain consequences. Despite these troubles, it is difficult to suppress a strange optimism, however irrational, that here is a place big enough, with sufficient space and time, to work things out – a place where true ecological recovery is possible. People and nature ought to be able to coexist here, if anywhere.

Editors Steven Hanser, Matthias Leu, Steven Knick, and Cameron Aldridge assembled the highly qualified scientists who led this massive ecological assessment, to write it up in book form. The research reported here was funded by several agencies of the U.S. Department of Interior and U.S. Department of Agriculture. The chapters investigate the potential impacts of energy development and other human land uses on ecosystems and species of conservation concern in the Wyoming Basins. Both field surveys and spatially explicit species distribution models were used to evaluate impacts and options for conservation and management. A systematic spatial assessment of this kind is absolutely necessary for illuminating the costs and benefits of alternative management policies and actions under a range of scenarios. The combination of new, extensive and intensive field surveys and GIS-based modeling of multiple species demonstrated in this book is especially impressive. Too many conservation assessments rely on old or sparse data for modeling of habitat suitability or impacts, or on extrapolation from studies done elsewhere. This assessment avoids that problem.

What use will policy-makers and managers make of the data, models, and projections offered in this volume? Predicting what decision-makers and managers will do is always hazardous. Citizens should insist that they make use of the information contained in this volume to better protect critical core areas and connectivity zones (wildlife corridors) throughout the region, while practicing truly sustainable stewardship of the multiple-use landscape matrix. We can hope that energy development, roads, transmission corridors, and other potentially damaging land uses will be shifted to degraded sites and avoid further fragmentation and alteration of areas with high conservation value. Importantly, the broad spatial scale of this ecoregional assessment allows the cumulative impacts of oil and gas development and other activities to be evaluated on a regional scale, which for many questions is more meaningful than the site-level assessments usually conducted for energy and other development projects. Information from the studies reported herein will be useful for designing and prioritizing restoration actions for lands that have been degraded, but are not past the point of no return, and which might serve as connectivity or buffer zones among sites of high conservation value. The 65 plant species and 28 of 40 sagebrush-associated vertebrate species of conservation concern in the study region depend on thoughtful, science-based decision-making for their survival and recovery.

As can be expected in any scientific endeavor, this multi-species research project raised as many new questions as it answered old ones. New research is needed to tackle these questions, for example the site-level habitat requirements and demographics of imperiled and invasive species. The present analysis was too coarse in scale to model habitat of rare plants effectively. New field data collection and finer-resolution modeling is needed for these species. Finer-scale analysis is also necessary to verify habitat suitability for imperiled animal species, such as the greater sage-grouse, which requires healthy native ground cover vegetation. Surprisingly, perhaps, the authors noted that they were not able to obtain reliable spatial data on livestock grazing; hence, they could not assess impacts of grazing systematically or accurately across the region. This deficiency urgently needs to be corrected, because livestock production remains a controversial activity in the Wyoming Basin, with previous studies from many regions showing a range of impacts that often are detrimental to native biodiversity. Unfortunately, data on off-road vehicle use, another potentially serious threat, also were not available for analysis in this assessment. Not surprisingly, given earlier studies, roads were identified in this assessment as a leading impact, for example in serving as conduits for the spread of non-native plants. As the authors appropriately note, updating data sets and building new ones is a necessity for meaningful adaptive management. Long-term funding for research, monitoring, and management must be assured.

I urge decision-makers in Congress and the land-managing agencies to take this ecoregional assessment very seriously and implement actions to prevent or mitigate the potential adverse impacts of energy development and other human land uses in the Wyoming Basins. Filling the knowledge gaps identified in this study, such as the spatially explicit impacts of livestock grazing and the detailed habitat relationships and demographics of imperiled species, is a huge need. It is critical that the agencies be given the money they require to properly manage and restore the landscape, and that agency and independent researchers have adequate funding to conduct studies to answer remaining questions.

Every time I visit a place that has sagebrush, I break off a few sprigs and take them home with me to keep my memories alive. People who live in this region are fortunate in many ways, and all Americans should feel immense gratitude that this remarkable region remains in relatively decent condition despite its many wounds and threats. We must strive to make the future of the region as bright as the Wyoming sky.

Reed Noss
Provost's Distinguished
  Research Professor
University of Central Florida
Orlando, FL
October 10, 2011

Availability Of Data

Data used in our analyses were developed in many formats, including tables, spreadsheets, databases, and GIS layers. Spatial datasets used in this volume are available on the SAGEMAP website (http://sagemap.wr.usgs.gov/wbea.aspx) in their final, validated format. Formal metadata documentation for this assessment also is posted on the SAGEMAP website. We emphasize that these data layers represent a snapshot from 1999–2006; data concurrent with the field data collection (2005–2006) was used when available. Therefore, new information should be incorporated when available to maintain the accuracy of the modeled predictions.

Sagebrush Ecosystem Conservation and Management: 1–9, 2011

Introduction: An Ecoregional Assessment of the Wyoming Basins

Steven T. Knick, Steven E. Hanser, Matthias Leu, Cameron L. Aldridge, and Michael J. Wisdom

The Wyoming Basins Ecoregional Assessment (WBEA) area in the western United States contains a number of important land cover types, including nearly one-fourth of the sagebrush (*Artemisia* spp.) in North America. Although relatively unappreciated until recent decades, the broad open landscapes dominated by sagebrush communities have received increasing attention for their ecological value and the resources that they contain (Knick and Connelly 2011). As many as 350 wildlife species depend on sagebrush ecosystems for all or part of their life requirements (Wisdom et al. 2005a). Within the WBEA, intact sagebrush landscapes provide an important stronghold for populations of greater sage-grouse (*Centrocercus urophasianus*), recently listed as a candidate species under the Endangered Species Act (U.S. Department of the Interior 2010). Numerous other plant and vertebrate species of state or national concern also occur within the WBEA study area (Ch. 2). Conserving sagebrush ecosystems is a major conservation challenge that will require an understanding not only of current trajectories and scales of habitat change due to natural and anthropogenic disturbances (Leu and Hanser 2011), but also the potential exacerbation of these trends from climate change (Wiens and Bachelet 2010, Miller et al. 2011).

The WBEA area contains significant amounts of resources important to sustain human populations. Oil, gas, and wind energy development as well as the necessary infrastructure for energy transmission are dominant land uses that can fragment landscapes and influence resource availability (Doherty et al. 2011, Naugle et al. 2011). Livestock grazing also occurs throughout the WBEA area, potentially altering vegetation structure and quality as well as other ecosystem processes (Freilich et al. 2003). Recreation and wilderness amenities on these lands impose additional physical and legal demands to more traditional commodity uses (Knick et al. 2011). Over half of the sagebrush within the WBEA area is public land; the largest land areas are managed by the U.S. Bureau of Land Management (BLM) and the U.S. Forest Service (FS) for multiple uses. Less than two percent of the sagebrush in the WBEA area receives legal protection from conversion of land cover in which only natural processes are allowed to influence the system (Ch. 1). Because most sagebrush habitats are managed by public agencies, federal land use actions can impact a large proportion of sagebrush habitats and their dependent wildlife.

The ecological importance of the WBEA area coupled with its abundant natural resources create a complex challenge for balancing land and resource use with long-term conservation. Systematic conservation planning can help resolve this challenge through development of spatially explicit objectives (Pressey et al. 2007); these objectives can be developed by delineating species distributions relative to habitat gradients and land-use patterns. Management strategies or conservation planning then can be based on trade-offs between land uses and important areas for species or biodiversity (Groves 2003, Doherty et al. 2011). To address these issues, we conducted an ecoregional assessment to determine broad-scale relationships among plant and wildlife species and gradients of habitat and disturbance. Our objec-

FIG. I.1. The Wyoming Basin Ecoregional Assessment study area.

tives were to: (1) identify primary land uses and their potential influence on sagebrush habitats, (2) identify plant and wildlife species of conservation concern, (3) delineate the distribution of sagebrush habitats and environmental and anthropogenic features from existing and updated Geographic Information System (GIS) coverages, (4) conduct field surveys to determine distribution and abundance of wildlife species and invasive plants, (5) integrate field- and GIS-based information to determine habitat relationships using spatially explicit models, and (6) apply spatially explicit models of habitat relationships to delineate species occurrence and abundance. The strength of our ecoregional assessment is based on our capability to accurately model species distributions in relation to both habitat characteristics and human activities across the large extent of the WBEA. These mapped relationships provide information that land managers can use to understand how and where current actions and future development may influence species and habitats within the WBEA study area.

RATIONALE AND PURPOSE OF ECOREGIONAL ASSESSMENTS

The ecoregional assessment process leads to the development of substantial information on wildlife-habitat relationships and the role of disturbance in shaping the patterns of species and habitat distributions (Wisdom et al. 2000, 2005a). Ecoregional assessments are inherently spatial analyses conducted at broad regional scales to identify habitat or species strongholds, quantify landscape features, describe natural disturbances, and delineate human activities (Ricketts et al. 1999, Noss et al. 2001, Jones et al. 2004, Wisdom et al. 2005a). Ecoregional assessments also can detect data gaps and identify key environmental variables that contribute to effective monitoring strategies for broad-scale and long-term change.

Conservation strategies developed at regional scales of an ecoregional assessment are an important part of effective conservation and land-use planning because processes operating at regional scales can be decoupled from those at intermediate or local scales (Wiens 1989, Kotliar and Wiens 1990, Jennings 2000). The distributions of many sagebrush-associated species considered in this assessment cover continental scales, which also renders broad regional understanding a necessary part of conservation planning (Knick et al. 2003). Thus, regional planning and analyses are important components of a hierarchical process in which broad-scale data, such as developed in this ecoregional assessment, establish a regional context that is complemented by fine-scale data useful for setting local objectives (Hansen et al. 1993, U.S. Bureau of Land Management 2005, Wisdom et al. 2005b).

Broad-scale assessments and conservation planning often are more cost-effective and efficient at projecting alternate management scenarios and outcomes than smaller-scale efforts. In contrast, small-scale assessments provide more detailed data on individuals or local populations but lack large-scale context (May 1994, Corsi et al. 2000). The large areas included in ecoregional assessments often permit conclusions independent of administrative jurisdictions and land stewardship patterns. Much of the data used in these broad-scale assessments can be existing data, which can improve the cost-effectiveness and efficiency of the process. Ecoregional assessments provide information important for developing management and conservation strategies commensurate with regional or continental distributions of many species (Dinerstein et al. 2000).

STUDY AREA

Boundaries of the WBEA (Fig. I.1) were determined primarily by the distribution of sagebrush within the Wyoming Basins and then expanded to include adjacent regions of ecological and management concern (Ch. 1). The total area encompassed 345,300 km^2, and included most of Wyoming, and smaller portions of southwestern Montana, northern Colorado, northeastern Utah, and eastern Idaho. Private lands constituted 33% of the WBEA area. The BLM and FS each manage one-fourth of the WBEA area; the remaining public lands are managed by state agencies, the U.S. National Park Service, and the U.S. Bureau of Indian Affairs. The Wyoming Basins and Utah-Wyoming-Rocky Mountains ecoregions, as defined by The Nature Conservancy (1997), were included in their entirety as were portions of the Southern Rocky Mountains and Middle Rockies-Blue Mountains ecoregions.

The WBEA area contains approximately 131,600 km^2 of sagebrush (38% of the total area), which represents nearly 24% of all sagebrush lands in the United States. The BLM manages 44% of the sagebrush within the WBEA; private land owners are responsible for 38% and the FS is responsible for 6%. Characteristics of sagebrush landscapes differ among land ownership and agency (Knick 2011). Private lands containing sagebrush typically are associated with more productive sites containing deeper soils and greater water availability. In contrast, lands managed by BLM often have shallow soils, low water availability, and lower precipitation. Sagebrush lands managed by the FS have greater precipitation but generally are on steeper, rockier locations. Consequently, management options vary by land ownership because of relative productivity, resistance to disturbance, and ability to recover or respond to treatment (Knick 2011).

ANALYSIS APPROACH

Assessment Methods

The foundation of an ecoregional assessment rests on analyzing a series of map overlays using a GIS to identify and delineate complex relationships among multiple spatial features. These overlays are effectively the basic components of an assessment; they lay the foundation for increasingly complex analyses to address more targeted questions. Coupled relationships, such as those between existing or proposed land use actions and habitat and species distributions, provide a powerful basis for informing management decisions. This process of data analyses and syntheses can resolve complications related to habitat alteration and loss, identify locations for conservation measures to retain important species or habitat strongholds, and set priorities for habitat restoration or rehabilitation (Pressey et al. 2007).

We combined both coarse- and fine-filter approaches in this assessment (Ch. 2). Coarse-filter assessments focus on species groups or dominant land cover types under the assumption that conserving representative ecological communities will provide the greatest benefit (Groves 2003). In contrast, a fine-filter approach recognizes that rare species or those with a narrow range of habitat requirements will be missed by a coarse-filter and may need individualized data development and analysis. Our hybrid approach captured a broad range of the sagebrush species and communities and also provided information on individual species of concern.

We conducted field surveys during 2005 and 2006 to collect data on plant and wildlife distributions relative to gradients of land cover and human land use. The hierarchical sampling design represented a novel approach that maximized efficiency for collecting information on a broad range of plant and wildlife species distributed over large areas and minimized personnel time and expense (Ch. 4). In contrast to ecoregional assessments based on existing information, the data collected from these surveys permitted us to develop empirical models relating species to habitats and disturbance that were directly applicable to the WBEA area and not extrapolated from elsewhere. We grouped individual species from field surveys into separate chapters on sage-grouse (Ch. 5), songbirds (Ch.6), other wildlife species (Ch. 7), pronghorn (*Antilocapra americana*) (Ch. 8), small mammals species (Ch. 9), and exotic plants (Ch. 10) (Table I.1).

Procedural steps for conducting an ecoregional assessment vary widely because data availability, existing knowledge, size of the region being assessed, funding, and the opportunity to collect empirical data to develop or validate modeled predictions likewise are highly variable (Dinerstein et al. 2000, Groves 2003, Wisdom 2005a, The Nature Conservancy and World Wildlife Fund 2006). Our approach for the WBEA was based on a process conducted in the Great Basin Ecoregion (Wisdom et al. 2005a) and included the following steps:

1. Identify spatial extents for the assessment (Ch. 1)
2. Identify species of conservation concern (Ch. 2)
3. Delineate ranges for species of conservation concern (Ch. 2, 5–9)
4. Estimate habitat requirements of species of conservation concern (Ch. 5–8)
5. Identify regional threats and their effects on habitats (Ch. 3, 10)
6. Estimate and map the risks of habitat loss or degradation posed by example threats (Ch. 3, 5–9, 10)
7. Estimate potential effects of threats on individual species of concern (Ch. 5–9)

TABLE I.1. Wildlife and plant species modeled for the Wyoming Basins Ecoregional Assessment by chapter. Abundance varied by species but was either (1) a predicted density estimate or (2) predicted probability ranking for classes ranging from absent to high abundance. These were based on either count of individuals or, in some cases, sign (e.g., pellets) indicating presence of the species. Probability of occurrence for a species was based simply on presence.

Chapter	Species	Scientific name	Abundance	Occurrence
5	Greater sage-grouse	*Centrocercus urophasianus*	X	X
6	Brewer's sparrow	*Spizella breweri*	X	X
	Sage sparrow	*Amphspiza belli*	X	X
	Sage thrasher	*Oreoscoptes montanus*	X	X
	Green-tailed towhee	*Pipilo chlorurus*		X
	Lark sparrow	*Chondestes grammicus*	X	X
	Vesper sparrow	*Pooecetes gramineus*	X	X
7	Harvester ant	*Pogonomyrmex* spp.	X	X
	Thatch ant	*Formica* spp.		X
	Short-horned lizard	*Phrynosoma hernandesi*		X
	White-tailed jackrabbit	*Lepus townsendii*		X
	Cottontail	*Sylvilagus* spp.		X
	Least chipmunk	*Tamias minimus*		X
8	Pronghorn	*Antilocapra americana*		X
9	Deer mouse	*Peromyscus maniculatus*		X
10	Crested wheatgrass	*Agropyrun cristatum*		X
	Cheatgrass	*Bromus tectorum*		X
	Halogeton	*Halogeton glomeratus*		X
	Russian thistle	*Salsola* spp.		X

8. List management guidelines, major assumptions, and limitations (Ch. 11)

Ecological Scales and Landscapes

Scale issues play an important role in understanding and interpreting our results. The ecological scale of an object or process is defined by its spatial and temporal dimensions (Table I.2), and generalizing across spatial scales can lead to inappropriate conclusions (Wiens 1989). Our study was designed to detect broad-scale patterns in species response to environmental characteristics at the cost of fine-scale conclusions. For example, at the scale of the WBEA, white-tailed jackrabbits (*Lepus townsendii*) were likely to occur when >82% of the land cover within a 0.27-km radius was dominated by sagebrush (Ch. 7). It is incorrect to conclude that jackrabbits will occupy every place having these land cover characteristics within the WBEA area.

Our ability to detect patterns in species response rested on correctly aligning the scales at which a species perceives its environment and the scales at which habitat or disturbance shapes the features within that environment. We attempted to align these scales for each environmental feature by varying the radius surrounding sampling locations, allowing us to assess influences on individual species that might be expressed at different spatial scales. The length of the radius was varied to reflect the home range size of the different

TABLE I.2. Definition of terms used to define spatial relationships (Turner et al. 1989) for the Wyoming Basins Ecoregional Assessment.

Term	Definition
Extent	The size of the study area or spatial area of interest. Extent can be used to describe radius of a moving window analyses used in a Geographic Information System to captured varying areas of interest.
Grain	The finest level of spatial resolution in the data. No finer patterns can be detected within the grain size (e.g., small habitat features covering 1-2 ha cannot be depicted in land cover maps with a grain size of 1 km). For all analyses conducted in this assessment, our grain size was 90 m.
Resolution	The precision of the measurement used in the analysis. Resolution ranges from fine to coarse but cannot be finer than the grain size. Data may be resampled to coarser resolution and still retain the original grain size.
Ecological scale	The spatial dimensions of an object or process. Ecological scale has been described by terms such as as broad, local, or landscape. Our ecoregional assessment was designed to identify patterns that occur over broad spatial scales.
Cartographic scale	The ratio of map to earth units used to reduce features represented on a map. Cartographic scale is often confounded with ecological scale, and is further confused because fine-scale ecological processes often are measured at a large cartographic scale (ratio of map to actual dimensions).

species in our assessment (Ch. 4). Thus, we assumed that the ecological scale of an individual home range was related to ecosystem structure (Holling 1992). The final predictive equations often combined environmental variables measured from multiple ecological scales. As such, our developed habitat relationships and mapped distributions of occurrence and abundance reflect a multi-scaled response by species to their environment.

Choice of spatial extent and grain of the data used in an investigation often are arbitrary because the true dimensions of ecological scale are frequently unknown (Wiens 1989). We used spatial extent in two contexts: the boundaries of the WBEA and the buffered distance or window surrounding a point within which environmental characteristics were measured. Even though the spatial extent of the analysis window changed with different radii length, the underlying grain of the data (90-m grid cells) remained the same.

MANAGEMENT CONTRIBUTIONS

This ecoregional assessment provides significant new information on distributions, abundances, and habitat relationships for a number of species of conservation concern that depend on sagebrush in the WBEA area. This information was primarily derived from field surveys. For some species, such as greater sage-grouse, we already have large amounts of information on distribution, habitat requirements, population trends, response to disturbance, and seasonal movements in the WBEA area (Holloran et al. 2005, 2010; Johnson et al. 2011; Naugle et al. 2011). However, most species in our assessment have been less thoroughly studied, and we have little data available on distributions and habitat relationships other than anecdotal information or relationships developed elsewhere. Our empirically driven spatial models provide significant new understanding of landscape-level needs for species across a range of taxa spanning insects, reptiles, birds, and mammals. Moreover, we documented response and dominant spatial scales to anthropogenic disturbance, including energy development, power lines, and major roads for 15 sagebrush-associated species in the WBEA including 10 species of conservation concern.

Our maps of predicted occurrence and abundance based on spatially explicit models of habitat relationships provide managers with information needed to effectively manage habitat for a suite of sagebrush-associated species. Our maps also provide a working hypothesis of areas that contain suitable environmental conditions to guide field surveys, to confirm species presence, and to evaluate species-habitat relationships. For example, our surveys for pygmy rabbits (*Brachylagus idahoensis*) were conducted independent of the known range map because ongoing work (Purcell 2006) identified that the species occurred in the WBEA outside of previously published range maps. We documented the presence of pygmy rabbits at several locations outside of the known range including one observation >100 km from any previously known location.

The response curves developed for each of the modeled species in the WBEA represent the changes in the probability of a species presence relative to changes in a single or suite of environmental variable(s). By using maps of predicted habitat change coupled with knowledge of the species response, managers can establish habitat protection and restoration plans that promote effective use of available and projected resources. Management of sagebrush ecosystems in the WBEA area currently is being driven by a core areas concept for a single-species based on sage-grouse distributions (Doherty et al. 2011). Thus, our multi-species assessment of distribution and response to disturbance provides additional information for managers to evaluate the efficacy of this management concept to benefit other species that depend on sagebrush in the WBEA area.

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Chapter 1: Study Area Description

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Abstract. The boundary for the Wyoming Basins Ecoregional Assessment (WBEA) was largely determined by the co-occurrence of some of the largest tracts of intact sagebrush (*Artemisia* spp.) remaining in the western United States with areas of increasing resource extraction. The WBEA area includes two ecoregions in their entirety, Wyoming Basins and Utah-Wyoming Rocky Mountains, and portions of two others (Southern Rocky Mountains and Middle Rockies-Blue Mountains). Over half the study area is in Wyoming; the remainder includes parts of Colorado, Utah, Idaho, and Montana. Private landowners manage most (33.1%) of the land base in the WBEA, followed by the U.S. Forest Service (27.3%) and U.S. Bureau of Land Management (25.6%). Sagebrush is the dominant land cover type in the study area, totaling >130,000 km^2; nearly half the sagebrush in the WBEA is managed by the U.S. Bureau of Land Management. Sagebrush in the WBEA faces many potential threats that also influence the broader sagebrush ecosystem. Climate change, drought, land-use practices (e.g., livestock grazing, oil and gas development), and human development have eliminated and fragmented the sagebrush ecosystem, altered fire regimes, and accelerated the invasion of exotic plants such as cheatgrass (*Bromus tectorum*). Less than 2% of sagebrush in the WBEA is permanently protected from land cover conversion.

Key words: ecoregional assessment, land cover, sagebrush, threats, Wyoming Basins.

Ecoregions have been widely adapted in conservation planning and are used by a variety of organizations and agencies such as The Nature Conservancy (TNC), World Wildlife Fund, U.S. Environmental Protection Agency (EPA), U.S. Bureau of Land Management (BLM), U.S. Forest Service (FS), and the U.S. Natural Resources Conservation Service (NRCS). Applications include regional conservation planning, biodiversity analysis, sustainable development, and agricultural census (Groves et al. 2000, McMahon et al. 2001, Noss et al. 2001, Bailey 2002). Ecoregions are large areas of relatively uniform climate, within which sites with similar landforms, slope, soils, and drainage systems support similar ecosystems (Groves et al. 2000, Noss et al. 2001, Bailey 2002). Ecosystems in turn are areas of interacting biological and physical components such that changes in any one component effect change in other components and the system as a whole (Bailey 2002). Although an ecoregion may contain a diversity of ecosystems, characteristic patterns of sites recur predictably due to the overriding influence of climate (Bailey 2002).

Regional conservation planning in the sagebrush (*Artemisia* spp.) ecosystem is especially critical because this ecosystem faces many potential threats. Climate change, drought, land-use practices, and human development have altered fire cycles and accelerated the invasion of exotic plants such as cheatgrass (*Bromus tectorum*) (D'Antonio and Vitousek 1992, Tausch et al. 1993, Knight 1994, Miller and Eddleman 2000, Smith et al. 2000, Neilson et al. 2005). Woody species, such as juniper (*Juniperus* spp.) and Douglas-fir (*Pseudotsuga menziesii*), are encroaching into the sagebrush ecosystem due to changes in fire regimes (Miller et al. 2000, Tausch and Nowak 2000, Miller and Tausch 2001, Grove et al. 2005). Habitat loss, degradation, and fragmentation associated with

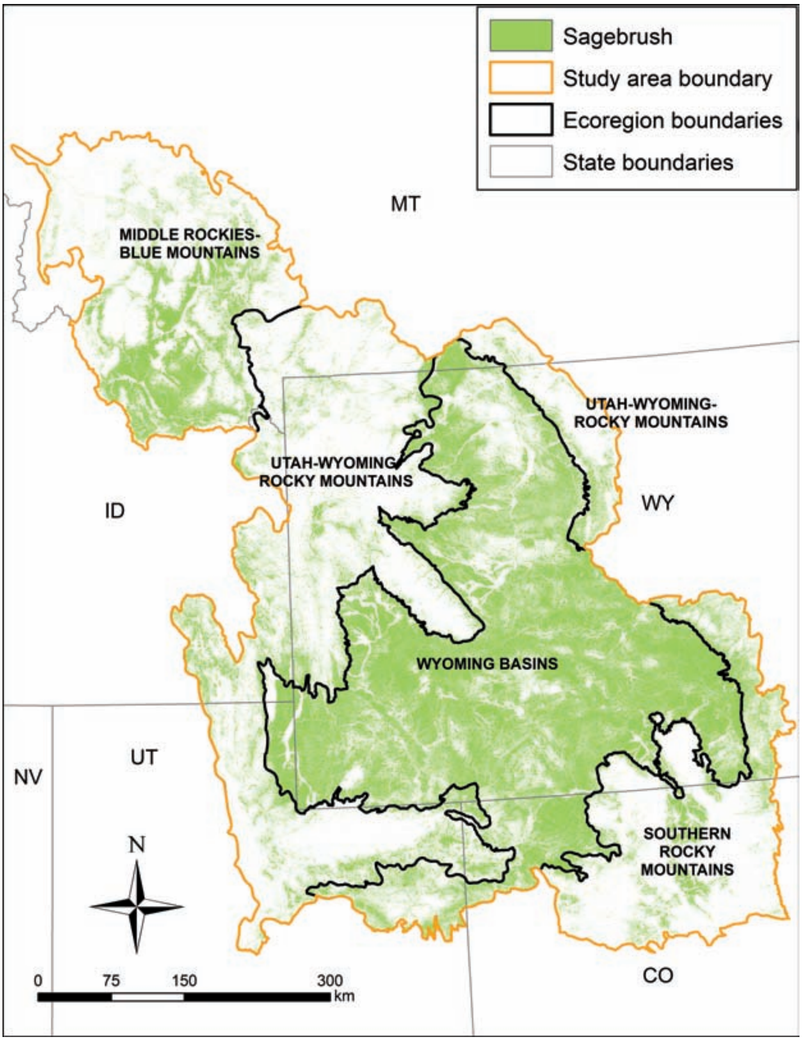

FIG. 1.1. Sagebrush plant communities within the Wyoming Basins Ecoregional Assessment study area. (See Appendix 1.1 for all sagebrush land cover types mapped as sagebrush). Ecoregion boundaries are those delineated by The Nature Conservancy, which are in turn a slightly modified version of ecoregions described by Bailey (1995); see Groves et al. (2000) and <http://gis.tnc.org/data/MapbookWebsite/map_page.php?map_id=9>.

road development are increasing (Forman et al. 2003, Gelbard and Belnap 2003, Thomson et al. 2005). Energy development has accelerated across the sagebrush ecosystem, resulting in increasing rates of habitat fragmentation and disturbance to native wildlife, such as greater sage-grouse (*Centrocercus urophasianus*), pronghorn (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*) (Weller et al. 2002, Lyon and Anderson 2003, Holloran 2005, Thomson et al. 2005, Sawyer et al. 2006, Knick and Connelly 2011).

Wyoming and portions of adjacent states encompass some of the most expansive sagebrush plant communities remaining in North America (Fig. 1.1; Knick et al. 2003) as well as areas of rapidly increasing development, especially of oil and gas fields (Weller et al. 2002, Thomson et al. 2005, Ch. 3). We conducted our regional assessment in this area and refer to it in this book as the Wyoming Basins Ecoregional Assessment (WBEA) area. The assessment name is derived from the largest ecoregion of the four that are wholly or partially contained within its boundaries. This ecoregion, the Wyoming Basins (The Nature Conservancy 2008) – hereafter, "Wyoming Basins" refers to the WBEA area, and when specifically referring to the area defining the Wyoming Basins Ecoregion we use "Wyoming Basins Ecoregion" – ranks third among all ecoregions in the western United States in extent of sagebrush cover (88,300 km^2), surpassed only by the Columbia Plateau (159,200 km^2) and Great Basin (98,400 km^2) ecoregions. The Utah-Wyoming Rocky Mountains Ecoregion contributes another 19,800 km^2 of sagebrush within the study area; sagebrush in this ecoregion and the Wyoming Basins Ecoregion, combined, comprises >20% of the sagebrush in the nation. Moreover, the percentage of the land base covered by sagebrush in the Wyoming Basins Ecoregion (60%) is greater than in any other ecoregion in the nation.

The Wyoming Basins Ecoregional Assessment was completed to provide information for developing strategies for conservation and management of sagebrush in this key area (Introduction). In this chapter, we describe: (1) rationale for selection of the study area boundary; (2) environmental and management conditions within the study area, including vegetation (emphasizing sagebrush ecosystems), wildlife, and land management status; and (3) potential threats to sagebrush ecosystems and associated habitats for species of concern in the WBEA.

DEFINING THE ASSESSMENT AREA BOUNDARIES

Regional assessment boundaries can be ecological, administrative, or a combination, depending on objectives of the assessment. Boundary selection, in turn, influences application of the results in land management and conservation planning. Ecologically based evaluations provide a biologically meaningful spatial framework for resource management agencies and conservation organizations (Groves et al. 2000, McMahon et al. 2001). However, management based solely on ecological boundaries may not effectively consider information gathered at administrative scales, because of the mismatch of spatial extents. The boundary for the Wyoming Basins Ecoregional Assessment was largely determined by the cooccurrence of some of the largest tracts of intact sagebrush remaining in the western United States with areas of increasing resource extraction. That is, the assessment boundary was first derived ecologically and then expanded to include adjacent regions of management concern.

To capture their extensive sagebrush communities, the WBEA contains two entire ecoregions: Wyoming Basins and Utah-Wyoming Rocky Mountains (Fig. 1.1). We extended the study area beyond these two ecoregions to include: (1) a portion of the northern extent of the Southern Rocky Mountains Ecoregion in Colorado and Wyoming; and (2) portions of the Middle Rockies-Blue Mountains Ecoregion in southwestern Montana, primarily the Bitterroot Valley and Beaverhead Mountain sections. We included the northern reaches of the Southern Rocky Mountains Ecoregion specifically to assess ongoing and proposed energy development, primarily of oil and natural gas in this area. By contrast, we included southwestern Montana to incorporate sagebrush ecosystems and associated species omitted from the broad-scale assessment of the Interior Columbia Basin (Hann et al. 1997, Wisdom et al. 2000). Southwestern Montana supports some of the most extensive stands of sagebrush in Montana, and populations of greater sage-grouse in this area are of concern due to long-term declines (Connelly and Braun 1997, Dusek et al. 2002, Roscoe 2002, Knick and Connelly 2011).

The WBEA complements other regional assessments in the Wyoming Basins area. The Nature Conservancy has developed conservation plans for all four ecoregions within the WBEA boundaries: Middle Rockies-Blue Mountains (The Nature Conservancy 2000); Southern Rocky Mountains (Neely et al. 2001); Utah-Wyoming Rocky Mountains (Noss et al. 2001); and Wyoming Basins (Freilich et al. 2001). The general objective of TNC plans is to identify a suite of conservation targets at multiple levels (e.g., species, communities) for long-term conservation of biodiversity. TNC plans and the WBEA share several common features: (1) a comprehensive and systematic approach, (2) a regional scope, (3) a scientific and ecoregional basis, (4) geographic area, (5) an identification of species of concern, and 6) a management and conservation focus. The WBEA differs from those developed by TNC; our assessment provides a broad-scale assessment of (1) anthropogenic disturbances and their effects explicitly focused on sagebrush communities and (2) sagebrush-associated vertebrates and plants in the Wyoming Basins.

Other conservation plans and assessments have been developed in this region. The Heart of the West Conservation Plan had boundaries similar to the WBEA and described a wildlands network incorporating the Wyoming Basins Ecoregion, Utah-Wyoming Rocky Mountains Ecoregion, and adjacent lands (Jones et al. 2004). Other work complementary to our assessment has been conducted within the sagebrush ecosystem across broader scales, such as the SAGEMAP Project [http://sagemap.wr.usgs.gov] (U.S. Geological Survey 2001) and the range-wide conservation assessment of greater sage-grouse (Connelly et al. 2004).

Although the WBEA area includes areas of exceptional biodiversity and national significance, such as Rocky Mountain and Yellowstone National Parks, our focus was on the sagebrush ecosystem and its management, with emphasis on lands managed by the BLM and FS. Thus, this book evaluates the current status of lower elevation shrublands and associated species in the WBEA area.

STUDY AREA

Overview

The WBEA area includes a diversity of habitat types, ranging from alpine tundra to arid shrublands, and a tremendous array of wildlife species. The Greater Yellowstone Ecosystem harbors populations of grizzly bears (*Ursus arctos horribilis*) and gray wolves (*Canis lupus*), as well as the entire suite of native ungulates of the Rocky Mountain West, including bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), white-tailed (*Odocoileus virginianus*) and mule (*O. hemionus*) deer, Rocky Mountain elk (*Cervus elaphus*), bison (*Bison bison*), and pronghorn. Wyoming supports more pronghorn than any other state (Clark and Stromberg 1987); the Sublette herd unit alone has an estimated 48,000 animals, more than the entire population in most western states (WEST 2003). The WBEA area also contains some of the key strongholds for greater sage-grouse populations (Knick and Hanser 2011).

For further details on the flora, fauna, and abiotic environment of the study area as a whole, the reader is referred to: TNC plans that apply to the study area (The Nature Conservancy 2000, Freilich et al. 2001, Neely et al. 2001, Noss et al. 2001); a summary of terrestrial ecoregions of North America (Ricketts et al. 1999); and the synthesis of Wyoming landscapes found in Knight (1994). Additional descriptions of sagebrush-associated vascular plants and vertebrates of concern are provided in Chapter 2.

The WBEA area incorporates 345,300 km^2, of which the majority (51.0%) is in Wyoming. The study area also includes parts of southwestern Montana (21.1%), northern Colorado (12.6%), northeastern Utah (10.4%), and a small part of eastern Idaho (4.9%). Among TNC ecoregions in the study area, 38.7% of the study area is within the Wyoming Basins, 31.7% in the Utah-Wyoming Rocky Mountains, 16.4% in the Middle Rockies-Blue Mountains, and 13.2% in the Southern Rocky Mountains.

Wyoming Basins

The Wyoming Basins Ecoregion encompasses 134,000 km^2 in five states (Fig. 1.1). The bulk (84%) of the ecoregion lies in Wyoming, with 15% in Utah and Colorado and only a trace in Montana and Idaho (1%; see Freilich et al. [2001] for further details). Climate is arid, with an average annual precipitation of 15-25 cm; the Wyoming Basins Ecoregion includes the most arid parts of the state of Wyoming (Freilich et al. 2001). Extremes of cold, wet winters and hot, dry summers in the region are typical of continental climate patterns.

Major river systems (including the North Platte, Bighorn, Upper Green, Yampa, and Sweetwater) support riparian corridors vital for maintaining biodiversity in the region. Although some mountain peaks exceed 3,300 m, most of the ecoregion lies between 1,800 m and 2,400 m. More than a dozen mountain ranges (e.g., Ferris and Pryor Mountains, Wyoming Range) dissect the ecoregion, forming "islands" in the surrounding sagebrush matrix (Freilich et al. 2001).

Vegetation communities in the Wyoming Basins Ecoregion are dominated by rolling sagebrush uplands, and Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*) is the dominant sagebrush taxon. Black sagebrush (*A. nova*) reaches its easternmost extension in Wyoming, and large expanses of little sagebrush (*A. arbuscula*) are present. Salt desert shrubs, such as greasewood (*Sarcobatus vermiculatus*) and saltbush (*Atriplex* spp.), replace sagebrush in more arid sites.

Despite its vast size, this ecoregion remains one of the least densely populated areas in the United States. Laramie, Wyoming, is the largest city in the ecoregion (population 25,700 in 2006), and most people are located in isolated rural areas (Freilich et al. 2001).

Utah-Wyoming Rocky Mountains

The Utah-Wyoming Rocky Mountains Ecoregion covers >42,100 km^2 in parts of five states: Colorado, Idaho, Montana, Utah, Wyoming (Fig. 1.1; Noss et al. 2001). Climate in this ecoregion is cold continental, with long winters and short summers (Noss et al. 2001). Precipitation is highly variable across the ecoregion, with some of the most arid portions of the region receiving <16 cm rainfall a year, contrasting with >200 cm in the southeastern portion of Yellowstone National Park (Noss et al. 2001). The ecoregion includes the Greater Yellowstone Ecosystem, along with much of the Beartooth Plateau in Montana, the Bighorn Mountains in eastern Wyoming, the Wasatch Range in Utah, and the Uinta Mountains in Colorado and Utah.

Shrub-grass communities dominate lower elevations in the ecoregion, whereas higher elevations, such as those in the Bighorn and Uinta Mountains, are forested. Common sagebrush species in lower elevation shrublands include basin big sagebrush (*A. t.* ssp. *tridentata*) and Wyoming big sagebrush, with mountain big sagebrush (*A. t.* ssp. *vaseyana*) found at somewhat higher elevations. Other high elevation sites support spiked sagebrush (*A. t.* ssp. *spiciformis*). Saltbush and greasewood shrublands also occur in lower elevations. Douglas-fir is the most abundant tree species in lower-elevation forests, whereas Englemann spruce (*Picea engelmanni*), lodgepole pine (*Pinus contorta*), and subalpine fir (*Abies lasiocarpa*) dominate mid-elevation forests. Alpine tundra occurs at the highest elevations, often >3,000 m.

Human populations in the Utah-Wyoming Rocky Mountain Ecoregion are largely concentrated along the Wasatch Front in Utah; however, counties in the Greater Yellowstone Ecosystem have also seen rapid growth in recent decades, particularly Teton County in both Wyoming and in Idaho (Noss et al. 2001).

Southern Rocky Mountains

The relatively small proportion of the Southern Rocky Mountains Ecoregion in the study area lies in Wyoming and Colorado (Fig. 1.1). Climate in this ecoregion is characterized as temperate semiarid steppe, with mean annual temperatures ranging from 1.7 to 7.2 C (Neely et al. 2001). Precipitation is generally higher in the northern portion of the ecoregion, reaching 140 cm annually in the Park Range. The Continental Divide is a dominant feature of the ecoregion. The many mountain ranges (including the Laramie Mountains, Medicine Bows, Front Range, Park Range, and Sierra Madres) and associated topographic relief greatly influence local weather patterns. Headwater watersheds of the Colorado, Mississippi, and Rio Grande rivers are located in the ecoregion (Neely et al. 2001).

This ecoregion includes large intermontane basins (e.g., North Park and Middle Park) that support extensive higher elevation sagebrush ecosystems of primarily mountain big sagebrush, little sagebrush, and silver sagebrush (*A. cana*) (Neely et al. 2001). Much of the research on greater sage-grouse in Colorado has been conducted in these parks (e.g., Petersen 1980, Remington and Braun 1985, Braun and Beck 1996, Johnson and Braun 1999, Zablan et al. 2003).

Major ecological zones range from lower montane-foothill, which includes more arid sagebrush ecosystems, pinyon (*Pinus edulis*)-juniper woodlands, and Douglas-fir/ponderosa pine (*Pinus ponderosa*) forests, to upper montane, subalpine, and alpine zones. Rates of human population increase are among the highest in the nation, with an average increase at the county level of 31% from 1990–2000 (Neely et al. 2001).

Middle Rockies-Blue Mountains

Two sections of the Middle Rockies-Blue Mountains Ecoregion are in the WBEA area – Beaverhead Mountains and Bitterroot Valley; both are in Montana (Fig. 1.1; The Nature Conservancy 2000). The climate here is characterized as cold, dry continental, with highly variable precipitation, falling primarily as snow in fall, winter, and spring. Elevation in the valleys ranges from 1,200 m to 2,100 m. This area is topographically complex, with steep, heavily glaciated mountains and intermontane valleys that have been widely developed for housing and other structures in the Bitterroot Valley. Rivers include the Bitterroot, Beaverhead, Blackfoot, and Clark Fork; major mountain ranges in this portion of the study area are the Anaconda Range, Centennial Mountains, and Madison Range (The Nature Conservancy 2000).

Sagebrush-grasslands are the dominant non-forest land cover type in this portion of the study area, with most of the sagebrush occurring in the southwestern corner of Montana (Fig. 1.1). Development of primary and secondary homes and resorts are considered major threats in this ecoregion (The Nature Conservancy 2000).

Land Management Status

Private landowners in the WBEA area manage >114,000 km^2 (33.1%) of the study area, more than any other management entity (Table 1.1). Private lands were well distributed across the entire study area and formed a “checkerboard” pattern where they are intermingled with lands managed by BLM and state agencies, especially in a wide swath across southern Wyoming (Fig. 1.2). Two federal land management agencies, the FS and BLM, are responsible for the majority of the non-private lands; the FS manages 94,300 km^2 (27.3%) and the

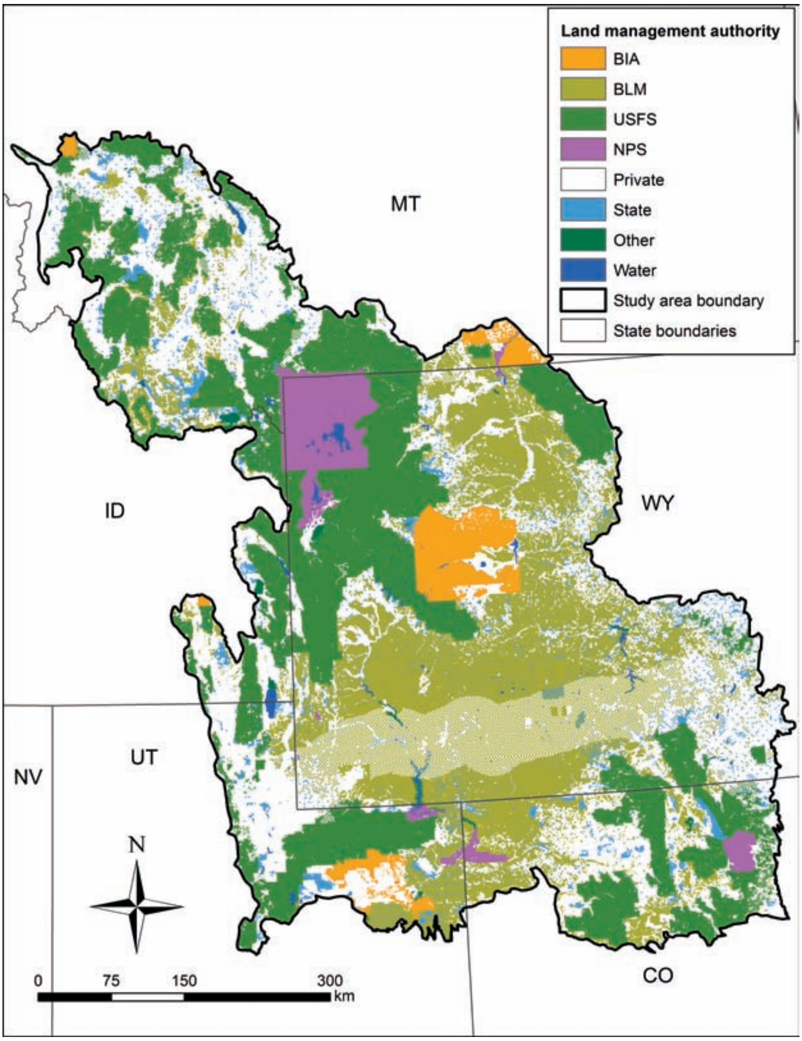

FIG. 1.2. Land management authority within the Wyoming Basins Ecoregional Assessment area.

BLM 88,300 km^2 (25.6%) within the study area. Most of the remaining land management authority rests with states (5.4%), the National Park Service (3.5%), and the Bureau of Indian Affairs (3.4%). The latter is comprised largely of the Wind River Indian Reservation in Wyoming (Fig. 1.2), whereas the majority of the National Park Service lands are in Yellowstone, Teton, and Rocky Mountain national parks.

Land stewardship patterns within the five states included in the WBEA differed somewhat from those for the study area as a whole (Table 1.1). For example, although private land was the dominant category across the WBEA, at the state level this was only true for Colorado, Montana, and Utah. Wyoming had the smallest percentage (28.0%) of private land and the largest percentage (37.3%) of land managed by the BLM among the states in the study area; public lands under BLM management extended across 65,500 km^2 of the study area in Wyoming. The FS had management responsibility for a relatively large percentage of the land within the

TABLE 1.1. Land stewardship by state and agency within the Wyoming Basins Ecoregional Assessment area.

Agency	Colorado		Idaho		Montana		Utah		Wyoming		Total	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
BIA[a]	<1	0.0	131	0.8	2,109	2.9	2,030	5.6	7,331	4.2	11,601	3.4
BLM	10,108	23.2	955	5.6	6,243	8.6	5,477	15.2	65,537	37.3	88,320	25.6
NPS	1,683	3.9	142	0.8	786	1.1	528	1.5	8,824	5.0	11,963	3.5
Private	15,143	34.7	6,457	38.1	29,724	40.8	13,812	38.4	49,208	28.0	114,346	33.1
State	2,202	5.0	841	5.0	4,348	6.0	2,179	6.1	8,980	5.1	18,551	5.4
FS	14,361	32.9	7,961	47.0	28,854	39.6	9,135	25.4	33,986	19.3	94,297	27.3
Other[b]	120	0.3	468	2.8	828	1.1	2,825	7.9	1,981	1.1	6,222	1.8
Total	43,618	100.0	16,955	100.0	72,892	100.0	35,987	100.0	175,847	100.0	345,300	100.0

[a] BIA – Bureau of Indian Affairs; BLM – U.S. Bureau of Land Management; NPS – National Park Service; FS – U.S. Forest Service.

[b] Includes Bureau of Reclamation, Department of Defense, The Nature Conservancy, U.S. Fish and Wildlife Service, water, local ownerships, and miscellaneous federal lands.

study area in Idaho (47.0%) and Montana (39.6%) (Table 1.1).

Land Cover

Use of LANDFIRE

For all WBEA analyses based on land cover type, including sagebrush, we used the LANDFIRE existing vegetation type (EVT) data layer (LANDFIRE 2007). The LANDFIRE project was designed to produce consistent maps of vegetation, fuels, and fire regimes for wildland fire management across the United States (http://www.landfire.gov/index.php). To increase accuracy of mapped land cover types and meet study objectives, we reclassified the LANDFIRE EVT map from the original 102 land cover types that occurred in the study area to 24 more generalized types (Appendix 1.1). The resulting land cover map was used to model the distribution and/or abundance of wildlife and invasive plants in the study area (Ch. 5–10). For summary statistics presented in this chapter, we further collapsed the 24 land cover types to 14 (Appendix 1.1). The primary reclassification of this second step was within the shrubland cover types; all sagebrush land cover types were combined as "sagebrush," and various shrub types (e.g., mountain mahogany [*Cercocarpus* spp.]) were reclassified as "mixed shrubland."

Sagebrush in the WBEA

Sagebrush is the dominant land cover in the WBEA area (38.1%; 131,600 km^2; Table 1.2, Fig. 1.3). The overwhelming majority (67.8%) of sagebrush is in Wyoming (89,200 km^2), but substantial amounts (37,400 km^2) also are found in portions of southwestern Montana, northeastern Utah, and northwestern Colorado (Fig. 1.3).

The BLM has management authority for 43.5% (57,300 km^2) of the sagebrush in the study area (Fig. 1.4), comparable to the 52% of sagebrush managed by BLM nationwide (Knick et al. 2003). This pattern varied, however, among states in the WBEA area.

For example, in Wyoming, BLM manages nearly 52% of the sagebrush vegetation (45,700 km^2); by contrast, BLM manages only 10.9% (530 km^2) of the sagebrush in the Idaho portion of the WBEA area (Fig. 1.4). Private landowners manage the second largest percentage (37.5%) of sagebrush in the study area, totaling 49,400 km^2 (Fig. 1.4). The remainder is evenly divided between the FS, state lands, and "other" management entities (e.g., National Park Service, Bureau of Indian Affairs).

The percentage of sagebrush on FS-managed lands in the WBEA (6.1%) is comparable to the percentage of sagebrush across the United States that is managed by the agency (9%; Wisdom et al. 2005). Relatively higher percentages of FS-managed sagebrush were found in Idaho, with considerably lower percentages in Colorado and Wyoming. Although a small percentage of sagebrush in the study area is managed by the FS, the majority of it is mountain big sagebrush. Management considerations for mountain big sagebrush and other sagebrush taxa found at higher elevations differ from those for sagebrush found at lower, warmer sites (U.S. Bureau of Land Management 2002, Miller et al. 2011). High elevation sagebrush types are often more resistant to fire, tend to occur within more diverse plant communities than sagebrush at lower elevations, and are often seasonally important for sagebrush-associated species of concern, such as providing late brood-rearing habitat for sage-grouse (Connelly et al. 2004).

TABLE 1.2. Area contained within land cover classes of the Wyoming Basins Ecoregional Assessment area.

Land cover class[a]	km^2	%
Agriculture	15,523	4.5
Aspen	11,311	3.3
Barren	9,275	2.7
Conifer forest	89,330	25.9
Developed	2,607	0.7
Grasslands	28,748	8.3
Greasewood	1,922	0.6
Juniper	5,387	1.6
Mixed shrubs	21,035	6.1
Riparian	12, 637	3.7
Sagebrush	131,573	38.1
Salt desert shrubland	12,780	3.7
Water	2,633	0.8
Wetland	592	0.2
Total	345,354	100

[a] For crosswalk of land cover classes from the LANDFIRE existing vegetation types map see Appendix 1.1.

Protected status of sagebrush

Only a small percentage of the sagebrush ecosystem is permanently protected (for example, in national parks or designated wilderness areas) from alteration or conversion (Wright et al. 2001, Knick et al. 2003, Knick et al. 2011). We evaluated the relative amount of sagebrush within the WBEA area by the four land status classes commonly used by TNC and the Gap Analysis Program (GAP) in assessing degree of protection for conservation targets (Scott et al. 1993, Crist 2000). These categories are: class 1 – areas permanently protected from conversion of natural land cover, with natural disturbance events allowed to proceed; class 2 – permanently protected as above, but where management practices or uses may degrade the natural communities; class 3 – permanently protected from conversion, but subject to resource extraction (e.g., logging, mining) and protection offered to federally listed species; and class 4 – no known mandates, either public or private, to prevent conversion of natural vegetation types (Crist 2000).

The dominant land status class for sagebrush in the WBEA was class 3 (51.1% of sagebrush), followed by class 4 (45.8%) (Figs. 1.5, 1.6). By contrast, only 1.7% of the sagebrush in the WBEA was under permanent legal protection (i.e., status class 1); sagebrush in this class is located primarily within National Park Service lands in Yel-

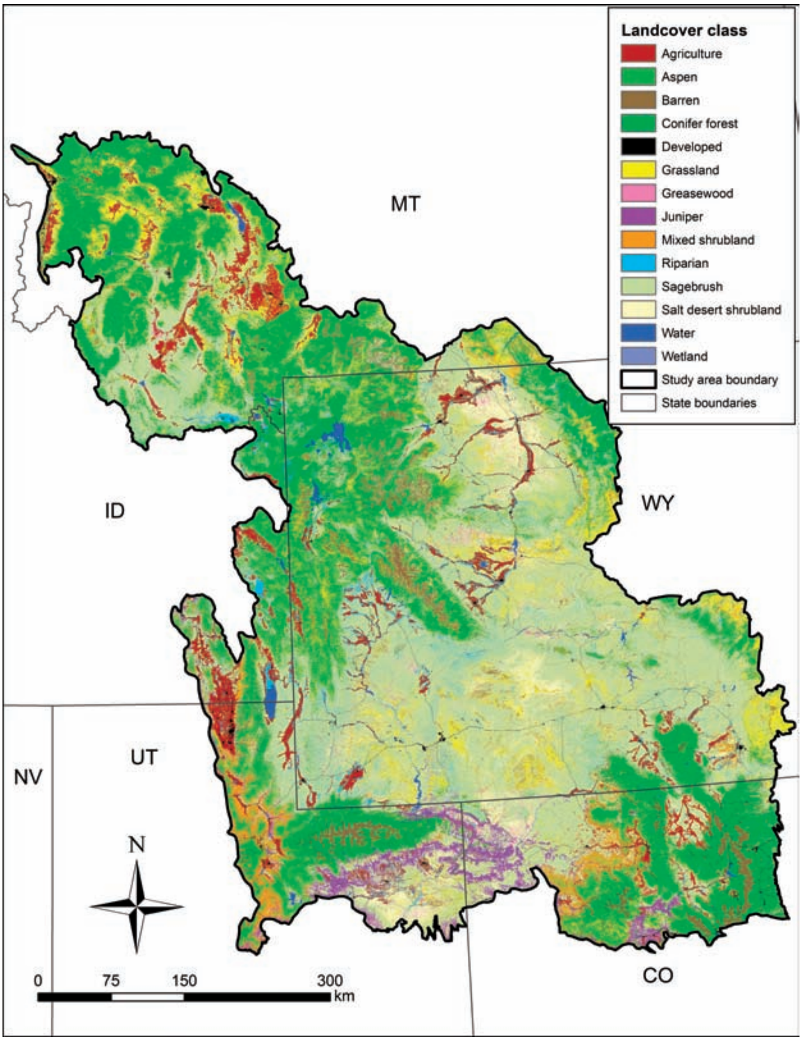

FIG. 1.3. Land cover classes within the Wyoming Basins Ecoregional Assessment area; cover types were modified from the existing vegetation type layer from LANDFIRE. See Appendix 1.1 for details on reclassification of the original map.

lowstone and Grand Teton National Parks, as well as in designated wilderness areas managed by the Forest Service (Fig. 1.6). This percentage is similar to that reported by Wright et al. (2001) for all sagebrush in the western United States. A similarly small fraction (1.4%) of sagebrush in the WBEA is in class 2. Compared to all land cover types within the study area, a disproportionately smaller percentage of sagebrush is protected (i.e., in status class 1 and 2; Fig. 1.5). Most of the sagebrush in class 4 is on privately owned lands or the Wind River Indian Reservation in central Wyoming. Therefore, multiple uses will likely continue to affect management policies related to sagebrush.

Other land cover classes in the WBEA

The second most common land cover class in the study area was "coniferous forest" (25.9%, or 89,300 km^2; Table 1.2).

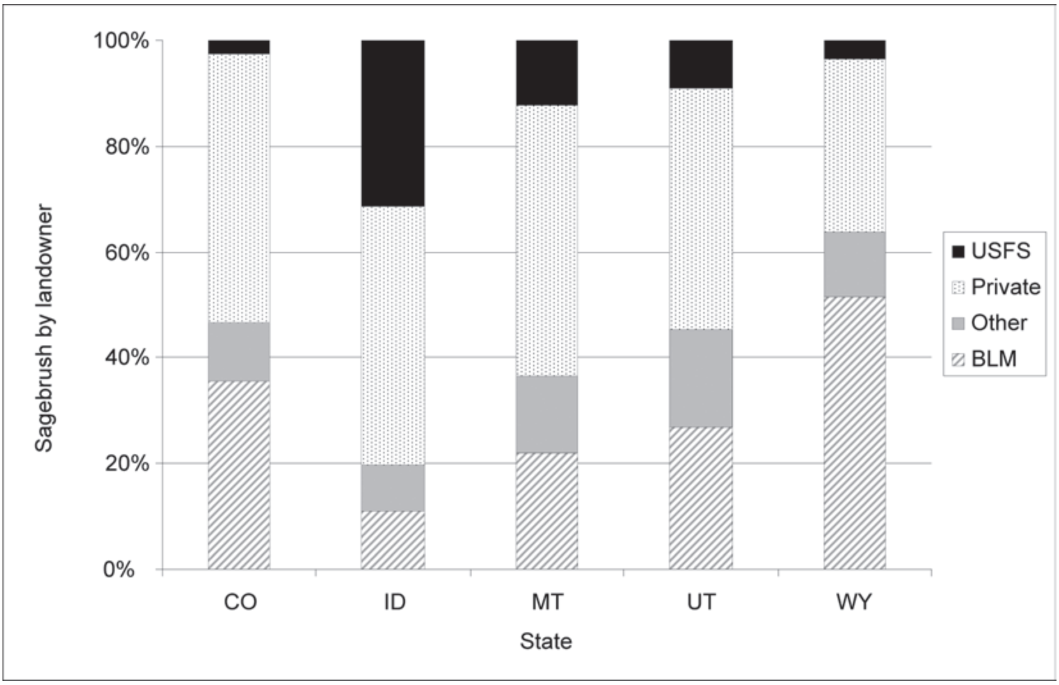

FIG. 1.4. Percentage of sagebrush by primary land management authority within states of the Wyoming Basins Ecoregional Assessment boundary.

Coniferous forest is found in mountainous and high elevation regions (e.g., Yellowstone National Park, FS wilderness areas in northeastern Utah and western Wyoming). No other land cover class spanned >10% of the study area (Table 1.2). Grasslands covered 8.3% (28,700 km^2) of the study area and were most prevalent in eastern Wyoming and southwestern Montana (Fig. 1.3). The salt desert shrubland class encompassed 3.7% (12,800 km^2) of the WBEA area, primarily in northcentral Wyoming, northeastern Utah, and northwestern Colorado. This class includes saltbush and a variety of other, primarily xeric, upland shrub types. Agricultural lands covered 4.5% (15,500 km^2) of the WBEA area, with large blocks found in northcentral Wyoming, southeastern Idaho, and across southwestern Montana. Juniper occupied a small portion (1.6%, 5,400 km^2) of the study area and was most common in Colorado, northeastern Utah, and northcentral Wyoming (Fig. 1.3). Only a small fraction (0.7%) of the study area was classified as "developed" (Table 1.2).

POTENTIAL THREATS TO SAGEBRUSH-ASSOCIATED SPECIES AND HABITATS IN THE WYOMING BASINS

Potential threats to habitats and species in the sagebrush ecosystem range from climate change and altered fire regimes to fragmentation by a multitude of anthropogenic disturbances (Knick et al. 2003, Connelly et al. 2004, Wisdom et al. 2005; Table 1.3). Threats previously identified within the WBEA area include: conversion of sagebrush to non-native perennial grasses, spread of exotic annual grasses, hard-rock mining, oil and gas exploration, inappropriate grazing by domestic livestock, logging, fire suppression, and expansion of recreational and residential developments (Ricketts et al. 1999, Freilich et al. 2001,

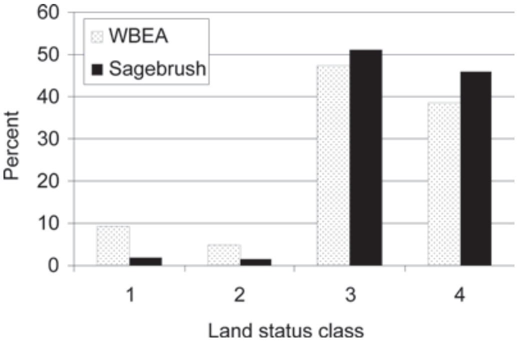

FIG. 1.5. Comparison of GAP land status class for all land cover types within the Wyoming Basins Ecoregional Assessment (WBEA) area versus only sagebrush. Land status was derived from standard GAP classifications (Crist 2000) and indicates the relative degree of protection from alteration.

Neely et al. 2001, Noss et al. 2001, Weller et al. 2002, U.S. Departments of the Interior, Agriculture, and Energy 2003). Although the level of risk posed by each threat varies geographically and temporally across the vast range of sagebrush, all of the threats listed in Table 1.3 have been documented to some extent within the WBEA. However, effects of many of these threats, especially anthropogenic disturbance, on sagebrush-associated wildlife have not been well quantified with empirical data (Freilich et al. 2001, WEST 2003). Furthermore, the synergistic effects of combined threats in the sagebrush ecosystem have not been fully investigated (Wisdom et al. 2005). The development and evaluation of predictive models to test hypotheses about cumulative effects of key threats in sagebrush ecosystems, as described in Chapters 4-10, will allow land managers to better address management actions that may influence the large landscapes of shrubland communities in the Wyoming Basins.

Primary Threats in the Wyoming Basins Ecoregional Assessment Area

Decisions about which potential threats to address in a particular assessment may be based on any of several criteria, including: (1) spatial extent or pervasiveness of the threat across the ecoregion, (2) capability to quantify and map the threat, (3) agreement among those conducting the assessment about the relative importance of the threat in the ecoregion, (4) available resources to address the threat, (5) timeframe required to implement effective treatments across the ecoregion, (6) costs versus benefits of addressing the threat, (7) significance of the threat in altering habitat or wildlife population dynamics, and (8) potential effects of addressing the threat on non-target species (Wisdom et al. 2005). We present below a brief summary of some of the key threats to sagebrush-associated species and their habitats in the WBEA.

Climate change and drought

There is increasing recognition of the effect of land cover change and human activities on global climate change (e.g., U.S. Environmental Protection Agency 1998, Schneider and Root 2002, Marland et al. 2003, Neilson et al. 2005, Parmesan 2006, Mawdsley et al. 2009). In Wyoming, mean temperature in Laramie has increased almost 1 C over the last 100 years, and precipitation levels have decreased by as much as 20% in parts of the state (U.S. Environmental Protection Agency 1998). Climate models for Wyoming predict an increasing frequency of extremely hot days in summer, continued increases in temperature during all seasons (e.g., 3.3 C in winter), and increasing fire frequencies (U.S. Environmental Protection Agency 1998). Estimates of future rainfall regimes are more variable, with slight decreases in summer rainfall, but increases in spring, fall, and winter precipitation (U.S. Environmental Protection Agency 1998). Precipitation in the Colorado River Basin, including southwestern Wyoming, is predicted to decrease slightly (1–6%) through the end of the century under a range of climate models (Christensen et al. 2004); however, model estimates for precipitation are highly variable, and regional patterns of precipitation may not follow more global models (Neil-

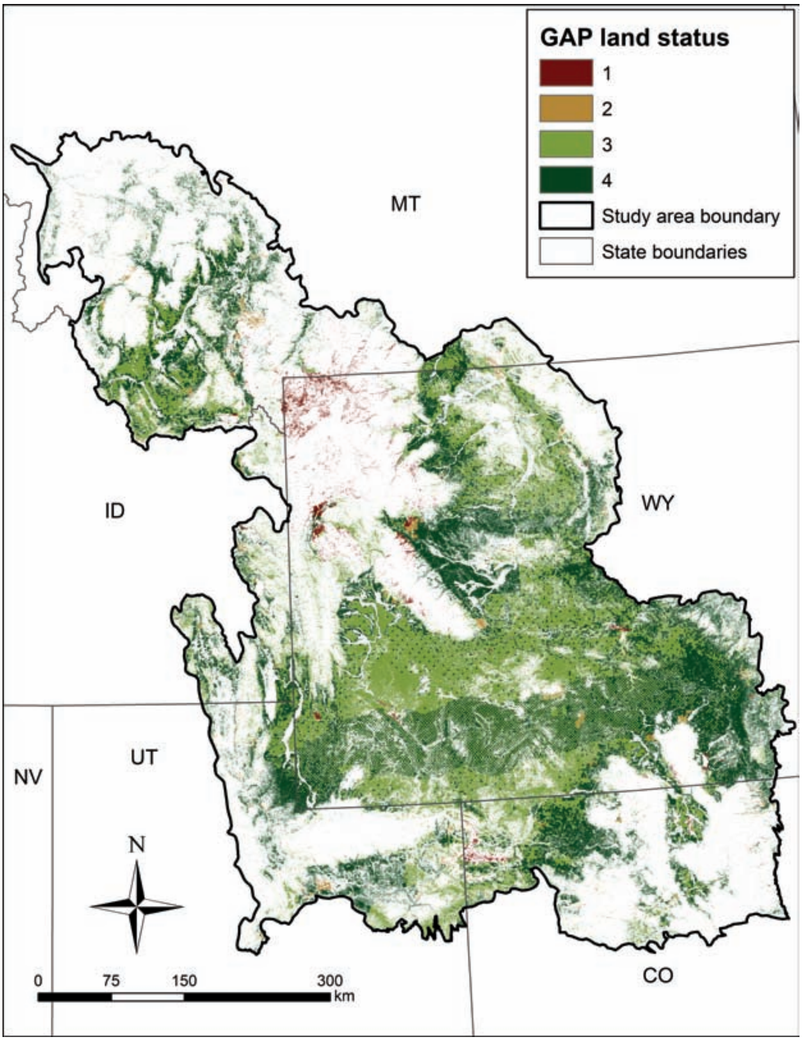

FIG. 1.6. Land status categories for sagebrush land cover types in the Wyoming Basins Ecoregional Assessment area based on the U.S. Geological Survey GAP program Protected areas database of the United States (PAS-US) <http://gapanalysis.usgs.gov/data/padus-data/>.

son et al. 2005). Shrublands and arid lands in the United States are predicted to decrease in spatial extent under a variety of climate change models and scenarios (e.g., Bachelet et al. 2001, Neilson et al. 2005). However, sagebrush in southwestern Wyoming is predicted to be the least affected by climate-induced losses of all sagebrush in the United States, and thus may represent a future stronghold for this ecosystem (Neilson et al. 2005). Although public lands management may have little effect on climate change in the WBEA, awareness of the potential synergistic effects of climate change with other ecological processes and land management actions (e.g., invasions by exotic, warm-season annual grasses [Smith et al. 2000], livestock grazing) will lead to more informed decision making concerning shrublands in this area.

Oil and gas development

One threat of special urgency in the WBEA is resource extraction, especially of natural gas and oil (Freilich et al. 2001, Neely et al. 2001, Weller et al. 2002, Thomson et al. 2005, Walker et al. 2007, Doherty et al. 2011; Ch. 3). Infrastructure associated with energy development was ranked second among threats confronting current populations of greater sage-grouse (U.S. Fish and Wildlife Service 2010). The area encompassed by the Wyoming Basins and Utah-Wyoming Rocky Mountains Ecoregions and surrounding areas in Colorado, Idaho, Montana, and Utah were identified as the center of the largest concentration of onshore oil and gas reserves in the contiguous 48 United States (U.S. Departments of the Interior, Agriculture, and Energy 2003). Moreover, the Greater Green River Basin, centered in southwestern Wyoming and northwestern Colorado (Fig. 3.1), holds the largest volume of oil and natural gas reserves among the key geologic basins inventoried for national oil and gas reserves (U.S. Departments of the Interior, Agriculture, and Energy 2003). The natural gas produced in the Intermountain West constitutes 20% of the nation's annual supply, and that region in turn holds 41% of the nation's gas reserves (Limerick et al. 2003).

Although oil, coal, and natural gas reserves in the WBEA have been tapped for decades (Weller et al. 2002, Connelly et al. 2004; Ch. 3), the development of advanced technologies to extract these reserves has led to an unprecedented proliferation of requests for permits to drill (Limerick et al. 2003, Walker et al. 2007, Kiesecker et al. 2009). Of particular concern in the WBEA is production of coal bed natural gas, also known as coal bed methane (CBM) (Braun et al. 2002, Gilbert 2002, Morton et al. 2002, Walker et al. 2007, Doherty et al. 2008). The development of technologies to profitably extract methane from water in coal bed seams has led to the drilling of thousands of wells in CBM fields, particularly in the Powder River Basin of northeastern Wyoming, which lies east of the study area boundary (Braun et al. 2002, U.S. Bureau of Land Management 2003, Walker et al. 2007; Ch. 3). Potentially profitable CBM reserves have been identified in many other portions of the Rocky Mountain region, including eastern Utah and southwestern Wyoming (U.S. Departments of the Interior, Agriculture, and Energy 2003). The Greater Green River Basin (Fig. 3.1) is projected to contain eight times the CBM reserves of the Powder River Basin.

Among the potential environmental effects from development of oil and gas wells and associated facilities are: (1) temporary displacement of wildlife or range abandonment due to disturbance from vehicle traffic and noise associated with compressor stations and other well-related structures; (2) direct loss of habitat from road and well-pad construction; (3) habitat fragmentation from the pipelines, power lines, roads, and other facilities associated with field development; (4) invasion of exotic plant species facilitated by soil disturbance around structures and connecting corridors; (5) depletion of aquifers from the pumping and discharge of millions of gallons of water during the extraction of methane in CBM fields; (6) changes in local hydrologic regimes as water is discharged into ephemeral streams; and (7) the potential for diseases such as West Nile virus to infect both humans and wildlife, a result of the creation of hundreds of water storage ponds for discharge from CBM wells (Walker and Naugle 2010; Table 1.3).

Despite nearly a century of energy extraction amid some of the greatest concentrations of native wildlife populations – particularly ungulates – in the western United States, a paucity of published research was available on effects of these activities on native plant and animal communities in the Wyoming Basins when we began our assessment (but see Weller et al. 2002, Powell 2003, WEST 2003, Wyoming Game and Fish Department 2004, Thomson et al. 2005). Several research projects have now been initiated or completed that rigorously examine effects of oil and

TABLE 1.3. Potential threats and associated effects on habitats and species in the sagebrush ecosystem, with example references (adapted from Wisdom et al. 2005).[a]

Potential threat	Associated effects	Examples	Example references
Weather, climate change, and catastrophes	*Environmental* – habitat loss or degradation	Drought and more severe and frequent wildfires from increasing temperatures, escalating spread of invasive plants such as cheatgrass; drought years in close succession, leading to losses of key forbs used by sagebrush-associated species	Tausch et al. 1993, U.S. Environmental Protection Agency 1998, Bachelet et al. 2001, Miller and Eddleman 2000, Smith et al. 2000, Schneider and Root 2002, Neilson et al. 2005, Hunt et al. 2006
	Population – stochastic events	Catastrophic events such as floods and severe drought, contributing to extirpation of small populations	Burgman et al. 1993, Andelman et al. 2001, Morris and Doak 2002, Aldridge et al. 2008
	Population – altered communities	Altered phenology leading to mismatches in timing of migrant arrivals and prey availability, changes in productivity; shifts in animal and plant distributions	Walther et al. 2002
Roads, highways, and associated rights-of-way	*Environmental* – habitat loss	Direct loss of habitat from road construction	Forman et al. 1997, 2003; Forman 2000; Trombulak and Frissell 2000; Gucinski et al. 2001; Spellerberg 2002
	Environmental – habitat fragmentation and degradation	Fragmented habitats; accelerated spread of invasive plants	Forman et al. 1997, 2003; Braun 1998; Parendes and Jones 2000; Gucinski et al. 2001; Neely et al. 2001; Havlick 2002; Spellerberg 2002; Gaines et al. 2003; Gelbard and Belnap 2003; Gelbard and Harrison 2003; Munger et al. 2003
	Population – barrier to migration or road avoidance	Movement or migration barriers to less mobile species; animals may avoid traffic, other activities associated with roads	Mader 1984; Bennett 1991; Reijnen et al. 1997; Wisdom et al. 2000; Berger 2004; Spellerberg 2002; Forman et al. 2003; Gaines et al. 2003; Brock and Kelt 2004; Ingelfinger and Anderson 2004; Sawyer et al. 2005, 2007; Aldridge and Boyce 2007
	Population – direct and indirect mortality	Death or injury from collisions with vehicles; increased mortality from poaching due to improved access	Patterson 1952, Olendorff and Stoddart 1974, Blumton 1989, Wisdom et al. 2000, Todd 2001, Havlick 2002, Forman et al. 2003

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Intensive livestock grazing	*Environmental* – habitat degradation	Ecologically inappropriate grazing by domestic stock, especially cattle and sheep, leading to loss of native perennial grasses and forbs in understory (changes in composition and structure) and declines in forage and other habitat components for species of concern and their prey (e.g., invertebrates); trampling, leading to destruction of burrows (e.g., of burrowing owls, pygmy rabbits)	Bock et al. 1993, Saab et al. 1995, Guthrey 1996, Schroeder et al. 1999, Beck and Mitchell 2000, Miller and Eddleman 2000, Johnson and O'Neil 2001, Freilich et al. 2001, Noss et al. 2001, Holmes et al. 2003, Knick et al. 2003, Dobkin and Sauder 2004, Thines et al. 2004
	Population – direct mortality	Mortality from trampling of nests	Beck and Mitchell 2000, Holmes et al. 2003
Oil and natural gas field development	*Environmental* – habitat loss and fragmentation	Fragmented habitat from pipelines, roads, well pads, and associated collection facilities; disruption of migration corridors; outright loss of habitat from roads and well pads, other facilities constructed for field development	Braun 1998, Braun et al. 2002, Weller et al. 2002, Berger 2004, Connelly et al. 2004, Sawyer et al. 2005, Thomson et al. 2005, Aldridge and Boyce 2007, Walker et al. 2007, Doherty et al. 2008
	Population – disturbance	Avoidance and potential abandonment of habitat due to vehicular traffic, other noise (e.g., compressor stations), and related human activity at well sites	Gillin 1989, Easterly et al. 1992, Bowles 1995, Warrick and Cypher 1998, Dyer 1999, Braun et al. 2002, Lyon and Anderson 2003, Powell 2003, Holloran 2005, Walker et al. 2007, Doherty et al. 2008
	Environmental – habitat degradation	Invasive species occupy disturbed sites (e.g., roadsides and well pads)	Zink et al. 1995, Parendes and Jones 2000, Trombulak and Frissell 2000, Forman et al. 2003, Gelbard and Belnap 2003, Bergquist et al. 2007
Fences	*Environmental* – habitat fragmentation	Fragmented habitats, interference with animal movement (e.g., pronghorn)	Braun 1998, Connelly et al. 2004, O'Gara and Yoakum 2004
	Population – direct mortality	Collisions or entanglement of animals with fences, leading to injury or death	Riddle and Oakley 1973, Fitzner 1975, Call and Maser 1985, Todd 2001, O'Gara and Yoakum 2004

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Expansion of juniper and other coniferous species in sagebrush communities	*Environmental* – habitat loss and degradation	Changes in climate and fire suppression leading to expansion of pinyon pine and juniper woodlands into sites previously occupied by sagebrush; especially mountain big sagebrush, Wyoming big sagebrush	Blackburn and Tueller 1970; Burkhardt and Tisdale 1976; Miller and Wigand 1994; Miller and Rose 1995, 1999; Commons et al. 1999; Miller and Eddleman 2000; Miller and Tausch 2001; Grove et al. 2005
Invasions of exotic plants	*Environmental* – habitat loss and degradation	Altered fire regimes and habitat degradation (e.g., from intensive livestock grazing), leading to increases in exotic plants (e.g., cheatgrass) in sagebrush ecosystems; noxious weeds accidentally introduced during reclamation of oil and gas well sites	Yensen 1981, Billings 1994, D'Antonio and Vitousek.1992, Knick 1999, West 1999, D'Antonio 2000, Miller and Eddleman 2000, Booth et al. 2003, Menakis et al. 2003, Dobkin and Sauder 2004, Bergquist et al. 2007
Reservoirs, dams, and other water developments	*Environmental* – habitat loss	Outright loss of habitat from construction of reservoirs	Braun 1998, Schroeder et al. 1999, Nachlinger et al. 2001
	Environmental – habitat degradation	Altered stream flows and hydrological regimes, degrading or altering habitat for aquatic and riparian species	Pierson et al. 2001, 2002, 2003
Herbicides	*Environmental* – habitat loss and fragmentation	Conversion and removal of sagebrush (especially prior to 1980), especially if native understory vegetation in relatively good condition	Best 1972; Braun and Beck 1977; Braun 1998; Connelly et al. 2000, 2004; Miller and Eddleman 2000
Power lines	*Environmental* – habitat degradation	Disturbance of vegetation and soils in power line corridors, leading to increased invasion of exotic species	Zink et al. 1995, Braun 1998
	Population – increased rates of predation	Poles and towers for transmission lines serving as perches or nest sites for corvids and raptors; increased potential for predation on sagebrush-associated species	Gilmer and Wiehe 1977, Knight and Kawashima 1993, Steenhof et al. 1993, Braun 1998, Boarman 2002
	Population – direct mortality	Collisions of birds and bats with power lines, resulting in injury or death; electrocution of perching raptors and other birds	O'Neil 1988, Harmata et al. 2001

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Communication towers	*Population* – direct mortality	Collisions of birds and bats with cell and radio towers, leading to injury and mortality	Evans and Manville 2000, Mabey and Paul 2007
Altered fire regimes	*Environmental* – habitat loss	Complete removal of sagebrush cover (i.e., type conversion), from increases in catastrophic wildfires, often related to invasions of cheatgrass, especially in Wyoming big sagebrush	Whisenant 1990, Billings 1994, D'Antonio and Vitousek 1992, Knick and Rotenberry 1997, Neely et al. 2001, Menakis et al. 2003
	Environmental – habitat degradation	Altered fire cycles in sagebrush ecosystems from fire suppression, resulting in changes in vegetation composition and structure, e.g. encroachment of woodlands into sagebrush	Schroeder et al. 1999, Miller and Eddleman 2000, Connelly et al. 2004
Loss of open space and housing development	*Environmental* – habitat loss	Direct loss of sagebrush from development of urban areas and “ranchettes” surrounding urban sites	Theobald et al. 1997, Braun 1998, Connelly et al. 2004, Hammer et al. 2007
	Population – human disturbance	Increasing human activities in urban and exurban areas, negatively affecting populations of sagebrush-associated species by displacement or abandonment; increases in predation rates on wildlife in sagebrush ecosystems from domestic dogs and cats in urban and rural settings, also from increased populations of predators (e.g., corvids) due to increased availability of food resources associated with human waste (e.g., garbage dumps).	Berry et al. 1998, Millsap and Bear 2000, Arrowood et al. 2001, Neely et al. 2001, Knick et al. 2003, Sawyer et al. 2005
Herbivory effects from wild ungulates	*Environmental* – habitat degradation	Localized, excessive herbivory by native ungulates, leading to degraded understory vegetation (e.g., changes in species composition and structure) and reduced sagebrush densities and canopy cover	McArthur et al. 1988, Singer and Renkin 1995, Wambolt and Sherwood 1999, Groves et al. 2000 (Appendix 20), Wisdom et al. 2006

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Disease transmission	*Population* – direct mortality	Disease transmission during winter season, exacerbated by human disturbance that causes concentrations of native ungulates on winter ranges; man-made water sources, esp. those changing from ephemeral to permanent, leading to increased transmission of mosquito-borne diseases such as West Nile virus.	Naugle et al. 2004, 2005; Rowland 2004; Walker et al. 2004; U.S. Fish and Wildlife Service 2005, Walker and Naugle 2010
Brood parasitism by brown-headed cowbirds	*Population* – direct mortality	Parasitism from brown-headed cowbirds, a species that may increase in human-altered environments (e.g., livestock feedlots and overgrazed pastureland), affecting populations of some birds (e.g., lark and vesper sparrows)	Friedmann and Kiff 1985, Robinson et al. 1995, Shaffer et al. 2003
Recreation	*Environmental* – habitat degradation	Degraded habitats from off-road vehicle use, e.g., by increasing establishment of exotic annual grasses like cheatgrass	Berry 1980, Havlick 2002, Munger et al. 2003, Chin et al. 2004, The Wilderness Society 2006
	Population – disturbance	Negative response, such as displacement or nest abandonment, to recreation-related disturbance, e.g., off-road vehicles; recreational shooting of small mammals	Berry 1980, White and Thurow 1985, Braun 1987, Knight and Gutzwiller 1995, Schroeder et al. 1999, Havlick 2002, Munger et al. 2003, Wisdom et al. 2004, Barton and Holmes 2007
Conversion of sagebrush to cropland or tame pasture for livestock	*Environmental* – habitat loss	Direct removal of sagebrush cover (e.g., via brush-beating, chaining, disking, or burning) and planting with crops or non-native perennial grasses such as crested wheatgrass for livestock forage	Vale 1974, Dobler 1994, Fischer et al. 1997, Braun 1998, Knick 1999, Schroeder et al. 1999, West 1999, Miller and Eddleman 2000, Johnson and O'Neil 2001, Knick et al. 2003
	Environmental – habitat fragmentation	Fragmented habitats from removal of sagebrush, resulting in interference with animal movements, dispersal, or population fragmentation	Knick and Rotenberry 1995, 1997, 2000; Johnson and O'Neil 2001; Knick et al. 2003; Connelly et al. 2004
	Population – direct mortality	Nest and egg destruction, or directly mortality of animals, from mechanical or other methods used to remove sagebrush or cultivate lands adjacent to sagebrush	Patterson 1952

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Mine development	*Environmental* – habitat loss and fragmentation	Fragmentation and outright loss of habitat to surface mines and associated mine tailings and roads, especially coal mines	Braun 1998, Remington and Braun 1991, Ricketts et al. 1999, Neely et al. 2001
	Population – disturbance	Disturbance and potential abandonment of habitat due to traffic, noise, and related human activity at mine site	Bednarz 1984, Braun 1998
Pesticides	*Environmental* – habitat degradation	Decreased forage base by killing insects used as prey by sagebrush-associated species	Johnson 1987, Holmes et al. 2003
	Population – mortality	Direct mortality of birds and other vertebrates exposed to pesticides and indirect mortality through consumption of contaminated insects	Patterson 1952, Blus et al. 1989, Blus 1996
Saline-sodic water	*Environmental* – habitat degradation	Salinization of surrounding soils and aquatic systems from disposal of millions of barrels of water produced during coal bed methane (CBM) extraction; high mortality rates (up to 100%) in vegetation exposed to sodic water discharge	Groves et al. 2000 (Appendix 20), McBeth et al. 2003
Wind energy development	*Environmental* – habitat degradation	Increased noxious weeds in areas around turbines or along roads needed to access turbines; loss of habitat from road construction and turbine installation; avoidance by wildlife of area near turbines from association of structures with nests or perches of avian predators	Forman et al. 1997, 2003; Leddy et al. 1999; Gelbard and Belnap 2003; U.S. Bureau of Land Management 2005; Mabey and Paul 2007, Doherty et al. 2011
	Population – mortality	Deaths and injuries of birds and bats from collisions with wind turbines	Leddy et al. 1999, Erickson et al. 2001, Young et al. 2003, Johnson et al. 2004, Arnett et al. 2008
Collection of specimens for personal, commercial, or scientific uses	*Population* – loss of individuals from the wild	Collection of rare plants and animals, especially herptiles such as midget faded rattlesnake, posing unknown risks to populations of these species	Wisdom et al. 2000, Freilich et al. 2001, Schlaepfer et al. 2005

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Groundwater depletion	*Environmental* – habitat degradation	Excessive groundwater withdrawal in well sites from pumping of water for CBM	Groves et al. 2000 (Appendix 20), Nachlinger et al. 2001
Grazing by feral horses	*Environmental* – habitat degradation	Loss of native perennial grasses and forbs in understory	U.S. Bureau of Land Management et al. 2000, Young and Sparks 2002, Beever 2003
Selenium and other environmental contaminants	*Population* – direct threat of mortality	Poisoning of animals from uptake of selenium in contaminated aquifers, primarily from agricultural runoff	Lemly 1997
Military training	*Environmental* – habitat fragmentation	Loss of shrubs from wildfire and destruction from tracked vehicles, leading to habitat fragmentation, from military training exercises in sagebrush ecosystems	Knick and Rotenberry 1997, Holmes and Humple 2000

[a] Threats are listed in order, from highest priority to lowest, based on rankings from BLM biologists working in the study area.

gas development on wildlife in sagebrush ecosystems, especially the Upper Green River Valley (contained within the WBEA area) and Powder River Basins in Wyoming. These projects incorporate radio telemetry and other techniques to evaluate potential impacts on wildlife, and include studies of greater sage-grouse (Lyon 2000, Lyon and Anderson 2003, Holloran 2005, Walker et al. 2007, Doherty et al. 2008), passerines (King and Holmes 2003, Gilbert and Chalfoun 2011), mule deer (Sawyer and Lindzey 2001, Sawyer et al. 2002, Sawyer et al. 2006), and pronghorn (Sawyer and Lindzey 2000, Sawyer et al. 2002). Long-distance migration of pronghorn in the Upper Green River Valley is severely compromised by existing and proposed development related to energy extraction in this area; furthermore, >75% of the traditional migration routes for this species in the Greater Yellowstone Ecosystem have been lost (Berger 2004).

Roads and trails

Roads, highways, trails, and off-highway vehicles affect wildlife habitats and biological systems in many ways; these effects have been succinctly described in reviews by Forman and Alexander (1998), Trombulak and Frissell (2000), Gucinski et al. (2001), Forman et al. (2003), and Gaines et al. (2003). Effects of roads and trails range from disturbance of wildlife due to vehicle traffic to the function of roads as conduits for invasive plants (see Table 1.3 for summaries of road effects in sagebrush ecosystems). Although past research focused largely on effects of roads and traffic on native ungulates, more recent research has demonstrated negative effects of roads and vehicles on a variety of taxa, such as sage-grouse (Oyler-McCance 1999, Braun et al. 2002, Lyon and Anderson 2003), passerines (Ingelfinger and Anderson 2004), small mammals (Brock and Kelt 2004), and snakes (Munger et al. 2003, Shine et al. 2004). Within the WBEA, the area affected by roads is increasing in part due to development of oil and natural gas fields. For example, in developed well fields in Wyoming, well pads and associated roads have eliminated >200 km^2 of shrublands since 1900 (Ch. 3).

One analysis evaluated impacts of the transportation network in the Upper Green River Valley near Pinedale, Wyoming (Thomson et al. 2005). Extensive roading in the study area has resulted in highly fragmented habitats for species such as greater sage-grouse, elk, pronghorn, and mule deer. Within the Jonah Field, a high-density natural gas field within the analysis area, road densities exceeded 1.2 km/km^2 across >95% of the area. Within the entire 11,700 km^2 analysis area, no greater sage-grouse lek was >5 km from a road, and 80% of the crucial winter range for pronghorn had road densities >0.6 km/km^2 (Thomson et al. 2005).

The impacts of roads and other infrastructure associated with human activities, such as urban and exurban developments, pipelines, power lines, oil and gas wells, and compressor stations, combine to impose an "ecological footprint" on the landscape (Sanderson et al. 2002, Weller et al. 2002, Leu et al. 2008; Ch. 4). Quantification of this footprint at broad scales has been greatly advanced because of the advent of spatial analysis conducted in Geographic Information Systems (GIS) and will be an important component of future analyses of impacts of anthropogenic disturbance on native ecosystems (Leu et al. 2008).

Invasive and noxious plants

An increasingly pervasive threat to the sagebrush ecosystem in the Wyoming Basins and elsewhere is the spread of noxious and invasive plants (Hartman and Nelson 2000, The Nature Conservancy 2000, Connelly et al. 2004, Miller et al. 2011; Ch. 10). Effects of invasive plants range from displacement of native vegetation to the creation of dense stands of fine fuels that carry wildfires (Table 1.3). Fragmented and disturbed habitats, which are increasing in the Wyoming Basins (Weller et al. 2002, Thomson et al. 2005, Ch. 3), are more susceptible to invasion by exotic plants (Pavek 1992; Knick and Rotenberry 1997, 2000; Pyke and Knick 2003).

In particular, the displacement of native sagebrush steppe by cheatgrass is one of the most dramatic changes observed in western landscapes (Billings 1994), and restoration of these communities will require tremendous resources (Knick 1999, Bunting et al. 2002, Hemstrom et al. 2002). It is estimated that greater than 50% of the sagebrush ecosystem in western North America has been invaded to some extent by cheatgrass (West 1999), with losses projected to accelerate in the future (Hemstrom et al. 2002, Suring et al. 2005, Miller et al. 2011). Cheatgrass invasion is most severe in Wyoming big sagebrush communities at lower elevations (Miller and Eddleman 2000, Hemstrom et al. 2002) and is less common in cooler, more mesic regions such as Montana and Wyoming. However, increases in atmospheric CO_2 predicted by climate change models will benefit C_3 plants such as cheatgrass (Smith et al. 2000, Miller et al. 2011).

Although cheatgrass is not considered a noxious weed in Wyoming (Wyoming Weed and Pest Control 2004), it poses an increasing threat in the study area as it expands into sites where it was previously thought unable to persist, possibly a result of climate change and the high degree of phenotypic plasticity that the species demonstrates (Knight 1994, Kinter 2003). The colder climate of Wyoming compared to the Great Basin, where cheatgrass has invaded vast acreages (Young and Sparks 2002), coupled with the absence of fall precipitation in many parts of the state, may have prevented comparable spread to date (Smith 2006). Cheatgrass currently is widespread in Wyoming (Ch. 10) but is not often a monoculture. However, the Bighorn Basin and eastern Wyoming have experienced recent increases in cheatgrass and other *Bromus* grasses (Smith 2006).

A compilation of invasive vascular plants in Wyoming listed 428 taxa, most of which originated outside North America (Hartman and Nelson 2000). The Wyoming Weed and Pest Council (2004) listed 24 plant species as noxious weeds. Knapweeds (*Centaurea* spp.), hardhead (synonym Russian knapweed) (*Acroptilon repens*), saltlover (synonym halogeton) (*Halogeton glomeratus*), slender Russian thistle (*Salsola collina*), and cheatgrass are of particular concern in Wyoming (Knight 1994, Wyoming Weed and Pest Council 2004).

Other threats

Livestock grazing is a pervasive management influence on the sagebrush ecosystem nationwide (Beck and Mitchell 2000, Crawford et al. 2004, Knick and Connelly 2011); however, we lacked consistent data on grazing seasons and stocking rates to conduct a formal analysis of its effects for our assessment. Grazing effects on sagebrush ecosystems are direct and indirect and include removal of nesting cover for birds, trampling of riparian vegetation, seeding of non-native grasses as livestock forage, increases in non-native annual grasses, and removal of sagebrush shrubs to increase forage production (Beck and Mitchell 2000, Crawford et al. 2004).

A variety of other threats impact the sagebrush ecosystem, such as transmission lines, fences, recreational use, urbanization and exurban expansion, encroachment of conifers, dams and reservoirs, and wind energy development (Table 1.3). Conversion of native shrub steppe in southwestern Montana to agriculture continues to remove habitat for sagebrush-associated species (The Nature Conservancy 2000, Dusek et al. 2002). An additional threat in this area is the encroachment of conifers, especially Douglas-fir, into mountain big sagebrush communities, resulting in reductions in sagebrush cover and habitat for sagebrush-associated species (Grove et al. 2005).

Wind farms currently are uncommon in the WBEA area although the potential for vastly increased wind energy development exists (Doherty et al. 2011). Within the study area, wind potential (i.e., wind speed and density) is greatest in northcentral Colorado and much of western Wyoming (U.S. Bureau of Land Management 2005). Effects of wind energy development on wildlife include: (1) mortalities of bats and birds from collisions with wind turbines (Table 1.3), (2) habitat loss and fragmentation due to the infrastructure needed to develop the wind farms, (3) disturbance from human and vehicle activities at wind energy sites (Leddy et al. 1999, Erickson et al. 2001, Young et al. 2003, U.S. Bureau of Land Management 2005, Mabey and Paul 2007), (4) noise that might disrupt reproductive and foraging behaviors, and (5) habitat degradation through the introduction and spread of invasive plants.

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APPENDIX 1.1

Crosswalk between existing vegetation types (mapped as ecological systems [Comer et al. 2003]) in LANDFIRE existing vegetation type (LANDFIRE 2007) and: (1) vegetation maps used to develop Wyoming Basins Ecoregional Assessment (WBEA) wildlife and invasive species models; (2) summary maps used for Chapter 1 tables and figures; and (3) vegetation maps used for Chapter 3 tables and figures. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

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Chapter 2: Sagebrush-Associated Species of Conservation Concern

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Abstract. Selection of species of concern is a critical early step in conducting broad-scale ecological assessments for conservation planning and management. Many criteria can be used to guide this selection, such as conservation status, existing knowledge base, and association with plant communities of interest. In conducting the Wyoming Basins Ecoregional Assessment (WBEA), we followed a step-wise process to select vascular plant and vertebrate species of concern. Based on our selection process, we identified 65 taxa of sagebrush-associated (*Artemisia* spp.) vascular plants of conservation concern. The vast majority were forbs, and nearly all are found in Wyoming (n = 59; 91%), reflecting its central location and spatial dominance (51%) of the study area. Forty-eight plants (74%) were ranked either S1 or S2 (state-level ranks indicating imperilment due to rarity, threats, or other factors) in at least one state within the assessment area. Forty vertebrates of concern were selected for our assessment, including 17 mammals, 18 birds, and 4 reptiles. Among these were 7 vertebrates commonly considered sagebrush-obligate species: sagebrush lizard (*Sceloporus graciosus*), greater sage-grouse (*Centrocercus urophasianus*), sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Amphispiza belli*), Brewer's sparrow (*Spizella breweri*), pronghorn (*Antilocapra americana*), and pygmy rabbit (*Brachylagus idahoensis*). Several vertebrate species of concern in the Wyoming Basins are either rare or imperiled, including black-footed ferret (*Mustela nigripes*) and Wyoming pocket gopher (*Thomomys clusius*).

Key words: ecoregional assessment, sagebrush ecosystem, species of conservation concern, species selection, terrestrial vertebrates, vascular plants, Wyoming Basins.

Ecoregional assessments may rely on coarse- or fine-filter approaches or both, depending on specific objectives of the assessment. Coarse-filter approaches, which are typically based on conserving ecological communities, are often easier to implement but may not capture occurrences of rare or locally common species or other key habitat elements (Scott et al. 1993, Noss and Cooperrider 1994, Haufler 1999b, Marcot and Flather 2007). Moreover, coarse filters such as plant associations and ecological processes are often less tangible concepts for the public to understand. Fine-scale methods may more effectively conserve the species or special elements addressed but are generally too impractical (i.e., costly and time-intensive) to apply to more than a handful of taxa, especially across large landscapes (Noss and Cooperrider 1994, Haufler 1999b, Groves 2003).

To address the inherent limitations in using only one approach, many broad-scale assessments, including those conducted by The Nature Conservancy (TNC), combine coarse-filter (e.g., plant associations or species guilds) and fine-filter (e.g., species) methods (Noss 1987; Haufler 1999a, b; Stein et al. 2000; Carignan and Villard 2002; Groves 2003; Wisdom et al. 2005a). For example, the conservation plan for the Utah-Wyoming Rocky Mountains Ecoregion, which lies within the boundaries of the WBEA (Ch. 1), identified 17

Artemisia communities as conservation targets (coarse filter) in addition to a suite of focal species (e.g., gray wolf [*Canis lupus*]) and special elements (e.g., petiolate wormwood [*A. campestris* var *petiolata*]) (fine filter; Noss et al. 2001). In the Great Basin ecoregional assessment, Wisdom et al. (2005a) evaluated conditions for both sagebrush-associated species and groups of species, with groupings based on similarities in habitat associations and total habitat area within various land cover types.

Recognizing the advantages of combining strategies, we also used a hybrid approach of coarse- and fine-filter strategies for the WBEA. The primary basis of our assessment was a variant of a coarse-filter strategy; that is, we focused on (1) identifying and quantifying all sagebrush land cover types within the study area and (2) identifying, mapping, and assessing the impact of anthropogenic disturbance on sagebrush cover types within the study area (Introduction). This approach allowed characterization of the entire sagebrush ecosystem within our study area, an advantage of a coarse-filter strategy (Haufler 1999a).

To complement this approach and meet additional WBEA objectives of identifying plant and wildlife species of conservation concern and assessing impacts of disturbance on these species (Introduction), we also selected a suite of vascular plant and vertebrate species that are associated with sagebrush. Wisdom et al. (2005a) identified >350 species of conservation concern associated with the sagebrush ecosystem in the western United States; we used their list as a starting point for our fine-filter selection, recognizing that we could not address all species of concern in our assessment due to limitations of time and funding. Our approach resembles that described by Marcot and Flather (2007) as a "multiple species" strategy based on entire habitat assemblages, with the assumption that if macrohabitat (i.e., sagebrush) is provided, the requirements of the entire assemblage will be met.

Criteria for selecting species may be based on a variety of factors, including perceived levels of risk to potential threats; sensitivity to disturbance; conservation status as indicated by state or federal lists of threatened, endangered, or sensitive species; representation of a broad range of spatial scales and ecological processes; current population trend; response to management actions; cost effectiveness of measuring or monitoring the species; and association with a land cover of interest (e.g., riparian communities, sagebrush, old growth forest) (Stephenson and Calcarone 1999, Carignan and Villard 2002, Andelman et al. 2004, Wisdom et al. 2005b). The state-level Comprehensive Wildlife Conservation Strategies use a variety of approaches to identify species of concern (see http://www.wildlifeactionplans.org/). For example, the Wyoming Action Plan incorporated a habitat x population status matrix, in which Native Species Status (NSS) ranks from 1 to 7 were assigned and used to select species (Wyoming Game and Fish Department 2005).

Our overall objective in selecting species for the WBEA was to capture a broad range of sagebrush-associated species that represented multiple spatial scales and elements of sagebrush ecosystems and were potentially sensitive to anthropogenic disturbance and management actions in the study area. Primary criteria for selection of species were (1) strong association with sagebrush ecosystems and (2) recognized status of conservation concern due to declining habitats, populations, or both. Our intention was to be more inclusive than exclusive to ensure that we considered all potential species of concern and their habitats in sagebrush ecosystems of the study area. This inclusive approach provided an opportunity to evaluate species that may not currently be of concern but may become so in the future (Wisdom et al. 2005b). Moreover, because information

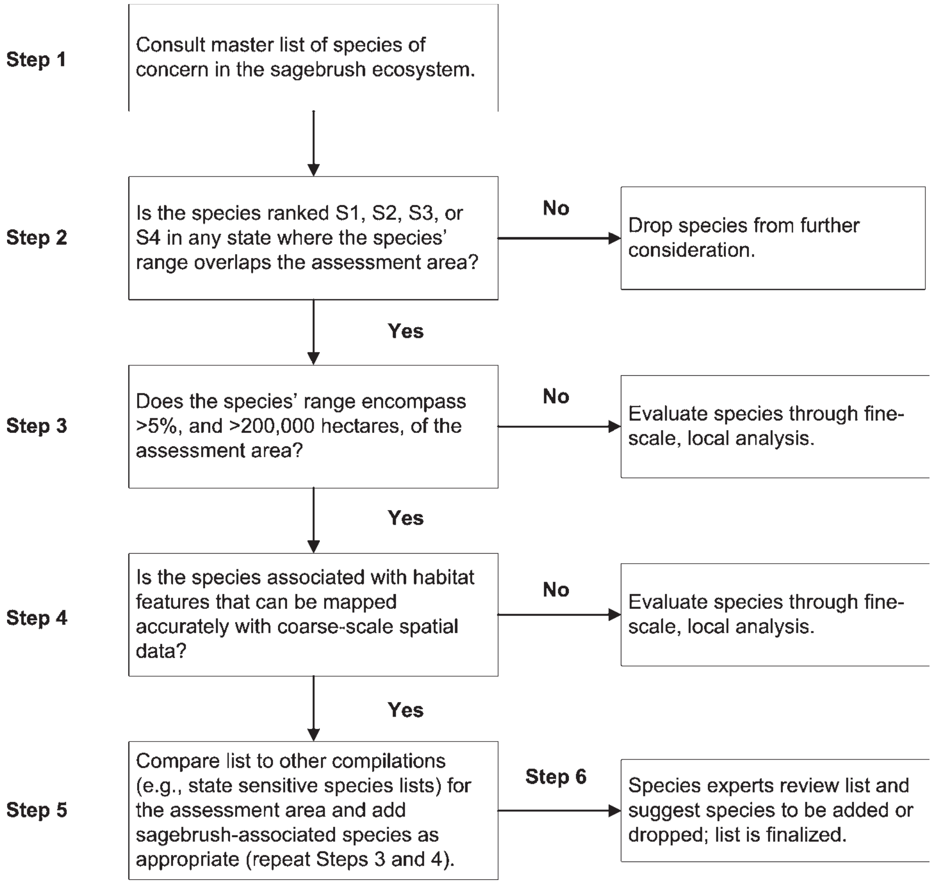

FIG. 2.1. Criteria and decision diagram for selecting species of conservation concern for multi-species assessment in an ecoregion (from Wisdom et al. [2005a]).

about populations and habitat association is relatively scarce for many species in nonforested ecosystems such as sagebrush (Dobkin and Sauder 2004), our approach increased the likelihood of evaluating species that are at risk but whose conservation status is not well understood.

The initial step in conducting the WBEA was to select species of concern, specifically vascular plants and terrestrial vertebrates. We then acquired or created range maps for vertebrates to understand patterns of species distribution across the study area and for constraining areas for modeling a subset of species of concern (Ch. 4).

SELECTING SPECIES FOR ASSESSMENT

The process for selection of species of concern for the WBEA followed a sequence of steps; species had to meet all criteria in this process to be retained for consideration (Fig. 2.1). Species with fine-grained environmental requirements were eliminated because of the coarse-scale spatial data available for assessing environmental conditions across the study area. Species with very limited geographic ranges, such as low bladderpod (*Lesquerella prostrata*), were generally not selected for this assessment because they are best suited for small-scale evaluations (Wisdom et al. 2005b) (see "Mapping Geographic Ranges" for the definition of geographic range used). We chose to limit our selection to major taxonomic groups of plants (vascular only) and animals (terrestrial vertebrates) because of the relatively greater knowledge base for these groups, the number of species in these groups, their relevance to management in the sagebrush ecosystem, and the large area encompassed by the WBEA (Raphael et al. 2007).

The list generated by Wisdom et al. (2005a) for species of conservation concern associated with the sagebrush ecosystem relied on state ranks (S-ranks; NatureServe 2007) to assess conservation status (this list is found in Appendix 2 of Wisdom et al. [2005a] and is available online at: http://www.fs.fed.us/pnw/pubs/sagebrush-appendices/). This ranking system, based on several factors such as number of occurrences of populations within each state, population size, and threats, is widely used in conservation planning throughout the United States and Canada (Master 1991, Raphael et al. 2007). The species selected by Wisdom et al. (2005a) were considered to be potentially at risk of regional extirpation in the sagebrush ecosystem owing to declines or rarity of habitat or populations, or both.

We consulted this "master" list as the first step in identifying potential species of concern for inclusion in the WBEA (Step 1, Fig. 2.1). First, we recorded the current (2007) S-ranks for each species in any state within the overlap of its geographic range and the boundaries of the WBEA area (Step 2, Fig. 2.1). Additional criteria for species selection were a geographic range that (1) was large enough to be appropriate for regional, broad-scale assessment and (2) overlapped sufficiently with the study area boundaries to warrant inclusion in the assessment (Wisdom et al. 2005b; Fig. 2.1). The 27 invertebrates listed by Wisdom et al. (2005a) were not retained on our list for the WBEA because they did not meet these criteria for inclusion.

Vascular Plants

We compiled an initial list of vascular plants of concern for the Wyoming Basins assessment from four primary sources: (1) the master list of Wisdom et al. (2005a), (2) a list of regional endemic vascular plants created by TNC, (3) a list of plants developed for the Wyoming GAP (Gap Analysis Program) project (Merrill et al. 1996), and (4) a report on globally rare plant taxa in the U.S. Bureau of Land Management (BLM) Dillon, Montana Field Office (Lesica 2003). Several botanists reviewed the draft list resulting from these four sources to evaluate the validity of the selection process and the taxa selected (Appendix 2.1).

Wisdom et al. (2005b) procedures

We identified 20 vascular plant taxa in the Wyoming Basins study area by applying the process outlined by Wisdom et al. (2005b) (Fig. 2.1). The resulting list was reviewed by a botanist for the Wyoming Natural Diversity Database (WYNDD), which maintains a comprehensive database of information about the distribution and ecological relationships of rare plants and animals in the state (B. Heidel, WYNDD, pers. comm.).

Fertig (1999) appendix

Heidel (WYNDD, pers. comm.) recommended expanding our list by focusing on regional endemics to identify sagebrush-associated plant taxa not currently tracked or treated as targets by WYNDD or TNC, but potentially of concern. Regional endemic species are found in a limited geographic area, usually 520-1,300 km^2 in one or more states (Fertig 1999). The Wyoming Basins Ecoregion has one of the highest rates of regional endemism for vascular plants in the north-central United States (Fertig 1999). Although we identified several regional endemics in our original selection process (source 1, above), we lacked range-wide distribution data for many of these taxa. Consequently, we were unable to determine whether some of these plants occurred in >5% of the study area (Fig. 2.1). We retained these taxa on our list of plants of concern, without full knowledge of their ranges, but recommend further evaluation of their suitability for regional assessment.

Additional regional endemics to consider for the WBEA were found in a TNC report for their Wyoming Basins ecoregional assessment (Appendix B in Fertig [1999]). This list was also reviewed by a U.S. Forest Service botanist who evaluated the association of the endemics with sagebrush plant communities (Appendix 2.2). Last, we reviewed Table 1 in Fertig (1999; targeted vascular plant elements) to identify other vascular plant taxa that might be suitable for our assessment.

Wyoming GAP project

We evaluated a list of plants developed for the Wyoming GAP project (Merrill et al. 1996) to identify additional regional endemics that met our criteria. We selected species on this list if they (1) were regional endemics, (2) had state rankings in Wyoming of S2 or S3, and (3) occurred in the Intermountain Desert Steppe biome, as described by Merrill et al. (1996). The rationale for our state rank screen was that species ranked S1 were rare and thus unsuitable for broad-scale evaluation, and that species ranked S4 or S5 were potentially secure and thus not of concern. We assumed that species in the Intermountain Desert Steppe biome would have a high probability of being associated with sagebrush ecosystems in Wyoming; thus, we used this attribute as a proxy for association with sagebrush.

BLM Dillon Field Office list of rare plants

We reviewed a report on the globally rare plant species of the BLM Dillon Field Office (Lesica 2003) to evaluate plants in the Montana portion of the study area. The Dillon Field Office contains the majority of the sagebrush in the Montana portion of the WBEA and is almost completely (97%) contained within the study area boundaries.

Other sources

Last, we compared our revised draft list of vascular plants with other lists of species of concern (e.g., sensitive species lists developed by the BLM for states within the project area and state Natural Heritage Program lists) and added any species that met our criteria. Several BLM botanists reviewed the final list (Appendix 2.1; Table 2.1).

Vertebrates

To select vertebrates for the WBEA, we first reviewed the master list of sagebrush-associated species of concern, as described above. We consulted other existing lists (Step 5, Fig. 2.1), including conservation targets identified by TNC within the WBEA area (The Nature Conservancy 2000, Freilich et al. 2001, Neely et al. 2001, Noss et al. 2001) and several sensitive species lists (e.g., Montana Natural Heritage Program 2004, Wyoming Game and Fish Department 2005).

Vertebrate species were removed at all steps of the screening process; for example, six mammals on the master list either did not occur within the study area or did not have a rank of S4 or lower in at least one of the five states within the assessment boundary. Application of the complete selection process (Fig. 2.1) resulted in 39 vertebrate taxa as potential species of concern.

The draft list of vertebrates was then reviewed by four biologists, who suggested changes. For example, bighorn sheep (*Ovis canadensis*) was added owing to (1) the importance of sagebrush for winter range habitats of this species in the Wyoming Basins (Irwin et al. 1993) and (2) the species' state rank (e.g., S3S4 in Wyoming).

TABLE 2.1. Vascular plants of conservation concern identified for regional assessment of sagebrush ecosystems in the Wyoming Basins Ecoregional Assessment area.

				State rank					
Species/subspecies/variety	Family	Life form	Global rank[a]	CO	ID	MT	UT	WY	Source[b]
Achnatherum contractum Contracted ricegrass[c]	Poaceae	Graminoid	G3G4	SU		S3	S1	S3S4	8, 9, 12
Achnatherum swallenii Swallen's needlegrass	Poaceae	Graminoid	G5		S5			S2	2, 7, 9
Antennaria arcuata Box pussytoes	Asteraceae	Forb	G2		S1			S2	1, 2, 5, 6, 7, 18
Artemisia tripartita var. *rupicola* Wyoming threetip sagebrush	Asteraceae	Shrub	G5T3					S3	17
Astragalus [*sericoleucus* var.] *aretioides* Cushion milkvetch[d]	Fabaceae	Forb	G4	S1		S2	S1	S3	8, 9, 14
Astragalus detritalis Debris milkvetch	Fabaceae	Forb	G3	S2			S3		1, 5, 7, 12, 14, 15
Astragalus grayi Gray's milkvetch	Fabaceae	Forb	G4?			S2		S3	7, 9, 11
Astragalus jejunus var. *jejunus* Starveling milkvetch	Fabaceae	Forb	G3T3	S1	S2		S1	S3	6, 7, 9, 14, 16, 18
Astragalus nelsonianus Nelson's milkvetch	Fabaceae	Forb	G3	S1			S1	S3	6, 7, 9, 14
Astragalus oreganus Oregon milkvetch	Fabaceae	Forb	G4?			S1		S3	7, 9, 11
Astragalus pubentissimus var. *pubentissimus* Green River milkvetch[e]	Fabaceae	Forb	G4	SNR			SNR	S2	8, 9
Astragalus scaphoides Bitterroot milkvetch	Fabaceae	Forb	G3		S3	S2			1, 3, 10, 11
Astragalus simplicifolius Little bun milkvetch	Fabaceae	Forb	G3					S3	7, 9
Castilleja pilosa var. *longispica* Longspike Indian paintbrush	Scrophulariaceae	Forb	G4G5T4		SNR	S3		S2	8, 8
Cirsium ownbeyi Ownbey's thistle	Asteraceae	Forb	G3	S2			S1	S2	1, 2, 4, 5, 6, 7, 9, 13, 14, 15, 16
Cryptantha caespitosa Tufted cryptantha	Boraginaceae	Subshrub Forb	G4	S2	S1		S1?	S3	1, 4, 5, 7, 9, 14
Cryptantha sericea Silky cryptantha	Boraginaceae	Subshrub Forb	G4	SNR		SNR	SNR	S3	8, 9, 18
Cryptantha stricta Yampa River cryptantha [Erect cat's-eye]	Boraginaceae	Subshrub Forb	G3	S3			S2S3	S3	7, 9, 14
Cymopterus evertii Evert's springparsley	Apiaceae	Forb	G2G3				S1	S2S3	2, 6, 7, 9

TABLE 2.1. Continued

Species/subspecies/variety	Family	Life form	Global rank[a]	State rank CO	ID	MT	UT	WY	Source[b]
Cymopterus lapidosus Talus springparsley	Apiaceae	Forb	G2G3				S1	S2S3	7, 9
Cymopterus longipes Longstalk springparsley	Apiaceae	Forb	G4?		SNR		SNR	S3	8, 9
Descurainia pinnata var. *paysonii* Western tansy-mustard [Payson's tansymustard]	Brassicaceae	Forb	G5T3?	SNR	SNR		SNR	S2	2, 7, 9, 12
Draba oligosperma Fewseed draba[f]	Brassicaceae	Forb	G5	S2	SNR	SNR	SNR	S5	2, 7, 9
Erigeron nanus Dwarf fleabane	Asteraceae	Forb	G4		SNR		S1	S2	8, 9
Erigeron nematophyllus Needleleaf fleabane	Asteraceae	Forb	G3	S2?			S1S2	S3	8, 9, 14
Eriogonum acaule Singlestem buckwheat	Polygonaceae	Forb	G3	S1				S3	7, 9, 14
Eriogonum brevicaule var. *micranthum* Shortstem buckwheat	Polygonaceae	Forb	G4T3					S3	8
Eriogonum exilifolium Dropleaf buckwheat	Polygonaceae	Forb	G3	S2				S2	2, 7, 9, 14, 19
Eriogonum lagopus Parasol buckwheat [Rabbit buckwheat][g]	Polygonaceae	Forb	G3			S3		S2	1, 6, 7, 9
Hymenopappus filifolius var. *luteus* Fineleaf hymenopappus	Asteraceae	Subshrub Forb	G5T3T5	SNR		SU	SNR	S3S4	8, 11, 12
Hymenopappus filifolius var. *nudipes* Fineleaf woollywhite	Asteraceae	Subshrub Forb	G5T4				SNR	S2	8, 9, 12
Tetraneuris torreyana Torrey's four-nerve-daisy[h]	Asteraceae	Forb	G4	SNR		S3	S1	S3	8, 9
Ipomopsis congesta Ballhead ipomopsis [Compact gilia][i]	Polemoniaceae	Subshrub Forb	G5T3T4	S1		S2	SNR	S3	7, 9, 14
Lesquerella condensata Dense bladderpod[j]	Brassicaceae	Forb	G4Q	SU		S3		S2	8, 9
Leymus simplex var. *simplex* Alkali lyme grass [Alkali wildrye][k]	Poaceae	Graminoid	G4?Q	SNR			S1	S2?	7, 9
Lomatium bicolor var. *bicolor* Wasatch desertparsley	Apiaceae	Forb	G4T3T4	S1	SNR	S3	SNR	S2	8, 14
Lomatium juniperinum Juniper biscuitroot	Apiaceae	Forb	G3G5	SNR	SNR		SNR	S2	8, 9
Lomatium nuttallii Nuttall's biscuitroot	Apiaceae	Forb	G3	S1		S1		S3	8, 9, 11, 14

TABLE 2.1. Continued

				State rank					
Species/subspecies/variety	Family	Life form	Global rank[a]	CO	ID	MT	UT	WY	Source[b]
Mentzelia pumila Dwarf mentzelia[1]	Loasaceae	Forb	G4	SNR		S2	S2	S3	8, 9, 11
Mertensia oblongifolia Oblongleaf bluebells	Boraginaceae	Forb	G4G5	SNR			SNR	S2	8, 9
Oenothera pallida var. *trichocalyx* Pale evening primrose	Onagraceae	Forb	G5T3T5	SNR			SNR	S3	8
Oxytropis besseyi var. *ventosa* Bessey's locoweed	Fabaceae	Forb	G5T3?			SU	S1?	S3	8, 9, 11
Oxytropis nana Wyoming locoweed	Fabaceae	Forb	G3					S3	7, 9
Penstemon angustifolius var. *vernalensis* Broadbeard beardtongue	Scrophulariaceae	Subshrub Forb	G5T3	S1			S3		1, 8, 14
Penstemon arenicola Sand penstemon	Scrophulariaceae	Forb	G3G4	SNR		SNR		S3S4	8, 9, 12
Penstemon eriantherus var. *cleburnei* Cleburn’s penstemon	Scrophulariaceae	Subshrub Forb	G4T2T3			SU	S1	S2S3	8, 9
Penstemon fremontii var. *fremontii* Fremont's beardtongue	Scrophulariaceae	Subshrub Forb	G3G4T3T4	SNR			S2S3	S3	8, 9, 12
Penstemon laricifolius var. *exilifolius* Larchleaf beardtongue	Scrophulariaceae	Forb	G4T2Q	S2				S2	2, 8, 9, 14
Penstemon lemhiensis Lemhi penstemon	Scrophulariaceae	Forb	G3		S3	S2			10
Penstemon pachyphyllus var. *mucronatus* Mucronate penstemon	Scrophulariaceae	Forb	G5T4	SNR			SNR	S2	8, 9
Penstemon paysoniorum Payson's beardtongue	Scrophulariaceae	Subshrub Forb	G3				SNR	S3	7, 9, 12
Phacelia glandulosa Glandular phacelia	Hydrophyllaceae	Forb	G4	SNR	SNR	S3	S1	S2?	7, 9
Phlox opalensis Opal phlox	Polemoniaceae	Forb	G3				S1	S3	6, 7, 9, 16
Physaria acutifolia var. *purpurea* Sharpleaf twinpod	Brassicaceae	Forb	G5T2				S2		8
Platyschkuhria integrifolia Basindaisy	Asteraceae	Subshrub Forb	G5	SNR		SU	S3	S3	8, 9, 11
Sphaeromeria argentea Silver chickensage	Asteraceae	Subshrub Forb	G3G4	S1	SNR	S3		S3	10, 14
Sphaeromeria capitata Rock tansy	Asteraceae	Forb	G3	S1		S3	S1	S3	8, 9, 11, 14, 16
Stanleya tomentosa var. *tomentosa* Woolly princesplume	Brassicaceae	Subshrub Forb	G4T3					S2	7, 9

TABLE 2.1. Continued

Species/subspecies/variety	Family	Life form	Global rank[a]	State rank CO	ID	MT	UT	WY	Source[b]
Tetradymia nuttallii Nuttall's horsebrush	Asteraceae	Shrub	G3G4	SNR			SNR	S2S3	8, 9
Tetraneuris torreyana Torrey's four-nerve-daisy[m]	Asteraceae	Forb	G4	SNR		S3	S1	S3	8, 9
Thelypodiopsis elegans Westwater tumblemustard	Brassicaceae	Forb	G3G5	SNR			S3	S2S3	8, 9, 12
Townsendia nuttallii Nuttall's Townsend daisy	Asteraceae	Forb	G3			S3	S1	S3	8, 9, 11
Townsendia spathulata Sword Townsend daisy	Asteraceae	Forb	G3			S3		S3	8, 9, 11
Townsendia strigosa Hairy Townsend daisy	Asteraceae	Forb	G4	S1			SNR	S3	8, 9, 14
Trifolium andinum Intermountain clover	Fabaceae	Forb	G3	S1			S2	S3	8, 9, 14

[a] Rankings obtained October 15, 2007 from NatureServe (http://www.natureserve.org/explorer/); G = Global rank indicator, based on worldwide distribution at the species level; T = Global trinomial rank indicator, based on worldwide distribution at the infraspecific level; S = State rank indicator, based on distribution within the state/province at the lowest taxonomic level; 1 = Critically imperiled, at very high risk of extinction or extirpation due to extreme rarity, very steep declines, or other factors; 2 = Imperiled due to rarity from very restricted range, very few populations, steep declines, or other factors; 3 = Vulnerable due to restricted range, relatively few populations, recent and widespread declines, or other factors; 4 = Apparently secure, uncommon but not rare, some cause for long-term concern due to declines or other factors; 5 = Secure, common, widespread, and abundant; SNR = Conservation status not yet assessed at the state/province level; ? = Inexact or uncertain numeric rank; Q = Questionable taxonomy; SU = Unrankable; present and possibly in peril, but not enough data yet to estimate rank.

[b] Sources were: (1) the selection procedures described in the text and Fig. 2.1; (2) Keinath et al. 2003 (includes both Species of Concern and Species of Potential Concern); (3) The Nature Conservancy 2000; (4) Noss et al. 2001; (5) Freilich et al. 2001; (6) U.S. Bureau of Land Management 2004d; (7) Fertig 1999, Table 1; (8) Fertig 1999, Appendix B; (9) Wyoming GAP screen (see "Selecting Species for Assessment"); (10) Lesica 2003; (11) Montana Natural Heritage Program 2003; (12) Seeds of Success 2004; (13) U.S. Bureau of Land Management 2002a; (14) Colorado Natural Heritage Program 2005; (15) Colorado Natural Heritage Program 2003; (16) Utah Native Plant Society, Inc. 2004; (17) C. Spurrier (Appendix 3.1); (18) Idaho Rare Plant Society 2004; and (19) Neely et al. 2001.

[c] Synonymous with *Oryzopsis contracta.*

[d] Synonymous with *A. sericoleucus* var. *aretiodes.*

[e] Ranks are for species, not variety.

[f] Ranks are for *D. oligosperma;* WY ranks *D. oligosperma* ssp. *juniperina* S2.

[g] Ranks are for *E. lagopus*; synonymous with *Eriogonum lagopus*.

[h] Synonymous with *Tetraneuris torreyana*.

[i] Synonymous with *I. congesta* var. *crebrifolia*.

[j] Synonymous with *L. alpina* var. *condensata*.

[k] Synonymous with *Leymus simplex*; ranks are for species, not variety.

[l] Includes *M. pumila* var. *pumila*.

[m] Synonymous with *Hymenoxys torreyana*.

Following this review, we addressed discrepancies among reviewers and finalized a list of 40 vertebrate taxa for analysis (Table 2.2).

Our list was intended to include all species of concern meeting our criteria and associated with sagebrush. The degree of dependency on sagebrush for many species is uncertain, and some species are likely to rely on some combination of sagebrush and other shrublands. Consequently, we referred to our list of species of concern as sagebrush-associated, rather than sagebrush-dependent. We assumed that any reduction in amount or quality of sagebrush was likely to affect all sagebrush-associated species on our list.

Species Modeled in the WBEA

To meet one of our assessment objectives, developing predictive models for species of concern (Introduction), we developed a modeling procedure (Ch. 4) to facilitate the development of robust empirical models from field collected data. Our field sampling effort was directed toward collecting the data necessary to model maximum number of sagebrush-associated species of concern (Ch. 5–9). We were able to develop spatially explicit models for 10 of the 40 vertebrate species of concern on our list as well as 5 other sagebrush-associated species.

MAPPING GEOGRAPHIC RANGES

Current range maps are necessary to quantify environmental conditions for species of concern in regional assessments and to ensure that conditions are evaluated in the area of relevance for the species. For our assessment, we defined a species' range as the polygon or polygons that encompass the outer boundaries of a species' geographic occurrence within the study area; this definition concurs with Gaston (1991) as the "extent of occurrence," rather than the area of occupancy of a species. These maps often overestimate the true range of species, especially when considered over large spatial extents (Fertig and Reiners 2002, Dobkin and Sauder 2004), but are commonly used in conservation planning and assessment at regional scales (e.g., Knick et al. 2003, Laliberte and Ripple 2004). Many species included in our assessment have geographic ranges that are largely based on incomplete data regarding the internal population structure or distribution within their range. Consequently, we used the more general definition of range as the outer boundaries of each species' currently estimated occurrence.

Vascular Plants

Geographic range maps, as defined above, are not readily available for many plant species. Digitized coverages of such maps are especially lacking, other than maps of presence/absence by state or county. Challenges in producing range maps for plants include (1) the large number of species (e.g., Wyoming supports >2,700 taxa of plants), (2) the necessity of merging state-level maps for many taxa, and (3) the fine-scale data (e.g., soils) typically needed to accurately map plant distributions. Given these challenges, we did not create range maps for vascular plants of concern in the WBEA.

Vertebrates

We developed geographic range maps in two primary ways for the 40 vertebrate species of concern in the WBEA. First, we imported existing range maps from six sources, most of them previously compiled by NatureServe for mammals (Patterson et al. 2003) and birds (Ridgely et al. 2003) of the western hemisphere (Appendix 2.3; Fig. 2.2). When more detailed, hard-copy range maps or distribution data were available (n = 8), primarily for amphibians and reptiles, we scanned and digitized the maps. Digital versions of the vertebrate range maps were used to highlight areas of

TABLE 2.2. Forty vertebrate species of conservation concern identified for regional assessment within sagebrush ecosystems of the Wyoming Basins Ecoregional Assessment area.

Common name	Scientific name	Global rank[a]	State rank					Source[b]
			Colorado	Idaho	Montana	Utah	Wyoming	
Amphibians								
Great Basin spadefoot	*Spea intermontana*	G5	S3	S4		S5	S3	1, 2, 7, 9, 16, 17
Reptiles								
Short-horned lizard[c]	*Phrynosoma hernandesi*	G5	S5		S3	S4	S4	1, 3, 6, 16, 17
Sagebrush lizard	*Sceloporus graciosus*	G5	S5	S5	S3	S5	S5	1, 3, 14, 17
Midget faded rattlesnake	*Crotalus viridis concolor*	G5T4	S3?				S1	1, 2, 4, 9, 16, 17
Great Basin gopher snake	*Pituophis catenifer deserticola*	G5T5	S4				S3	2, 17
Birds								
Ferruginous hawk	*Buteo regalis*	G4	S3B,S4N	S3B	S2B	S2S3B, S2N	S4B,S5N	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19(II), 21
Golden eagle	*Aquila chrysaetos*	G5	S3S4B, S4N	S4B,S4N	S4	S4	S3B, S3N	2
Swainson's hawk	*Buteo swainsoni*	G5	S5B	S4B	S3B	S3B	S4B	1, 3, 6, 10, 13, 17, 21
Prairie falcon	*Falco mexicanus*	G5	S4B,S4N	S5B,S3N	S4	S4	S4B,S4N	1, 3, 10 (III), 13, 15, 16
Greater sage-grouse[c]	*Centrocercus urophasianus*	G4	S4	S4	S3	S2?	S4	1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 14, 15, 16, 17, 19(II), 20, 21
Columbian sharp-tailed grouse	*Tympanuchus phasianellus columbianus*	G4T3	S2	S3	S1		S1	1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13, 15, 16, 17, 19(II), 20, 21
Mountain plover	*Charadrius montanus*	G2	S2B		S2B	S1B	S2	2, 3, 6, 10, 11, 14, 16, 17, 19(II), 20
Burrowing owl	*Athene cunicularia*	G4	S4B	S3S4	S2B	S3B	S3	1, 2, 3, 4, 7, 8, 9, 10, 12, 13, 15, 16, 17, 19(II), 20, 21

TABLE 2.2. Continued

Common name	Scientific name	Global rank[a]	State rank					Source[b]
			Colorado	Idaho	Montana	Utah	Wyoming	
Gray flycatcher	*Empidonax wrightii*	G5	S5B	S2B,S2N		S4S5B	S4B,S4N	1, 10, 13, 15
Sage thrasher[c]	*Oreoscoptes montanus*	G5	S5	S5B	S3B	S4S5B	S5	1, 2, 3, 9, 10, 13, 14, 15, 17, 19(II)
Loggerhead shrike	*Lanius ludovicianus*	G4	S3S4B	S3	S3B	S4B, S3S4N	S3	1, 2, 3, 9, 10, 11, 13, 14, 15
Sage sparrow[c]	*Amphispiza belli*	G5	S3B	S4B	S1S3B	S3S4	S3	1, 2, 3, 6, 7, 8, 9, 10, 13, 14, 15, 16, 17, 19(III)
Lark sparrow	*Chondestes grammacus*	G5	S4	S5B	S5B	S5B,S2N	S5B,S5N	1, 10, 13, 15
Green-tailed towhee[c]	*Pipilo chlorurus*	G5	S5	S5B	S4B	S4B	S5B,S5N	1, 13, 15
Vesper sparrow[c]	*Pooecetes gramineus*	G5	S5	S4B	S5B	S5B,S2N	S5B,S5N	1, 10, 13, 15
Brewer's sparrow[c]	*Spizella breweri*	G5	S4B	S4B	S2B	S4S5B	S5	1, 2, 3, 6, 9, 10, 13, 14, 15, 17, 19(III), 21
Brewer's blackbird	*Euphagus cyanocephalus*	G5	S5B,S4N	S5B,S5N	S5B	S4S5	S5B,S5N	1, 15
Western meadowlark	*Sturnella neglecta*	G5	S5	S5B,S3N	S5B	S5	S5B,S5N	1, 13, 15
Mammals								
Merriam's shrew	*Sorex merriami*	G5	S3	S2?	S3	SH	S3S4	1, 3, 7, 15, 18, 19(III), 21
Spotted bat	*Euderma maculatum*	G4	S2	S2	S2	S2S3	S3	1, 2, 3, 12, 15, 16, 17, 18, 19(II), 20, 21
Western small-footed myotis	*Myotis ciliolabrum*	G5	S4	S4?	S4	S3S4	S3B	1, 2, 17, 18
Townsend's big-eared bat	*Corynorhinus townsendii*	G4	S2	S2	S2	S3?	S2	1, 2, 3, 4, 12, 16, 17, 18, 19(II), 20, 21
Pronghorn[c]	*Antilocapra americana*	G5	S4	S5	S5	S4	S5	1, 14
Bighorn sheep	*Ovis canadensis*	G4	S4	S3	S4	S3?	S3S4	2, 6, 14, 17, 19(II), 21
Black-footed ferret	*Mustela nigripes*	G1	S1		S1	S1	S1	2, 3, 4, 6, 12, 14, 16, 17, 19(I), 20

TABLE 2.2. Continued

Common name	Scientific name	Global rank[a]	State rank					Source[b]
			Colorado	Idaho	Montana	Utah	Wyoming	
White-tailed prairie dog	*Cynomys leucurus*	G4	S4		S1	S2?	S3	1, 2, 3, 6, 9, 12, 16, 17, 19(II), 20
Uinta ground squirrel	*Spermophilus armatus*	G5		S4?	S3S4	S5	S3S4	1, 2, 3, 8, 17
Wyoming ground squirrel	*Spermophilus elegans*	G5	S5	S4?	S3S4	SH	S3S4	1, 2, 3, 8, 17, 19(III), 21
Wyoming pocket gopher	*Thomomys clusius*	G2					S2	2, 9, 17
Idaho pocket gopher	*Thomomys idahoensis*	G4		S4?	S2S3	SH	S2	1, 2, 3, 8, 9, 17, 19(III), 21
Great Basin pocket mouse	*Perognathus parvus*	G5	S1	S5	S2S3	S4	S2	2, 3, 15, 16, 17, 20
Sagebrush vole	*Lemmiscus curtatus*	G5	S1	S4	S4	S3S4	S5	1, 6, 15, 16, 17
White-tailed jackrabbit[c]	*Lepus townsendii*	G5	S4	S5	S4	S3S4	S4	1
Black-tailed jackrabbit	*Lepus californicus*	G5	S5	S5	S2	S5	S5	1, 3
Pygmy rabbit	*Brachylagus idahoensis*	G4		S3	S3	S2	S1	1, 2, 3, 8, 9, 12, 14, 15, 17, 18, 19(II), 20, 21

[a] Rankings were obtained on October 15, 2007 from NatureServe [http://www.natureserve.org/explorer/] and are as follows: G = Global rank indicator, based on worldwide distribution at the species level; T = Global trinomial rank indicator, based on worldwide distribution at the infraspecific level; S = State rank indicator, based on distribution within the state/province at the lowest taxonomic level; 1 = Critically imperiled, at very high risk of extinction or extirpation due to extreme rarity, very steep declines, or other factors; 2 = Imperiled due to rarity from very restricted range, very few populations, steep declines, or other factors; 3 = Vulnerable due to restricted range, relatively few populations, recent and widespread declines, or other factors; 4 = Apparently secure, uncommon but not rare, some cause for long-term concern due to declines or other factors; 5 = Secure, common, widespread, and abundant; SH = Possibly extirpated; ? = Inexact or uncertain numeric rank; B = Conservation status for breeding populations in the state/province; N = Conservation status for non-breeding populations in the state/province.

[b] Sources included: (1) the selection procedure developed by Wisdom et al. (2005b); (2) Keinath et al. 2003 (includes both Species of Concern and Species of Potential Concern); (3) Montana Natural Heritage Program 2004; (4) Colorado Division of Wildlife 2005b; (5) The Nature Conservancy 2000; (6) Neely et al. 2001; (7) Noss et al. 2001; (8) Freilich et al. 2001; (9) U.S. Bureau of Land Management 2002b, (10) Nicholoff 2003; (11) U.S. Bureau of Land Management 2004e; (12) Utah Department of Natural Resources 2005; (13) Rich et al. 2005; (14) International Union for the Conservation of Nature 2007; (15) Dobkin and Sauder 2004; (16) Colorado Natural Heritage Program 2005; (17) Wyoming Game and Fish Department 2005; (18) Idaho's Special Status Mammals http://fishandgame.idaho.gov/cms/tech/CDC/animals/mammals.cfm (copyright 2006, Idaho Fish and Game); (19) Utah Division of Wildlife Resources 2005; (20) Montana Fish, Wildlife and Parks 2005; and (21) Idaho Department of Fish and Game 2005.

[c] Spatially explicit models developed for these species in Ch. 5-10.

uncertainty in the maps of species occurrence and abundance in Chapters 5–9.

For two species, pygmy rabbit (*Brachylagus idahoensis*) and pronghorn *(Antilocapra americana)*, we created hand-digitized range maps specifically for our assessment. The most current range map for pygmy rabbit when we initiated our study (Patterson et al. 2003) did not extend into Wyoming. However, pygmy rabbits were known to occur in the state (e.g., Campbell et al. 1982; Clark and Stromberg 1987; Beauvais 2004; WYNDD, unpublished data). To update the range map for this species in Wyoming, we used the predicted distribution from an Optimal DOMAIN Model developed by WYNDD (Beauvais 2004; D. Keinath, WYNDD, pers, comm,). The map was expanded and refined in 2005 based on recent surveys conducted by the University of Wyoming in Carbon and Freemont counties (Purcell 2006). In Idaho, surveys for pygmy rabbits revealed locations of active burrows in the southeastern corner of the state, east of the boundary displayed by Patterson et al. (2003) (Rachlow and Svancara 2003); we updated the map accordingly. For the Montana portion of the WBEA, we used the map of Rauscher (1997); in Utah, we relied on a map of recent (2004) positive occurrences of pygmy rabbit(A. Kozlowski, Utah Division of Wildlife Resources, pers. comm.). The final, combined range map for pygmy rabbit in the WBEA encompassed about 611 km^2 of the study area (Fig. 7.1c).

We developed a range map for pronghorn based on information obtained from the wildlife agencies of each state in our study area (Montana Fish, Wildlife and Parks 2002, Idaho Department of Fish and Game 2004, Utah Division of Wildlife Resources 2004, Wyoming Game and Fish Department 2004, Colorado Division of Wildlife 2005a). The range maps were merged into a single shapefile. Our range map combined all seasonal ranges of pronghorn (i.e., year-round, summer, winter).

SELECTED VASCULAR PLANTS OF CONSERVATION CONCERN

We identified 65 taxa of sagebrush-associated vascular plants of conservation concern for our assessment (Table 2.1). Nearly all are found in Wyoming (n = 59; 91%), reflecting its central location and relatively large percentage (51%) of the study area. Only 15 taxa on the list occur in Idaho, which had the smallest area among the five states within the assessment boundary (Ch. 1). Colorado and Utah had similar representation on the list (n = 40 and 43, respectively). By contrast, Montana comprised 21% of the study area, nearly twice the percentage of Colorado (12.6%) and Utah (10.4%), but had only 28 taxa on the list.

The vast majority (n = 47; 72%) of the vascular plants of concern were forbs, followed by subshrubs/forbs (n = 13; 20%) and graminoids (n = 3; 5%). Only two shrub species, Wyoming threetip sagebrush (*Artemisia tripartita* ssp. *rupicola*) and Nuttall's horsebrush (*Tetradymia nuttallii*), were included (Table 2.1). Families most commonly represented included Asteraceae (n = 16), Fabaceae (n = 12; primarily *Astragalus* spp.), and Scrophulariaceae (n = 9). Many of the plants on the list, such as Ownbey's thistle (*Cirsium ownbeyi*), were found on several other lists of special status or sensitive species, or were brought forward from more than one of our selection approaches (Table 2.1).

Although no taxa were ranked G1, one was ranked G2 (box [meadow] pussytoes [*Antennaria arcuata*]) and two as G2G3 (Evert's springparsley [*Cymopterus evertii*] and talus springparsley [*C. lapidosus*]). Global rank indicators ("G-ranks") reflect the status of each taxon based on worldwide distributions (Master 1991). Only three plants were ranked G5 ("demonstrably secure" at a global scale; see footnotes, Table 2.1); most taxa were ranked intermediate to these extremes (i.e., G3 and G4), consistent with our culling of plants either too rare or ubiquitous for effective assessment at a regional scale. Forty-eight plants (74%) were ranked S1 or S2 in at least one state within the assessment area (Table 2.1). Fifteen subspecies or varieties had trinomial ranks of T2 to T4, indicating low to moderate risk to these taxa at the infraspecific level (Table 2.1).

Of the 20 plants brought forward from the selection process outlined by Wisdom et al. (2005b), seven were retained (taxa retained have a source code of "1" in Table 2.1) and 13 were dropped. Plants excluded from further consideration either were not associated with sagebrush, were too common (e.g., ranked S5 in all states within their range in the study area) to retain as species of concern or had distributions largely outside the study area.

SELECTED VERTEBRATES OF CONSERVATION CONCERN

Forty vertebrates of concern were identified for the WBEA: one amphibian (Great Basin spadefoot [*Spea intermontana*]), four reptiles, 18 birds, and 17 mammals (Table 2.2). The reptiles included two snakes and two lizards. The majority of the avian taxa were passerines; also included were five raptors and two gallinaceous species (greater sage-grouse [*Centrocercus urophasianus*] and Columbian sharp-tailed grouse [*Tympanuchus phasianellus columbianus*]). The 17 mammals included a wide range of taxa, from small mammals to bats, a carnivore, and two ungulates (Table 2.2). All seven vertebrates commonly denoted as sagebrush-obligate species (Paige and Ritter 1999) were identified as species of concern: sagebrush lizard (*Sceloporus graciosus*), greater sage-grouse, sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Amphispiza belli*), Brewer's sparrow (*Spizella breweri*), pronghorn, and pygmy rabbit.

Most species occurred in all five states of our assessment, and all 40 were found in Wyoming (Table 2.2). Idaho had the lowest representation, with 33 of the 40 species (83%) present. Species not found in all states had limited distributions in the region, such as midget faded rattlesnake (*Crotalus viridis concolor*) and mountain plover (*Charadrius montanus*). Some species on our list are endemic to shrubsteppe vegetation of the Intermountain West, such as Great Basin pocket mouse (*Perognathus parvus*) and pygmy rabbit (Dobkin and Sauder 2004).

Several vertebrate species of concern in the WBEA area are either rare or imperiled (see G-ranks, Table 2.2). The rarest species on our list, black-footed ferret (*Mustela nigripes*), is ranked G1 and listed as endangered by the U.S. Fish and Wildlife Service (FWS) (NatureServe 2007). This species had been extirpated in the wild and is now found only in very limited numbers in sites where animals have been successfully re-introduced (Dobson and Lyles 2000, NatureServe 2009). Two additional species, mountain plover and Wyoming pocket gopher (*Thomomys clusius*), were ranked G2, which indicates imperilment at a global scale. The mountain plover is currently ranked G3 (NatureServe 2009). The Wyoming pocket gopher is endemic to Wyoming, where it was ranked S2. At the trinomial (i.e., infraspecific) level, two subspecies were ranked T3 or T4: midget faded rattlesnake (T4) and Columbian sharp-tailed grouse (T3; Table 2.2). The majority of the species on our list, however, were considered secure on a global basis, ranked either G4 (n = 10; 25%) or G5 (n = 24; 60%).

At the state level, nine species (23%) were ranked S1 in one or more of the five states in the study area. Only three species were ranked either S4 or S5 (i.e., relatively secure status) in all states in which they occurred in the study area: green-tailed towhee (*Pipilo chlorurus*), Brewer's blackbird (*Euphagus cyanocephalus*), and pronghorn (Table 2.2).

In addition to black-footed ferret, several species of concern in the WBEA have

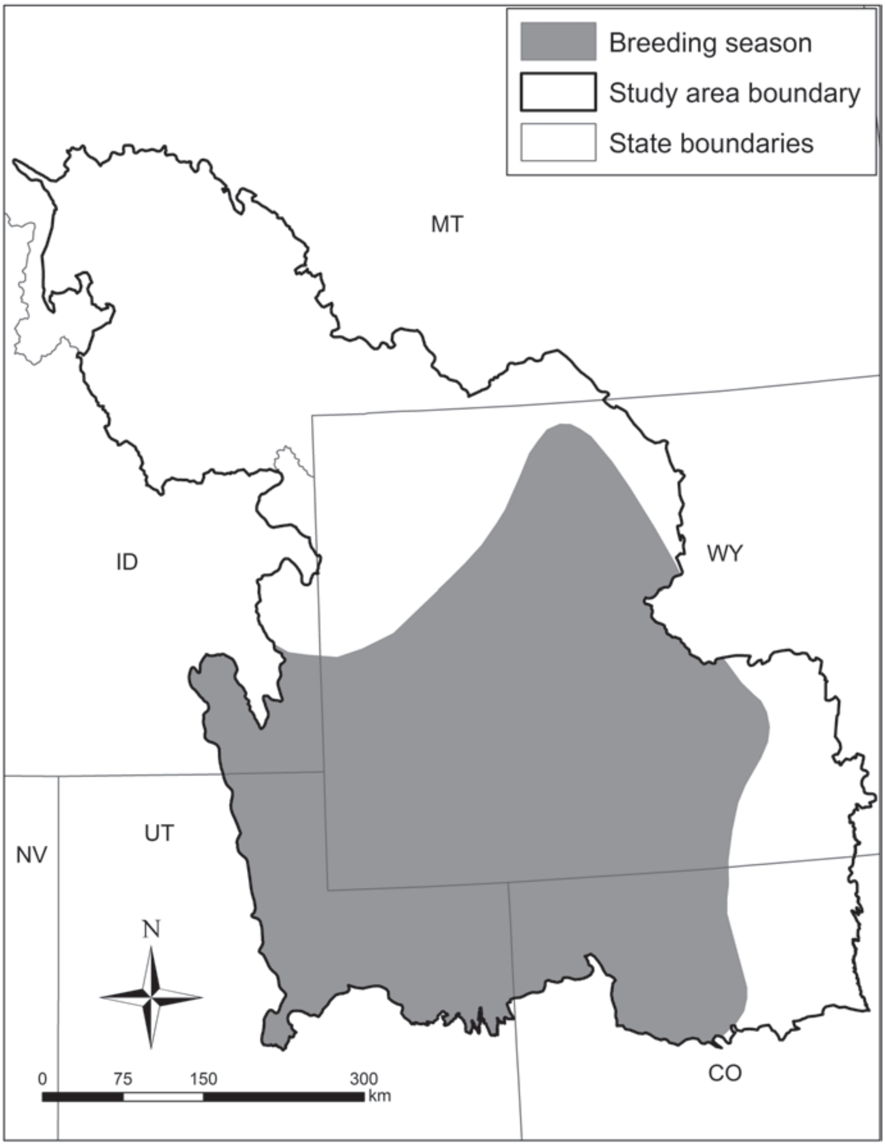

FIG. 2.2. Example geographic range map used in the Wyoming Basins Ecoregional Assessment; sage sparrow shown (from Ridgely et al. 2003).

been considered for listing by the FWS in response to petitions submitted under the Endangered Species Act (ESA). Petitions to list the greater sage-grouse as threatened or endangered range-wide were found not warranted by the FWS in January 2005 (U.S. Fish and Wildlife Service 2005a). A court challenge to the decision resulted in an additional review and determination in 2010 that listing greater sage-grouse as endangered was warranted but precluded (U.S. Fish and Wildlife Service 2008c, 2010a). Two petitions to list the pygmy rabbit as threatened or endangered across its range have been considered by FWS, May 2005 and September 2010, but the agency found listing to be "not warranted" (U.S. Fish and Wildlife Service

2005b, 2010d). The mountain plover was petitioned for listing under the ESA, but withdrawn in 2003 (Dinsmore 2003); in 2010, the FWS reinstated a proposal to list the species as threatened under the ESA (U.S. Fish and Wildlife Service 2010b). The white-tailed prairie dog (*Cynomys leucurus*) was petitioned for listing in 2002, but listing was denied by the FWS in 2004; the FWS initiated another status review in May 2008, again finding that listing as an endangered species was not warranted (U.S. Fish and Wildlife Service 2008a, 2010c). A petition to list the Columbian sharp-tailed grouse as threatened or endangered across its historical range was submitted in 2004 (Banerjee 2004), with a finding by FWS that current information did not warrant listing (U.S. Fish and Wildlife Service 2006).

Twenty-eight (70%) of the vertebrate species of concern selected for the WBEA were also found on at least one of the state-level lists of species of concern compiled as part of the Comprehensive Wildlife Conservation Strategy process (Table 2.2). For example, 27 (68%) species of concern in the WBEA are listed in Wyoming's action plan (Wyoming Game and Fish Department 2005). Similarly, 17 of our selected vertebrate species (43%) are listed in Utah's strategy (Table 2.2; Utah Division of Wildlife Resources 2005).

Species of Concern Modeled in the WBEA

We modeled 10 vertebrate species of concern in the WBEA area based on vegetation, abiotic, and anthropogenic disturbance variables: Brewer's sparrow, greater sage-grouse, green-tailed towhee, lark sparrow (*Chondestes grammacus)*, pronghorn, sage sparrow, sage thrasher, short-horned lizard (*Phrynosoma hernandes*), vesper sparrow (*Pooecetes gramineus)*, and white-tailed jackrabbit (*Lepus townsendii*) (see Ch. 5-10 for modeling methods and results). Greater sage-grouse was modeled owing to its prominence as a species of concern in sagebrush ecosystems (Knick and Connelly 2011) and the commitment by the BLM to managing habitats for this species (U.S. Bureau of Land Management 2004a, b, c). Moreover, five of these species—Brewer's sparrow, greater sage-grouse, pronghorn, sage sparrow, and sage thrasher—were included in the 2007 "red list" of threatened species (International Union for the Conservation of Nature 2007).

SUMMARY

Our assessment area harbors a large proportion of the sagebrush remaining in the western U.S. (Ch. 1). These expansive tracts support a wide array of vertebrates and plants that rely on sagebrush communities for all or part of their life cycles. Many of the avian species selected for our evaluation have declined in abundance, including greater sage-grouse (Connelly et al. 2004, Knick and Connelly 2011) and a host of shrub steppe passerines (Vander Haegen et al. 2000, Knick and Rotenberry 2002, Knick et al. 2003, Dobkin and Sauder 2004). Likewise, population declines for several of the mammals on our list, such as white-tailed prairie dog and pygmy rabbit, have been noted in portions of their ranges (Hays 2003, Thines et al. 2004).

The 65 vascular plants and 40 vertebrates of concern identified for our assessment met our criteria of strong association with sagebrush and a recognized status of conservation concern. The group is diverse; species selected span a range of taxonomic groups (e.g., avian vs. herptile species), sensitivity to disturbance (short-horned lizard [no important anthropogenic disturbance factors; Ch 7] vs. greater sage-grouse [three anthropogenic disturbance factors; Ch. 5]), levels of conservation risk (e.g., Wyoming pocket gopher [G2] vs. Great Basin spadefoot [G5]), spatial extents at which they select habitats (midget faded rattlesnake vs. American pronghorn), and reliance on sagebrush communities (e.g., sagebrush obligates such as greater sage-grouse vs. species that use sagebrush in tandem with a variety of shrublands, such as Swainson's hawk [*Buteo swainsoni*]). Together these species provide a comprehensive basis for an integrated assessment of potential threats from anthropogenic disturbance, including land use change, on species of concern and their habitats in sagebrush communities of the WBEA. Many of our selected taxa are also featured in other contemporary assessments of species of concern in shrub steppe communities (Knick et al. 2003, Connelly et al. 2004, Dobkin and Sauder 2004, Rich et al. 2005, Wisdom et al. 2005a). Thus, our selection corroborates the importance of these taxa for management consideration in sagebrush ecosystems of the Wyoming Basins.

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APPENDIX 2.1

Experts consulted for (1) review of selection methods and draft lists of species of conservation concern, or (2) predictive models of example species, in conjunction with the Wyoming Basins Ecoregional Assessment. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 2.2

Literature sources used to determine sagebrush association of potential vascular plant species of concern for the Wyoming Basins Ecoregional Assessment area. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 2.3

Sources used for developing geographic range maps for 40 vertebrates of conservation concern in the Wyoming Basins Ecoregional Assessment area. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

Sagebrush Ecosystem Conservation and Management: 69–87, 2011

Chapter 3: Changes to the Wyoming Basins Landscape from Oil and Natural Gas Development

Sean P. Finn and Steven T. Knick

Abstract. Oil and natural gas have been produced in Wyoming since the late 1800s although the rate of extraction has increased substantially in the last two decades. Well pads, roads, and infrastructure built to support resource development alter native vegetation configuration; however, the rate and effect of land cover change resulting from oil and gas extraction has not been quantified across the region. We used a Geographic Information System (GIS) to model development through time and assess change to native vegetation at two spatial extents (field and subbasin) within the Wyoming portion of the Wyoming Basins Ecoregional Assessment (WBEA) area. Since 1900, a minimum of 1,703 km^2 of native vegetation in the WBEA area has been replaced by well pads or roads. Shrublands were, and continue to be, the dominant land cover class and the cover type most affected by oil and gas extraction. Average shrubland patch size has decreased by approximately 10% at the subbasin extent in the WBEA. Core area (≥60 m from edge) size declined by 13% as road development fragmented formerly continuous patches. To date, the majority of land cover change has occurred in formally identified oil and gas fields, which cover about 1% of the WBEA in Wyoming. Approximately 7.5% of shrubland within oil and gas fields has been converted to well pad or a road supporting a well, and shrubland patch size has declined by 45%. Resource reserves, especially natural gas, have been identified outside traditional fields, and development will likely expand as resource development becomes more cost-effective. Revegetation guidelines are in place for development areas addressed by Environmental Impact Assessments although no quantitative data are available to assess how well restoration efforts are restoring landscapes and connecting fragments.

Key words: fragmentation, GIS, land cover change, landscape, oil and gas development, shrublands, Wyoming.

Oil and natural gas extraction has occurred in Wyoming since at least 1884 (Keefer 1965). Before 1960, extraction activities were relatively dispersed because resource detection and delivery technologies were poor and access to resource rich areas was low. Since 1960, increasing demand and development of advanced technologies to extract reserves has driven an exponential increase in permit requests (Limerick et al. 2003) along with an increase in infrastructure needed to support extraction and delivery. Worldwide demand for energy has increased by more than 50% in the last half-century (National Petroleum Council 2007). Production of natural gas in the US has increased by 60% since 1990 (U.S. Department of Energy 2007), and current projections predict the trend to continue (National Petroleum Council 2007).

Natural gas produced in the western U.S. constitutes 20% of the United States' annual supply, and the region holds 41% of the nation's total natural gas reserve (Limerick et al. 2003). The area encompassed by the Wyoming Basins Ecoregional Assessment (WBEA, Fig. 3.1) is the center of the largest concentration of onshore oil and gas reserves in the contiguous 48 United States (U.S. Departments of the Interior, Agriculture, and Energy 2003).

The Greater Green River Basin, located primarily in southwestern Wyoming and northwestern Colorado, holds the largest volume of oil and natural gas reserves among the key geologic basins recently inventoried (U.S. Departments of the Interior, Agriculture, and Energy 2003).

A recent trend in the WBEA area is production of coal bed natural gas, also known as coal bed methane (CBM; Braun et al. 2002, Gilbert 2002, Morton et al. 2002, Noon 2002, Walker et al. 2007a). Potentially profitable CBM reserves have been identified in southwest Wyoming; the Greater Green River Basin alone is projected to contain eight times the CBM reserves of the already developed Powder River Basin (U.S. Departments of the Interior, Agriculture, and Energy 2003), and CBM development is well underway in the Pinedale Anticline area (Walston et al. 2009).

Well pad and road networks built to access oil and natural gas resources replace native vegetation on the landscape (Weller et al. 2002, Walston et al. 2009). However, the rate and extent of this replacement has not been quantified for the WBEA area. Here we applied spatio-temporal data and Geographic Information System (GIS) techniques to recreate changes in land cover distribution and configuration due to oil and gas development in western Wyoming.

Potential environmental effects from development of oil and gas wells and associated facilities are: (1) direct loss of habitat from road and well-pad development; (2) habitat fragmentation from road, pipeline, power line, and other facility construction associated with development; (3) temporary or permanent displacement of wildlife or range abandonment due to disturbance from vehicle traffic and noise associated with compressor stations and other well-related structures; (4) potential for increased soil erosion and consequent reduction in surface water quality; (5) invasion of exotic plant species facilitated by soil disturbance around structures and connecting corridors; (6) depletion of aquifers from pumping and discharge of millions of metric tons of water during extraction of methane in CBM fields; (7) changes in local hydrologic regimes as water is discharged into ephemeral streams; and (8) the potential for diseases such as West Nile virus to infect both humans and wildlife, a result from the creation of hundreds of water storage ponds for discharge from CBM wells (Table 1.3). Our objective was to estimate the direct loss and fragmentation of native land cover due to energy well and road development.

Habitat loss, degradation, and fragmentation associated with road development are increasing throughout the western U.S. (Forman et al. 2003, Gelbard and Belnap 2003, Thomson et al. 2005). Concern for the alteration, loss, and fragmentation of native shrubland has been voiced in the scientific literature (Rotenberry 1998, Braun et al. 2002, Bryner 2003, Knick et al. 2003), but few studies have quantified landscape-scale changes as a result of oil and gas development (Weller et al. 2002, Walston et al. 2009). Roads, highways, trails, and off-highway vehicles affect wildlife habitats and biological systems in many ways (Forman and Alexander 1998, Trombulak and Frissell 2000, Gucinski et al. 2001, Forman et al. 2003, Gaines et al. 2003). Effects of roads and trails range from disturbance of wildlife due to vehicle traffic (Lyon and Anderson 2003) to the function of roads as conduits for invasive plants (Bergquist et al. 2007; see Table 1.3 for a summary of road effects in the sagebrush [*Artemisia* spp.] ecosystem). Although past research focused largely on effects of roads and traffic on native ungulates (Berger 2004, Sawyer et al. 2006), other research has demonstrated negative effects of roads and vehicles on a variety of taxa, such as greater sage-grouse (*Centrocercus urophasianus*; Oyler-McCance 1999, Braun et al. 2002, Lyon and Anderson 2003), passerines (Ingelfinger and Anderson 2004, Gilbert and Chalfoun 2011), small mammals (Brock and Kelt 2004), and reptiles (Munger et al. 2003, Shine et al. 2004). Many other factors (i.e., surface mining, wildfire, urbanization, pipeline and power line construction, and livestock management) also influence sagebrush landscapes but were not included in this analysis because they are not well mapped (e.g., power lines) or have minimal effect in our focal area (e.g., urban development).

We provide a historical perspective on WBEA area land cover change as a result of oil and natural gas development. We modeled changes to the Wyoming Basins landscape resulting from development using temporally-precise data on well construction paired with the most accurate available data on road location to retrospectively delineate road and well construction trends over the last 110 years. We then overlaid these reconstructions on 30-m resolution land cover data to evaluate changes to shrublands and other common native vegetation types. We evaluated changes at two spatial extents: the field extent, which estimated changes within defined oil and gas fields designated by the Wyoming Geological Survey (De Bruin 2002), and the subbasin extent, which assessed change in the broader landscape resulting from oil and gas development within the WBEA area (Fig 3.1).

METHODS

Source Data

Source data (Table 3.1) used for this assessment were the most complete, consistent data sets available. We used the 30-m resolution LANDFIRE existing vegetation type (EVT) data layer (LANDFIRE 2007) to evaluate potential impacts on native vegetation. To increase thematic accuracy of mapped land cover types, we reclassified 102 land cover types that occurred in our study area to 10 land cover classes (Appendix 1.1).

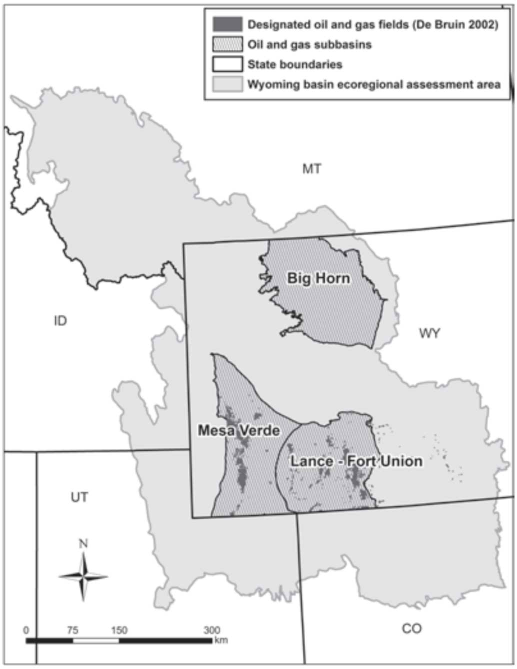

FIG. 3.1. Oil and natural gas fields and subbasins within the Wyoming portion of the Wyoming Basins Ecoregional Assessment (WBEA) area.

We restricted this analysis to the State of Wyoming (Fig. 3.1) because of the availability of consistent data on well construction and road location. Well location data was provided by the Wyoming Oil and Gas Conservation Commission (2009) and included the year that well construction was initiated for over 99% of records (n = 100,727). Road data, acquired from the U.S. Bureau of Land Management (BLM), was hand digitized from 2009 National Agriculture Imagery Program (NAIP) imagery at ~1:3000 screen resolution (U.S. Bureau of Land Management 2010) and contained over 500,000 road segments. Although BLM road data described 66% more roads than comparable data available from the U.S. Census TIGER data (M. O'Donnell, pers. comm.), evaluations made during our assessment indicated that BLM road data also underestimated amount of roads as much as 30%.

Table 3.1. Source data used to create time series (1900–2009) land cover data in the Wyoming portion of the Wyoming Basins Ecoregional Assessment. LANDFIRE refers to the LANDFIRE existing vegetation type dataset (LANDFIRE 2007).

Date	Source data	Representing
1900	LANDFIRE, PRIMARY ROADS	Wyoming landscape without oil and gas development
1959	LANDFIRE, Primary Roads, Wells 1900–1959, roads – 1959	Oil and gas development in Wyoming through 1959
1969	LANDFIRE, Primary Roads, Wells 1900–1969, roads – 1969	Oil and gas development in Wyoming through 1969
1979	LANDFIRE, Primary Roads, Wells 1900–1979, roads – 1979	Oil and gas development in Wyoming through 1979
1989	LANDFIRE, Primary Roads, Wells 1900–1989, roads – 1989	Oil and gas development in Wyoming through 1989
1999	LANDFIRE, Primary Roads, Wells 1900–1999, roads – 1999	Oil and gas development in Wyoming through 1999
2009	LANDFIRE, Primary Roads, Wells 1900–2009, roads – 2009	Oil and gas development in Wyoming through 2009

GIS Analyses

Well and road construction

The LANDFIRE map included a developed cover class that identified roads and wells along with human population centers although visual inspection indicated these were under represented. Moreover, the data was static (at the time of the source imagery) and therefore did not have the temporal information contained in our vector-based source data. We elected to convert narrow linear (road) and small polygonal (well pad) developed patches back to a pre-construction cover class using the ArcGrid SHRINK command with a three-pixel (90 m) width. SHRINK uses a nearest neighbor process to reclassify cells within the "shrink" area to the most common class present in the surrounding pixels. Using SHRINK at 90 m effectively converted small developed patches to the surrounding values while maintaining larger patches (e.g., populated areas, surface mines), albeit at a slightly smaller size.

We modified the BLM road layer data for use in the ArcGIS Network Analyst (ESRI 2002) environment. Network Analyst facilitated dynamic modeling of realistic network conditions but required that points on the network (i.e., wells) were spatially overlaid on the linear network (i.e., roads). The source data for roads did not always include short access roads (i.e., resource roads, in BLM terminology) leading to well pads. Therefore, we generated a line from each well coordinate to the closest point on the source road layer using a custom Python script (Appendix 3.1). We then merged the newly created resource road layer to the initial BLM road layer and used this as our derived road network for analysis. This technique partially corrected for the approximate 30% underestimate of actual roads from the BLM layer.

Our next step was an iterative process to simulate well and road construction on the Wyoming landscape in approximate 10-yr time steps from 1900-2009 (the first iteration simulated development prior to 1959) using the Network Analyst Closest Facility (ESRI 2002) function. Closest Facility models the best way to get from one location (incident) on the network to another location (facility) based on user-defined criteria (impedance). We used the Closest Facility function to identify the shortest distance (impedance) from a well (incident) along the road network to an existing road intersection (facility).

We assumed that all county-maintained roads were present on the landscape prior to 1900, although not likely of the same construction type. We defined these as primary roads and extracted them from the source roads layer. Primary road intersections (nodes) were defined as facilities for the first Network Analyst iteration. Closest Facility was then used to generate a layer of roads associated with oil and gas wells drilled from 1900-1959. The Closest Facility function first produced a line feature that represented the shortest distance from each well to a node along the source road layer. This line feature was then merged to the primary roads layer to produce an estimate of roads on the 1959 landscape. Working in 10-yr intervals, we identified facilities (road intersections on the most recent road layer) and incidents (wells constructed in each decade) to create a road layer for 1969, 1979, 1989, 1999, and 2009 that represented our model of temporal road construction on the landscape.

The primary road layer, all six modeled road layers, and six temporally-identified well layers (representing existing wells from 1900-1959, 1900-1969, …, and 1900-2009) then were converted to raster layers using the extent of the disturbance footprint of each feature type (primary roads: 60 m, modeled roads: 30 m, well pads: 90 m) based on literature review, NAIP image evaluation, and the source data resolution (M. O'Donnell, unpublished data; E. T. Rinkes, pers.comm.). These were then merged with the LANDFIRE data to estimate land cover condition at the close of each decade starting in 1959.

Landscape metrics

To understand how oil and gas resource development has influenced the Wyoming landscape, we evaluated our derived spatial data using FRAGSTATS (McGarigal and Marks 1998), a spatial analysis pattern program for categorical maps. FRAGSTATS quantifies the areal extent and spatial configuration of patches within a landscape producing an array of landscape metrics. We generated patch size, edge density, core area size (defined as ≥60 m [2 pixels] from patch edges), and patch shape metrics to provide insight on how landscape and native land cover communities have changed due to oil and gas development. Computer limitations prevented generation of 30-m landscape metrics for the entire WBEA area so we ran FRAGSTATS at three broad-scale subsets (Bighorn Basin Province, Lance-Fort Union Composite, and the Mesa Verde Total Petroleum System) of the subbasin extent (Fig. 3.1). Subbasin boundaries were defined by U.S. Geological Survey National Oil and Gas Assessment (U.S. Geological Survey 2002).

Spatial scales of analyses

We conducted our analyses at two spatial extents to highlight differences among intensely developed areas and the larger landscape of western Wyoming. The subbasin extent approximates the larger landscape of the WBEA area within the state of Wyoming whereas the field extent quantifies landscape change within defined oil and gas fields (De Bruin 2002). De Bruin's (2002) oil and natural gas fields were derived by plotting all producing wells from a formation in an area and then assigning a 0.2-km buffer zone from each producing well to outline a field boundary.

We present raw landscape change trend data for field and subbasin extents. We did not statistically test the results because the developed land cover data were known to be incomplete. We estimated the proportion of missing road data by hand digitizing extant roads on six 162-km^2 ortho-images (1-m ground resolution; U.S. Geological Survey 2005) and comparing road densities to the source road data (U.S. Bureau of Land Management 2010).

RESULTS

Field Extent

Shrubland comprised 79.6% of the land cover prior to development (circa 1900) in designated oil and gas fields along with minor components of exotic land cover (7.0%), Grassland (4.1%), and other cover types (Table 3.2). Historically, shrubland patches tended to be much larger ($\bar{x}$= 36.9 ha, SE = 6.6) than average (all cover types; $\bar{x}$= 2.9 ha, SE = 0.4), and shrubland contributed to over 98% of habitat edges. Therefore, we focused our assessment on changes in designated oil and gas fields to shrubland land cover. Since 1900, approximately 10,237 wells have been drilled in designated oil and gas fields. We estimated that before development only 0.3% (12 km^2) of fields contained roads. By 2009, approximately 8.3% (286 km^2) of the native land cover had been converted to road or well pad, of which 97% (278 km^2) can be associated with oil and gas development. Within the 3,436 km^2 area of designated fields, 205.8 km^2 of shrubland had been converted to a well pad or road between 1900-2009 accounting for a loss of 7.5% of shrubland cover types. All other land cover classes showed declines (0.8-11.1%) except for the developed class, but the summation of these changes amounted to only 1.8% of fields (Table 3.2).

Shrubland patch sizes were reduced by 45.0% from 1900 to 2009, and core areas declined by 55.6% (Fig. 3.2). Habitat edge increased by 33% overall including a 26% increase in shrubland edge density (Fig. 3.2). Edge density and patch shape for classes other than shrubland and developed were little changed though these minor changes contributed to overall changes in landscape configuration. As expected, the most abrupt changes were observed in shrubland and developed landscape metrics, which resulted in an overall increase in landscape complexity. Developed patch shape and core areas exhibited notably different trends than other classes due to their linear shape and recent infilling of the heavily developed fields that led to well pad/road footprints merging on the landscape (Table 3.2, Figs. 3.2, 3.3).

Subbasin Extent

The WBEA landscape in the State of Wyoming, as represented by the three subbasins, is predominantly shrubland (61.0%) and forest (19.1%) with smaller amounts of grassland (6.5%) and riparian (4.1%) land cover types (these estimates vary slightly from others in this book [Ch. 1] because of different analysis extents and reclassification methods, see Appendix 1.1). Since 1900, 33,767 wells were drilled in the Wyoming portion of the WBEA (10,237 inside fields designated by De Bruin [2002], 23,530 outside those fields [Wyoming Oil and Gas Conservation Commission 2009]), and approximately 111,000 km of roads were constructed to service those wells. Well pad and road construction since 1900 converted approximately 0.97% (1,703 km^2) of native land cover to the developed class. To provide context, approximately 5.2% of the Wyoming portion of the WBEA in the three subbasins can presently be classed as developed based on the best available road data (U.S. Bureau of Land Management 2010). Therefore, about 20% of native land cover conversion to developed class was related to oil and gas development. Shrubland (78%) was the most commonly converted land cover followed by exotic (6%; although exotics may not have occurred at time of road construction) and grassland (6%). Only 3% of conversions occurred in riparian and <1% in forest cover types.

Discrete land cover patches historically were relatively small (2.7–3.2 ha) in the three subbasins that we analyzed (Big Horn, Mesa Verde, and Lance-Fort Union, Fig. 3.4), with shrubland patches consistently being the largest (24.5–45.1 ha). Shrubland patches had relatively large core areas (14.0–30.1 ha, SE = 8.8) compared to other patch types (1.3–1.8 ha; SE

Table 3.2. Landscape indices within designated oil and gas fields (De Bruin 2002) in Wyoming within the Wyoming Basins Ecoregional Assessment area, 1900–2009. Land cover classes derived and reduced from LANDFIRE existing vegetation type data (LANDFIRE 2007; Appendix 1.1) and metrics generated using FRAGSTATS (McGarigal and Marks 1995).

Class	Year	Total area (ha)	Percent of area	Patch size (ha) $\bar{x}$(SE)	Edge density (m/m^2)	Patch shape (SE)	Core area (ha) $\bar{x}$(SE)
Agriculture	1900	6,432	1.9	3.8 (0.8)	3.6	1.3 (0.02)	1.8 (1.2)
	1959	6,343	1.8	3.7 (0.7)	3.7	1.3 (0.02)	1.7 (1.0)
	1969	6,283	1.8	3.6 (0.7)	3.7	1.3 (0.02)	1.6 (0.9)
	1979	6,258	1.8	3.5 (0.6)	3.8	1.3 (0.02)	1.6 (0.9)
	1989	6,206	1.8	3.5 (0.6)	3.8	1.3 (0.02)	1.5 (0.8)
	1999	6,100	1.8	3.3 (0.5)	3.8	1.3 (0.01)	1.4 (0.7)
	2009	6,049	1.8	3.3 (0.5)	3.8	1.3 (0.01)	1.4 (0.7)
Forest	1900	3,749	1.1	1.1 (0.6)	3.2	1.1 (0.01)	0.4 (1.8)
	1959	3,733	1.1	1.1 (0.6)	3.2	1.1 (0.01)	0.4 (1.8)
	1969	3,726	1.1	1.1 (0.6)	3.1	1.1 (0.01)	0.4 (1.8)
	1979	3,724	1.1	1.1 (0.6)	3.1	1.1 (0.01)	0.4 (1.8)
	1989	3,665	1.1	1.1 (0.4)	3.2	1.1 (0.01)	0.4 (1.2)
	1999	3,617	1.1	1.1 (0.4)	3.2	1.1 (0.01)	0.4 (1.0)
	2009	3,608	1.0	1.1 (0.4)	3.2	1.1 (0.01)	0.4 (1.0)
Sparse/barren	1900	9,071	2.6	0.5 (0.01)	17.7	1.2 (0.003)	0.02 (0.02)
	1959	8,930	2.6	0.5 (0.01)	17.5	1.2 (0.003)	0.02 (0.02)
	1969	8,856	2.6	0.5 (0.01)	17.4	1.2 (0.003)	0.02 (0.02)
	1979	8,786	2.6	0.5 (0.01)	17.3	1.2 (0.003)	0.02 (0.02)
	1989	8,631	2.5	0.5 (0.01)	17.0	1.2 (0.003)	0.02 (0.02)
	1999	8,323	2.4	0.4 (0.01)	16.4	1.2 (0.003)	0.02 (0.02)
	2009	8,089	2.4	0.4 (0.01)	16.0	1.2 (0.003)	0.02 (0.02)
Shrubland	1900	273,555	79.6	36.9 (6.6)	76.5	1.4 (0.02)	22.4 (4.5)
	1959	270,517	78.7	32.7 (4.0)	71.5	1.5 (0.02)	19.2 (2.6)
	1969	268,834	78.2	31.1 (3.5)	78.7	1.5 (0.02)	18.0 (2.3)
	1979	267,220	77.8	29.6 (2.9)	80.8	1.5 (0.01)	16.8 (1.9)
	1989	264,594	77.0	27.2 (2.3)	83.9	1.5 (0.01)	15.1 (1.5)
	1999	259,143	75.4	23.6 (1.7)	90.1	1.5 (0.01)	12.4 (1.1)
	2009	252,969	73.6	20.3 (1.3)	96.4	1.6 (0.01)	10.0 (0.8)
Exotic	1900	24,905	7.2	0.8 (0.1)	36.3	1.2 (.003)	0.08 (0.1)
	1959	24,494	7.1	0.8 (0.1)	36.0	1.2 (0.003)	0.08 (0.1)
	1969	24,328	7.1	0.8 (0.1)	35.8	1.2 (0.003)	0.08 (0.1)
	1979	24,093	7.0	0.8 (0.1)	35.7	1.2 (0.003)	0.08 (0.1)
	1989	23,676	6.9	0.8 (0.1)	35.4	1.2 (0.003)	0.07 (0.1)

TABLE 3.2. Continued

Class	Year	Total area (ha)	Percent of area	Patch size (ha) $\bar{x}$(SE)	Edge density (m/m^2)	Patch shape (SE)	Core area (ha) $\bar{x}$(SE)
	1999	22,933	6.7	0.8 (0.1)	34.5	1.2 (0.003)	0.07 (0.1)
	2009	22,140	6.4	0.7 (0.1)	33.9	1.2 (0.003)	0.06 (0.1)
Riparian	1900	10,101	2.9	1.2 (0.1)	12.8	1.3 (0.007)	0.2 (0.1)
	1959	10,012	2.9	1.2 (0.1)	12.8	1.3 (0.007)	0.1 (0.1)
	1969	9,961	2.9	1.2 (0.1)	12.8	1.3 (0.007)	0.1 (0.1)
	1979	9,924	2.9	1.2 (0.1)	12.7	1.3 (0.007)	0.1 (0.1)
	1989	9,859	2.9	1.2 (0.1)	12.7	1.3 (0.006)	0.1 (0.1)
	1999	9,767	2.8	1.2 (0.1)	12.7	1.3 (0.006)	0.1 (0.1)
	2009	9,649	2.8	1.1 (0.1)	12.6	1.3 (0.006)	0.1 (0.1)
Grassland	1900	14,175	4.1	0.3 (0.06)	35.3	1.1 (0.002)	0.002 (0.005)
	1959	14,069	4.1	0.3 (0.06)	35.0	1.1 (0.002)	0.002 (0.005)
	1969	14,011	4.1	0.3 (0.06)	34.9	1.1 (0.002)	0.002 (0.005)
	1979	13,909	4.0	0.3 (0.06)	34.7	1.1 (0.002)	0.002 (0.005)
	1989	13,731	4.0	0.3 (0.06)	34.3	1.1 (0.002)	0.002 (0.005)
	1999	13,332	3.9	0.3 (0.05)	33.4	1.1 (0.002)	0.002 (0.004)
	2009	12,912	3.8	0.3 (0.05)	32.6	1.1 (0.002)	0.002 (0.004)
Woodland	1900	230	0.1	0.2 (0.03)	0.6	1.1 (0.009)	0.0005 (0.008)
	1959	227	0.1	0.2 (0.02)	0.6	1.1 (0.009)	0.0005 (0.008)
	1969	224	0.1	0.2 (0.02)	0.6	1.1 (0.009)	0.0005 (0.008)
	1979	224	0.1	0.2 (0.02)	0.6	1.1 (0.009)	0.0005 (0.008)
	1989	222	0.1	0.2 (0.02)	0.6	1.1 (0.009)	0.0005 (0.008)
	1999	219	0.1	0.2 (0.02)	0.6	1.1 (0.009)	0.0005 (0.008)
	2009	218	0.1	0.2 (0.02)	0.6	1.1 (0.009)	0.0005 (0.008)
Wetland/water	1900	252	0.1	0.3 (0.04)	0.6	1.1 (0.01)	0.008 (0.16)
	1959	252	0.1	0.3 (0.04)	0.6	1.1 (0.01)	0.008 (0.16)
	1969	252	0.1	0.3 (0.04)	0.6	1.1 (0.01)	0.008 (0.16)
	1979	252	0.1	0.3 (0.04)	0.6	1.1 (0.01)	0.008 (0.16)
	1989	251	0.1	0.3 (0.04)	0.6	1.1 (0.01)	0.008 (0.16)
	1999	251	0.1	0.3 (0.04)	0.6	1.1 (0.01)	0.008 (0.16)
	2009	250	0.1	0.3 (0.04)	0.6	1.1 (0.01)	0.008 (0.16)
Developed	1900	1,197	0.3	17.9 (4.4)	1.1	3.0 (0.25)	0.0 (0.0)
	1959	5,092	1.5	13.6 (2.7)	9.0	3.9 (0.19)	0.04 (0.01)
	1969	7,194	2.1	15.2 (3.2)	12.5	4.2 (0.19)	0.02 (0.02)
	1979	9,278	2.7	16.4 (3.0)	16.1	4.4 (0.18)	0.01 (0.03)
	1989	12,833	3.7	17.3 (2.9)	22.0	4.3 (0.17)	0.01 (0.06)

TABLE 3.2. Continued

Class	Year	Total area (ha)	Percent of area	Patch size (ha) $\bar{x}$(SE)	Edge density (m/m^2)	Patch shape (SE)	Core area (ha) $\bar{x}$(SE)
	1999	19,983	5.8	17.8 (2.8)	33.0	4.2 (0.14)	0.01 (0.17)
	2009	27,783	8.1	19.9 (3.1)	43.9	3.8 (0.13)	0.06 (0.10)
All	1900	343,669	100.0	2.9 (0.4)	91.4	1.2 (0.002)	1.5 (0.9)
	1959	343,669	100.0	2.9 (0.3)	97.4	1.2 (0.002)	1.4 (0.6)
	1969	343,669	100.0	2.9 (0.3)	100.1	1.2 (0.002)	1.4 (0.5)
	1979	343,669	100.0	2.8 (0.2)	102.7	1.2 (0.002)	1.3 (0.4)
	1989	343,669	100.0	2.8 (0.2)	106.7	1.2 (0.002)	1.3 (0.4)
	1999	343,669	100.0	2.8 (0.2)	114.1	1.2 (0.002)	1.2 (0.3)
	2009	343,669	100.0	2.8 (0.1)	121.7	1.2 (0.002)	1.1 (0.2)

= 0.3). A large proportion (75.6–82.0%) of the total edge had shrubland as one component. At these broad extents, landscape changes due to oil and gas development are relatively subtle. Shrubland patch size declined by 9.6–10.4%, whereas mean patch size of all land cover types declined by <1%. The mean size of shrubland core areas (≥60 m from edge) were reduced by 13.0–13.6%. Edge densities increased slightly (7.5–8.2%), and patch shape tended to become more irregular but only slightly so (Fig. 3.4).

DISCUSSION

Effects of Development on Land Cover Change

We used a retrospective analysis to estimate historical landscape condition in designated oil and gas fields and three subbasins within Wyoming portion of the WBEA area to provide a spatiotemporal perspective on land cover changes due to oil and natural gas development. Our objective was to assess how landscapes have changed during oil and gas development but recognize that other natural and cultural factors also have influenced land cover condition and change over the last century. Our results suggest that oil and natural gas extraction is driving important landscape change including loss and fragmentation of shrubland land cover. We estimated that at least 1,703 km^2 of native land cover in Wyoming portion of WBEA area has been converted to well pad or road over the last 110 years. Landscape change due to oil and gas development has been most acute within designated oil and gas fields. Whereas these alterations amount to only about 1% of the three subbasins assessed, conversion represents a much greater portion (7.8%) of the landscape in the more heavily developed designated oil and gas fields.

Beyond direct loss of native vegetation, shrubland patch size in the heavily developed fields has declined by 45% since 1900, suggesting that historically intact landscapes are being divided into smaller parcels. Shrubland land cover types were the most intensely fragmented by oil and gas development; other land cover types were not as affected. Shrublands, especially sagebrush, are of particular conservation concern because areas currently under development contain some of the highest densities of greater sage-grouse (Connelly et al. 2004, Kiesecker et al. 2009, Doherty et al. 2011, Naugle et al. 2011) and other sagebrush-obligate species (Knick et al. 2003, Wisdom et al. 2005) in western North America. Fragmentation (defined

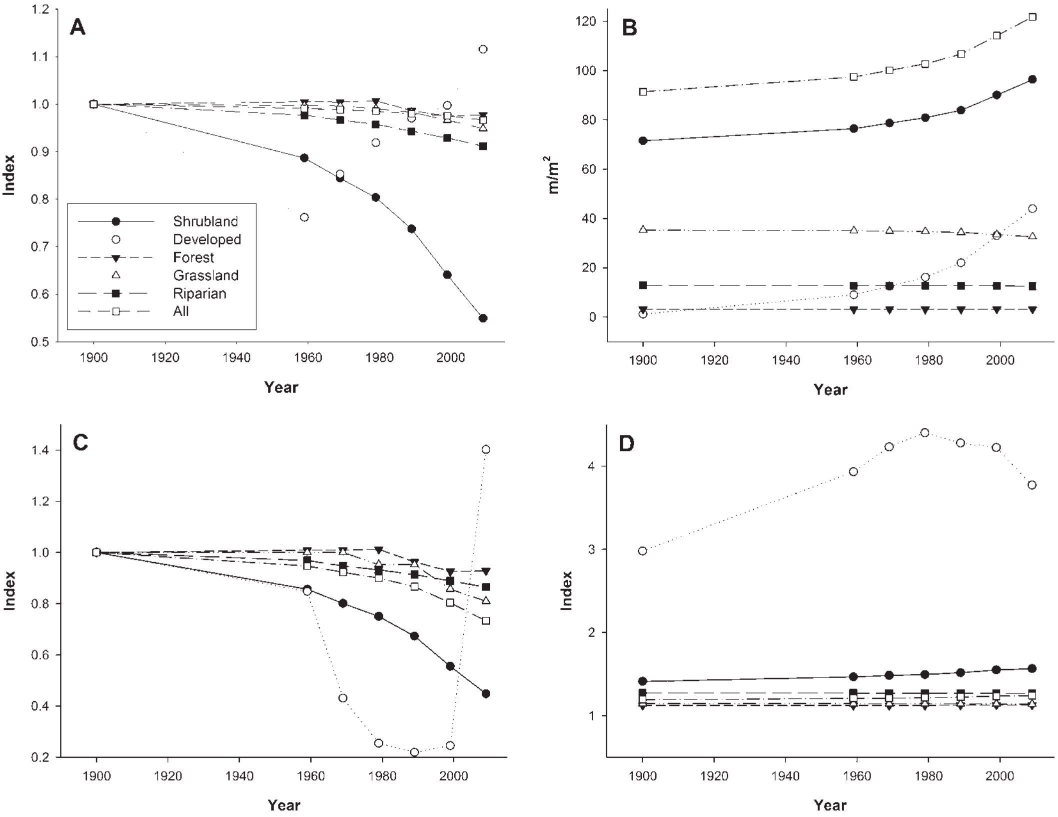

FIG. 3.2. (A) patch size (ha), (B) edge density (m/m^2), (C) core area size (ha), and (D) patch shape index of select land cover classes in oil and gas fields (De Bruin 2002) in the Wyoming portion of the Wyoming Basins Ecoregional Assessment area, 1900–2009. Years indicate all landscape change from energy development prior to and including year noted. Patch size and core area are graphed as departures from year 1900, set at 1.0.

as the loss of a natural habitat and division of remaining habitats into isolated patches [Wilcove et al. 1986]) of sagebrush may adversely influence native vegetation communities by altering microclimate factors such as light, soil, temperature, moisture, and wind conditions along patch edges potentially leading to altered plant composition and diversity (Saunders et al. 1991, Miller et al 2011). Shifts in composition and configuration of plant communities may be most detrimental to rare or sensitive species such as the 25 sensitive plant species present within the Jonah Field (U.S. Bureau of Land Management 2006). The BLM has established management criteria and mitigation plans for these species but acknowledged that "habitat loss (direct and indirect) would occur due to construction, and human presence would further reduce habitat quality in some of the remaining undisturbed or minimally disturbed areas. This would result in decreased populations of some…species," (U.S. Bureau of Land Management 2006:v. 4, p. 77).

Fragmentation can also alter the frequency and extent of fire, affect dispersal and regeneration of native plants, facilitate invasion by non-native plants (Bergquist et al. 2007), and strongly influence the spread of other disturbances (Daszak et al. 2000, Turner et al. 2001). Habitat loss and fragmentation due to human activities may be the most important factor contributing to the decline and

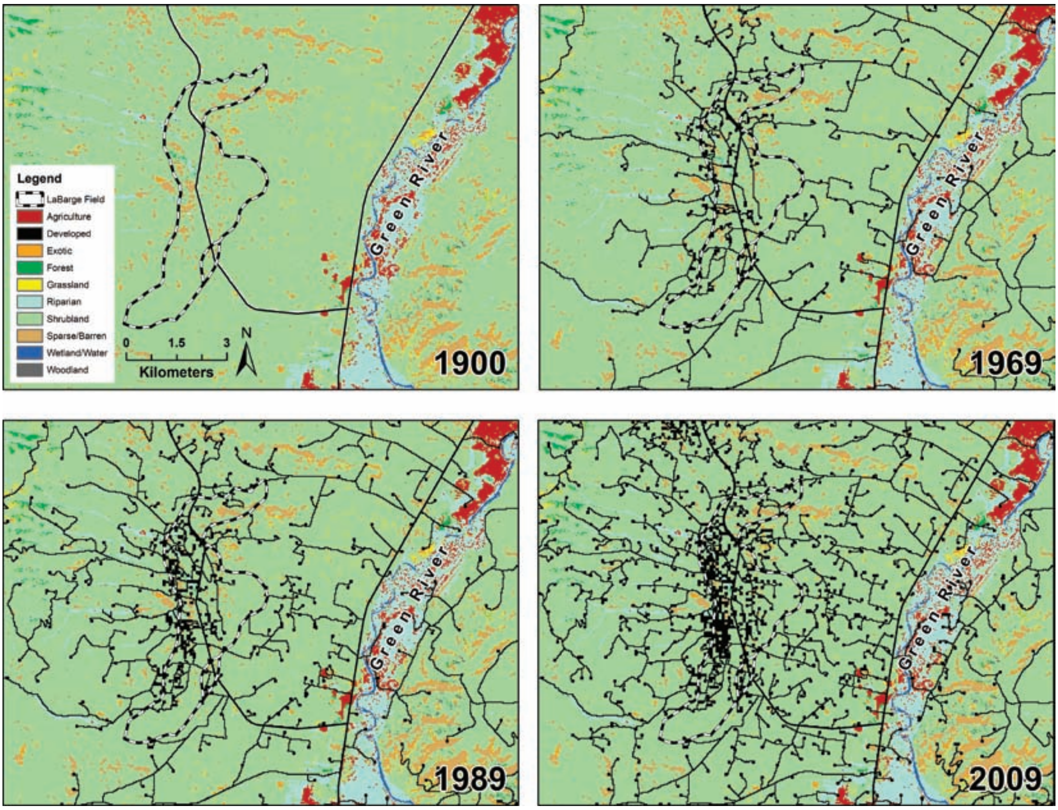

FIG. 3.3. Successive views of the LaBarge Oil Field area of southwest Wyoming, 1900–2009. Map center is approximately 110.24W, 42.30N. Years indicate all landscape change from energy development prior to and including year noted.

loss of native fauna in shrublands (Braun et al. 1976, Noss and Csuti 1994, Knick et al. 2003). Habitat fragmentation can have negative consequences for songbirds (Vander Haegen et al. 2000, Tewksbury et al. 2002, Inglefinger and Anderson 2004), greater sage-grouse (Holloran and Anderson 2005, Walker et al. 2007a, Doherty et al. 2008), pronghorn (*Antilocapra americana*; Berger 2004), and small mammals (Diffendorfer et al. 1995). However, landscape-scale effects, especially the consequences of fragmentation, have not historically been included in management assessments. Project-focused Environmental Assessments (e.g., U.S. Bureau of Land Management 2000, 2003) would benefit from this broader spatial perspective (Wisdom et al. 2005; Ch. 5–10).

Energy and associated road development also may impact wildlife directly through collisions with vehicles (Forman et al. 2003), mortality during construction, and human activity and noise disturbance that initiate behavioral modifications (e.g., Holloran and Anderson 2005, Sawyer et al. 2006). Collectively the amount of direct disturbance may encompass <8% of the landscape at the field extent. However, avoidance and stress by wildlife can extend the influence of each well pad, road, and facility into surrounding habitats (Walston et al. 2009) resulting in functional habitat loss (Aldridge and Boyce 2007). Zones of negative response can extend up to 3.7 km for ungulates (Sawyer et al. 2006). Sage-grouse hens captured on leks <3.2 km from energy development (well pad or road)

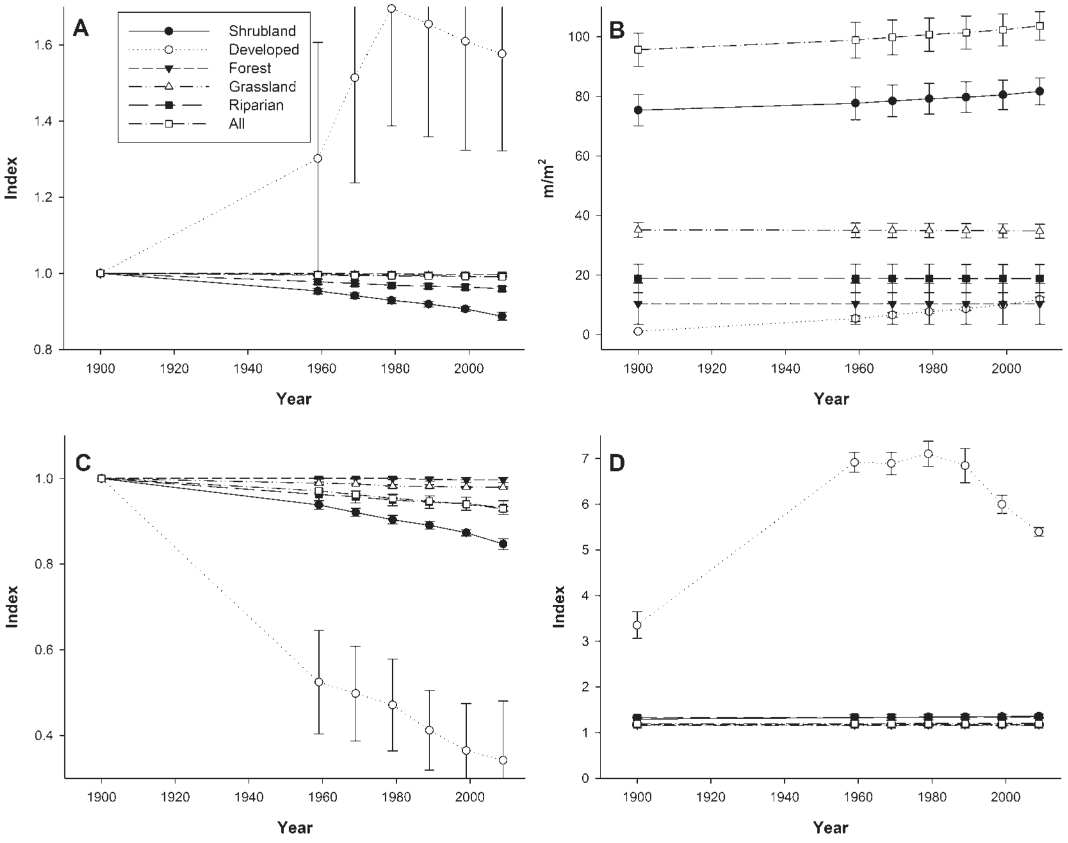

FIG. 3.4. Mean (error bars = SE) (A) patch size (ha), (B) edge density (m/m^2), (C) core area size (ha), and (D) patch shape index in three subbasins (Bighorn Basin Province, Lance-Fort Union Composite, and the Mesa Verde Total Petroleum System) of the Wyoming Basins Ecoregional Assessment area, 1900–2009. Years indicate all landscape change from energy development prior to and including year noted. Patch size and core area are graphed as departures from year 1900, set at 1.0.

had lower nest-initiation rates and moved longer distance to nest sites than females on leks >3.2 km from any development (Lyon and Anderson 2003). Even low levels of oil and gas development and widely-spaced wells can negatively influence wintering distributions of greater sage-grouse (Walker et al. 2007a, Doherty et al. 2008) and lek persistence (Copeland et al. 2009). These examples suggest that avoidance or stress effects further compromise the value of remnant patches because wildlife may not use those patches effectively.

Additional questions about how oil and gas development influences ecosystem function, soil erosion, and water quality in western Wyoming remain unanswered. Data from the Powder River Basin and other areas undergoing energy development indicate that oil and gas extraction can introduce air pollutants and reduce water quality into formerly low-disturbance environments (Regele and Stark 2000, Bryner 2003, Peterson et al. 2009, Farag et al. 2010). Shifts in ecosystem functioning also may influence patterns and rates of land cover change in a negative feedback loop. Impacts to soils from removal of vegetation include exposure of the soil to wind and water erosion, mixing of soil horizons, loss of topsoil productivity, and soil compaction. Loss of vegetation and exposure of the soils could result in a loss of organic matter in the soil, increased runoff, erosion, and sedimentation (Furniss et al. 1991, McCaffery et al. 2007). These impacts might lead to a further reduction of native land cover thereby increasing landscape fragmentation and its effects on ecosystem function. For example, significant impacts to soils are anticipated under all project alternatives assessed for development in the Jonah oil fields in southwestern Wyoming (U.S. Bureau of Land Management 2006).

Introduction of groundwater to the surface, especially during CBM production may also influence ecosystem function. Discharge water is used for crop and livestock production, injected back into the ground, released into stream channels, or impounded on the surface in temporary reservoirs (Bryner 2003). Increased surface water associated with CBM production provides ideal habitat for mosquitos resulting in increased risk and mortality from West Nile virus in greater sage-grouse (Naugle et al. 2004; Zou et al. 2006, 2007; Walker et al. 2007b). Surface water impoundments are typically small (≤1 ha; T. Rinkes, pers. comm.) although there may be several ponds associated with a single CBM well. Impacts on the landscape from these ponds outlast the short lifespan of the surface water because residual salts or metals may compromise soil function after evaporation, and clay soils may become hardpan resulting in a permanent land cover shift in and around an impoundment. Not all wells have water impoundments but very few ponds created by natural gas extraction are mapped in Wyoming. Therefore, their contribution to the loss and fragmentation of terrestrial habitats is unknown and could not be measured with our analysis of land-cover change in relation to oil and gas development.

Caveats

Our retrospective analysis of WBEA land cover change resulting from oil and gas development is incomplete because data describing several change sources were not available. The source road layer we used is on the order of 60% more accurate than any previously available data set. However, our sampled assessment suggests it still underestimates roads related to development of oil and gas wells by as much as 31%. We estimated that 3,725 km (3.5% of initial source roads) of resource roads were not accurately represented in the initial source road layer based on the length of resource roads necessary to connect well locations to the nearest road. Additional evaluations within six 162-km^2 digital ortho-quarter quadrangles suggested the source road data underrepresented actual on-the-ground roads by 18–28%. Road construction occurs quickly during oil and gas development (Bryner 2003). Weller et al. (2002) estimated road density of 5.3 km/km^2 in the 430 km^2 Big Piney-LaBarge natural gas fields by carefully digitized roads from imagery. However, the road data we used (combined source roads and estimated resource roads) only had a road density of 3.1 km/km^2 in the same fields.

Power lines, pipelines, and other linear features that potentially fragment native land cover are not well-mapped and difficult to quantify. Many of these linear features are adjacent to roads and, therefore, some unknown portion is accounted for in the road layer, but cumulative effects of multiple disturbances should be further quantified.

Point infrastructure features such as gas compressors, pumping stations, storage tanks, retention ponds, and parking areas are also not well mapped. Consequently, their footprint is not represented in this analysis even though collectively they may represent more than 70% of the total surface disturbance of a fully operational CBM field (U.S. Bureau of Land Management 2003).

We did not quantify vegetation restoration efforts at dry wells or reclaimed well pads and roads. Restoration of disturbed areas at oil and gas development sites has been legally required since at least 1984 (U.S. Bureau of Land Management and U.S. Forest Service 1984). Typically, revegetation is applied to a reclaimed site within one growing season following well pad or road decommission. Monitoring follows within 1-2 years post effort and may continue for up to eight years. Criteria defining success and monitoring evaluations are typically qualitative (i.e., seedling production observed). Sites not meeting defined standards are often re-treated. Some portion of the native land cover that we classified as developed has been revegetated and would more correctly be assigned to a different class (i.e., exotic or shrubland). This may account for a portion of the missing resource roads in the original resource road layer developed from 2009 NAIP imagery. However, consistent monitoring data describing site reclamation in the Wyoming Basins are not available (D. Stroud, pers. comm.); therefore we cannot quantify that source of land-cover change.

Potential Uses of Data

Development of expansive oil and natural gas deposits that underlie crucial wildlife habitat constitutes one of the greatest contemporary challenges to the conservation of western wildlife (Wyoming Game and Fish Department 2005). Therefore, we assembled the spatial data presented here to provide a historic perspective of landscape changes and the opportunity to apply the data to retrospective analyses of wildlife population trends, modeling of future scenarios, and current and future land-use planning, mitigation, and natural resource management.

Future Development

Temporal trends in land cover change have accelerated in the last two decades, especially within designated oil and gas fields even though several fields had not yet been fully developed at the time of our 2009 analysis (Knick et al. 2011). Our assessment included only 1,195 wells in the Jonah Field, whereas 3,100 wells are expected to be drilled over the next decade (U.S. Bureau of Land Management 2006). The volume of natural gas in the Wyoming portion of the WBEA was estimated at 85 million cubic meters (Ayers 2002). Additionally, over 317 million cubic meters of oil remain to be recovered in the area *circa* 2002 (Energy Policy and Conservation Act 2002). Therefore, we expect more development and consequent landscape fragmentation throughout the WBEA.

Growth in U.S. energy demand is estimated at 0.5–1.3% annually (National Petroleum Council 2007), and demand for natural gas alone is expected to increase by 25% over the next 15 years (U.S. Department of Energy 2007). Therefore, it seems likely that the land-cover conversion rates we documented at the designated oil and gas field extent will become more commonplace across the larger WBEA. Presidential Executive Order 13212 (Bush 2001) expedited the review and approval of oil and gas development proposals in the western United States, indicating a continuing trend of energy development and subsequent conversion and fragmentation of native habitat in Wyoming. Similar developments are occurring in surrounding areas of Utah, Colorado, and Montana (Doherty et al. 2011), suggesting that the fragmentation we describe is also a potential consideration at a broader spatial extent.

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APPENDIX 3.1

Python script language to generate a new line dataset linking point locations to the closest node in line vector data set in ArcGIS 9.3. This process was used to create the resource road layer, linking oil and gas wells in Wyoming to the BLM road data (U.S. Bureau of Land Management 2010) for use in an analysis of landscape change due to oil and gas development in the Wyoming Basins Ecoregional Assessment area. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

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Chapter 4: A Sampling and Analytical Approach to Develop Spatial Distribution Models for Sagebrush-Associated Species

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Abstract. Understanding multi-scale floral and faunal responses to human land use is crucial for informing natural resource management and conservation planning. However, our knowledge on how land use influences sagebrush (*Artemisia* spp.) ecosystems is limited primarily to site-specific studies. To fill this void, studies across large regions are needed that address how species are distributed relative to type, extent, and intensity of land use. We present a study design for the Wyoming Basin Ecoregional Assessment (WBEA) to sample sagebrush-associated flora and fauna along a land cover-human land use gradient. To minimize field costs, we sampled various taxonomic groups simultaneously on transects (ungulates and lagomorphs), point counts (song birds), and area-searches of 7.29-ha survey blocks (pellet counts, burrow counts, reptile surveys, medium-sized mammals, ant mounds, rodent trapping, and vegetation sampling of native and exotic plants). We then present an exploratory approach to develop species occurrence and abundance models when *a priori* model building is not an option. Our study design has broad applications for large-scale evaluations of arid ecosystems.

Key words: anthropogenic disturbance, data collection, ecoregional assessment, habitat, hierarchical multi-stage modeling, land use, model evaluation, species distribution model.

Ecoregional assessments have become common tools for researchers to evaluate ecosystem health across large extents (Freilich et al. 2001, Groves et al. 2000, The Nature Conservancy 2000, McMahon et al. 2001, Neely et al. 2001, Noss et al. 2001, Weller et al. 2002, Wisdom et al. 2005). The recognized value of such assessments in addressing the functioning of entire ecosystems has resulted in multiple agency initiatives to conduct landscape-scale assessments, such as the recently developed U.S. Bureau of Land Management Rapid Ecoregional Assessments and U.S. Fish and Wildlife Service Landscape Conservation Cooperatives. Crucial management actions will rest on the guidance provided by ecoregional assessments. However, most input parameters and understanding of habitat or species responses used to develop previous assessments stem from data collected from different spatial and temporal locations or scales and frequently from ecosystems not represented within the assessment region. Responses of species to anthropogenic disturbances and the underlying mechanisms or processes may be applicable across different ecosystems, but the generality of these responses should be evaluated (Lobo et al. 2008). In addition, evaluations are rarely conducted to assess model fit (Freilich et al. 2001) resulting in large uncertainty in the confidence of assessment results and subsequent management recommendations.

We present methods for developing spatial models driven by empirical data allowing for inferences to be made based on relationships directly assessed between species of interest, land cover composition and configuration, abiotic factors, and potential anthropogenic drivers. Complete faunal and floral inventories are logistically difficult and prohibitively costly (for

TABLE 4.1. Distances used to delineate effect zones surrounding anthropogenic features to define the ecological human footprint gradient for the Wyoming Basins Ecoregional Assessment.

Anthropogenic feature	Range of reported empirical distances[a]	Effect zone distance (m)
Agricultural land	≈260 m surrounding pivot fields	135
Communication towers, including associated infrastructure[b]	≈113 m (10 acres, assuming circular shape)	90
Human impact zone	≈610 m	405
Interstate highways	365-1,200 m	855
Irrigation channels	No empirical support	0
Oil/gas wells abandoned/inactive[b]	0.5-1 ha for well pad 0.7 ha/km for roads	90[c]
Oil/gas wells active, including associated infrastructure[b]	0.5-2 ha for well pad 0.7-2.2 ha/km for roads 3.2 km: Distance avoided by greater sage-grouse	225[d]
Power lines	300-4,000 m	135
Railroads	0-500 m	135
Secondary roads	100–600 m	135
State/federal highways	100–600 m	405

[a] See Appendix 4.1 for detailed information on effect zone delineation.

[b] Because we only had point locations for these anthropogenic features, we included surface disturbance associated with infrastructure such as roads, condensation tanks (oil and gas wells only), and power lines.

[c] 90 m: 4 cells surrounding center cell (5-cell pattern), area = 4.05 ha.

[d] 225 m: 20 cells surrounding center cell (21-cell pattern), area = 17.01 ha.

discussion see Mac Nally and Fleishman 2004). We therefore developed a sampling design that incorporated data collection across various taxonomic groups, including birds, mammals, reptiles and plants, while minimizing overall sampling costs and ensuring that modeled relationships would be applicable to the entire ecoregion.

We describe the design and analytical approaches developed for the Wyoming Basin Ecoregional Assessment (WBEA) that combined traditional field methods integrated within a Geographical Information System (GIS). We also present an exploratory approach to develop species occurrence and abundance models when *a priori* model building is not an option, and illustrate how these models can be predicted spatially for management purposes and evaluated for their strengths and weaknesses. Finally, we discuss implications and limitations of our sampling design, providing insights for future ecoregional assessments.

FIELD SAMPLING METHODS

Defining the Sampling Space

A challenge in land management is to identify thresholds at which land-use patterns influence the distribution of flora and fauna. This challenge exists because species occurrence and abundance models are often based either on land cover or human land-use gradients but rarely incorporate both (but see e.g., Sawyer et al. 2005, Aldridge and Boyce 2007, Walker et al. 2007, Doherty et al. 2008, Avila-Flores et al. 2010). To account for potential synergistic species responses to anthropogenic as well as land cover-based drivers, we developed a stratified sampling design across the WBEA according to two gradients: (1) land use, based on a human footprint analysis and (2) land cover, based on Normalized Difference Vegetation Index (NDVI).

Land use: ecological human footprint

We used 11 anthropogenic features to delineate land use across the WBEA (Table 4.1). We selected these anthropogenic features because they influence species distribution, demography, or both, for one or more species of interest (Appendix 4.1, Leu et al. 2008, Leu and Hanser 2011). We delineated land use based on the ecological human footprint (Leu et al. 2008) represented by a cumulative map of land-use intensity and influence on ecological processes.

We derived the ecological human footprint based on three point features (communication towers, oil/gas wells abandoned/inactive, and oil/gas wells active), six linear features (interstate highways, irrigation channels, power lines, railroads, secondary roads, and state/federal highway), and two polygonal features (agricultural land and human impact zone [industrial areas, urban, exurban, and rural]). For each anthropogenic feature, we delineated its effect zone (the extent at which an anthropogenic feature influences ecological processes) based on a comprehensive literature review to understand the extent of anthropogenic impacts on wildlife and their habitats (Appendix 4.1). We took a conservative approach in delineating effect zones by employing the reported effect distances or areas (Table 4.1) adjusted to fit multiples of the 90-m resolution of our spatial data.

We delineated effect zones for each of 11 anthropogenic features in ArcMap 9.2 (ESRI 2006) by first creating proximity grids for each feature (Euclidian distance). We then used these proximity grids to derive effect zones surrounding anthropogenic features based on distances summarized from existing literature (Table 4.1). The resulting map consisted of a binary surface where cells within the effect zone received a value of one, and all other cells were coded as zero. For oil and gas wells, we used two approaches to model effect zones: (1) for abandoned/inactive wells, we used a distance of 90 m from the pixel containing the point location, which resulted in the selection of the four adjacent pixels in the cardinal directions (area = 4.05 ha); and (2) for active wells, we used a distance of 135 m from center point of pixel, which resulted in the selection of eight pixels surrounding the center pixel (area = 7.29 ha). This captured the larger disturbance associated with active wells. Once the effect zones were delineated, we merged the 11 individual anthropogenic layers (maximum cell value = 11) and reclassified this layer to a binary layer with cell values zero or one. We did not incorporate cumulative anthropogenic effects because empirical data to weight individual anthropogenic features were not available. Rather, we focused on whether an area overlapped with the effect zone of at least one anthropogenic feature.

We then put the ecological human footprint in the context of sagebrush (*Artemisia* spp.)-associated vertebrate responses. First, we calculated the relative extent of the ecological human footprint, using moving window analyses (circular shape) on the binary ecological human footprint. Sizes of moving windows were based on seven "model" home ranges that captured published results for 38 of the 40 vertebrate species of concern (Appendix 4.2). We could not find any empirical data on home range size for the Great Basin spadefoot toad (*Scaphiopus intermontanus*) and omitted home range estimates for the spotted bat (*Euderma maculatum*), given the enormous estimated foraging distances of this species (Rabe et al. 1998). Spatial extents used included: 0.8 ha (raw data, no moving window analysis), 2.5 ha (1-cell radius window extent), 41 ha

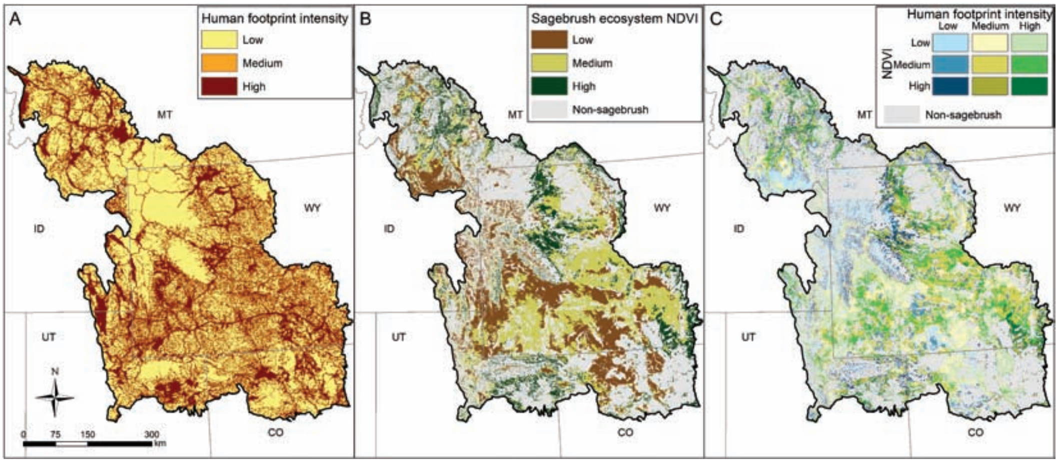

FIG. 4.1. Spatial representation of (A) human footprint intensity, (B) sagebrush ecosystem productivity (NDVI), and (C) sampling matrix (combined human footprint and NDVI gradients) across the Wyoming Basin Ecoregional Assessment area. Human footprint intensity and NDVI were used to stratify sampling locations.

(4-cell radius), 125 ha (7-cell radius), 430 ha (13-cell radius), 2,771 ha (33-cell radius), and 6,361 ha (50-cell radius). Last, we averaged the seven layers to create an ecological human footprint within the average home range of sagebrush-associated vertebrates (Fig. 4.1A).

Sagebrush ecosystem productivity

The primary land-cover map available for this region in 2004, the "Sagestitch Map" (Comer et al. 2002), did not distinguish sagebrush taxa at the subspecies (variety) level; therefore productivity of sagebrush ecosystems (mesic versus xeric sagebrush ecosystems) could not be differentiated. As a result, we defined sagebrush ecosystem productivity using the Normalized Difference Vegetation Index (NDVI) derived from MODIS (Moderate Resolution Imaging Spectroradiometer, Carroll et al. 2006) classifications from May to August of 2004. We clipped the NDVI layer to the extent of the combined shrub-grassland land cover identified in the "Sagestitch Map" (Comer et al. 2002) (Fig. 4.1B).

Sampling design spatial data set

We allocated equal sampling effort across gradients of the ecological human footprint and NDVI by using a 3 x 3 matrix. We reclassified the mean ecological human footprint value within a 33-cell radius according to three ordinal categories containing equal areas ranging from low (0–0.20), moderate (>0.20–0.38), to high (>0.38–1). The 33-cell radius dataset was used to facilitate placement of sample locations by generalizing the ecological human footprint over a broader area than the surface created from the average home range size. Similarly, we reclassified the NDVI layer into three ordinal categories of equal area ranging from low (-1–0.37), moderate (>0.37–0.53), to high (>0.53–1). We combined the reclassified gradients spatially to produce a spatial data set consisting of nine sampling strata (Fig. 4.1C).

Sampling Location Selection

We used a hierarchical-spatial sampling design to survey flora and fauna across the WBEA area (Ch. 2) during spring/summer of 2005 and 2006. We restricted our surveys to WBEA areas consisting of shrub-grassland land cover within Wyoming and Colorado, given the focus of the assessment on the sagebrush ecosystem. To increase sampling efficiency, we first randomly placed 49 non-overlapping circles of 30-km radius throughout the WBEA within Wyoming in 2005 (29 circles), and Wyoming and Colorado in 2006 (20 circles). We selected center locations of circles using the RANDOM POINT GENERATOR in ARCVIEW (Version 1.1, Utah State University). We populated the area within each 30-km circle overlapping the combined gradients of the ecological human footprint and shrub-grassland land cover productivity (i.e., area covered by nine sampling stratum of the 3 x 3 matrix) with as many random points (1-km apart) we could fit. We restricted potential random points within each circle to areas with <25% slope, based on 90-m Digital Elevation Models (DEM; National Elevation Dataset, USGS EROS, http://seamless.usgs.gov/), such that observers were able to walk to random points while collecting data. These random points represented the center of two types of points in relation to roads (Fig. 4.1): near-road = 0-750 m from road, and far-road = >750-3,000 m from road. We then selected a third set of on-road points using COSTPATH in ARCINFO (ESRI 2006) (Fig. 4.1). These on-road points were located at the road end of the least-cost path in terms of pixel-based elevation change (using DEM) between the far-road points and the road network.

We then selected a preliminary set of points from this pool to ensure equal replication within each of nine sampling stratum; consequently, not all 30-km circles contained the same number of points because the area covered by each of nine sampling stratum varied among 30-km circles. In the field, we first attempted to sample the original set of points. However, this was not always possible due to access issues (mainly private land). In such cases, we selected the next nearest point within the same disturbance-productivity class. We were unable to get access to replacement points in some 30-km circles, resulting in slightly unbalanced sampling across strata and in relation to roads (n = 330; 162 in 2005 and 168 in 2006; on-road n = 104, near-road n = 125, far-road = 101). Nearest neighbor distance among all points averaged 2.36 km (SD ± 2.27 km, range = 0.69–19.6 km), among far-road points averaged 4.98 km (SD ± 3.15 km, range = 1.20–19.6 km), and among on-road and near-road points averaged 4.82 km (SD ± 3.07 km, range = 1.20–20.79 km) apart. Selected points were converted to 270 m x 270 m survey blocks (7.29 ha) centered on points and oriented on cardinal axes, with corners facing northeast, southeast, southwest, and northwest (Fig. 4.2).

We surveyed larger-sized vertebrates on 145 transects that extended between the center points of survey blocks (Figs. 4.1 and 4.2). The combined transect/survey block sampling design allowed us to sample multiple vertebrate species, thereby decreasing travel time and sampling cost. We used two types of transects: (1) short transects, starting at roads (mainly gravel roads), and ending at centers of near-road survey blocks; and (2) long transects, starting at centers of on-road survey blocks and ending at centers of paired far-road survey blocks. Transects between on-road and far-road survey blocks were identified by the least-cost path used to select the on-road survey blocks. Least-cost paths were also developed between near-road survey blocks and the closest point on the road using the same analysis procedure. For field application, transects were converted from the COSTPATH raster output into line shapefiles and uploaded into GPS units (Garmin E-trex Venture) using the Minnesota Department of Natural Resources Garmin software (Version 4.41, http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/DNRGarmin/DNRGarmin.html) to aid field navigation. We recorded track logs of altered transects for subsequent sampling if observers deviated from predetermined transects due to obstacles encountered during the first sampling bout of the season.

Floral and Faunal Sampling Protocol

Our surveys incorporated multiple techniques designed to detect the full suite of

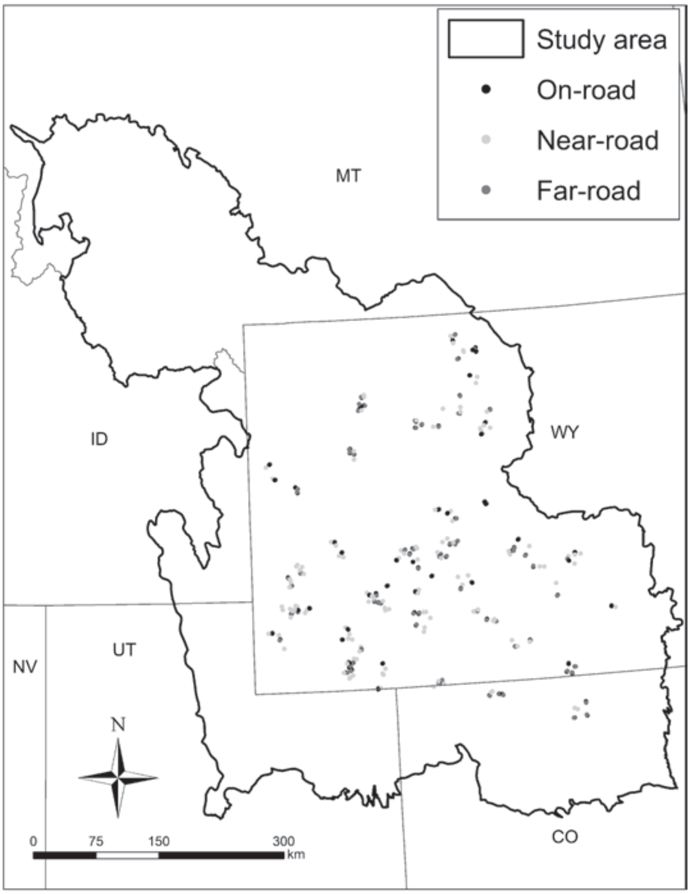

FIG. 4.2. Distribution of survey blocks and transect across the Wyoming Basin Ecoregional Assessment area. Shown are locations for survey block for on-road = directly adjacent to road (n = 104), near-road = 0-750 m (n = 125), and far-road = >750-3,000 m (n = 101). Transects (n = 145), not shown, occur between near-road and far-road survey blocks (n = 101) and between roads and near-road survey blocks (n = 44; transects > 100-m long) (see Fig. 4.3).

sagebrush steppe-associated fauna as well as information on plant community composition. Our survey protocols were applied as follows: (1) surveys conducted on transects while navigating between the on-road and far-road survey blocks or roads and near-road survey blocks and (2) surveys conducted within each survey block (Fig. 4.3).

On short and long transects, we applied distance sampling (Buckland et al. 2001, 2004) to enable density estimation for medium to large-sized mammals. For each detected individual or group, we recorded location of observer (latitude and longitude), azimuth using a compass, and distance between observer and object using a rangefinder (Bushnell Yardage Pro Legend).

Within survey blocks, we used variable-width point counts (Bibby et al. 1992) centered on survey blocks (Fig. 4.3) to survey sagebrush-associated songbirds. We estimated distance between observer and birds using a rangefinder. We used area-searches based on within survey block transects of 2.16-km length (Fig 4.3) to survey medium-sized mammals (lagomorphs and larger rodents), pygmy rabbit (*Brachylagus idahoensis*) burrows, reptiles, ant mounds, and greater sage-grouse (*Centrocercus urophasianus)* pellets. We sur-

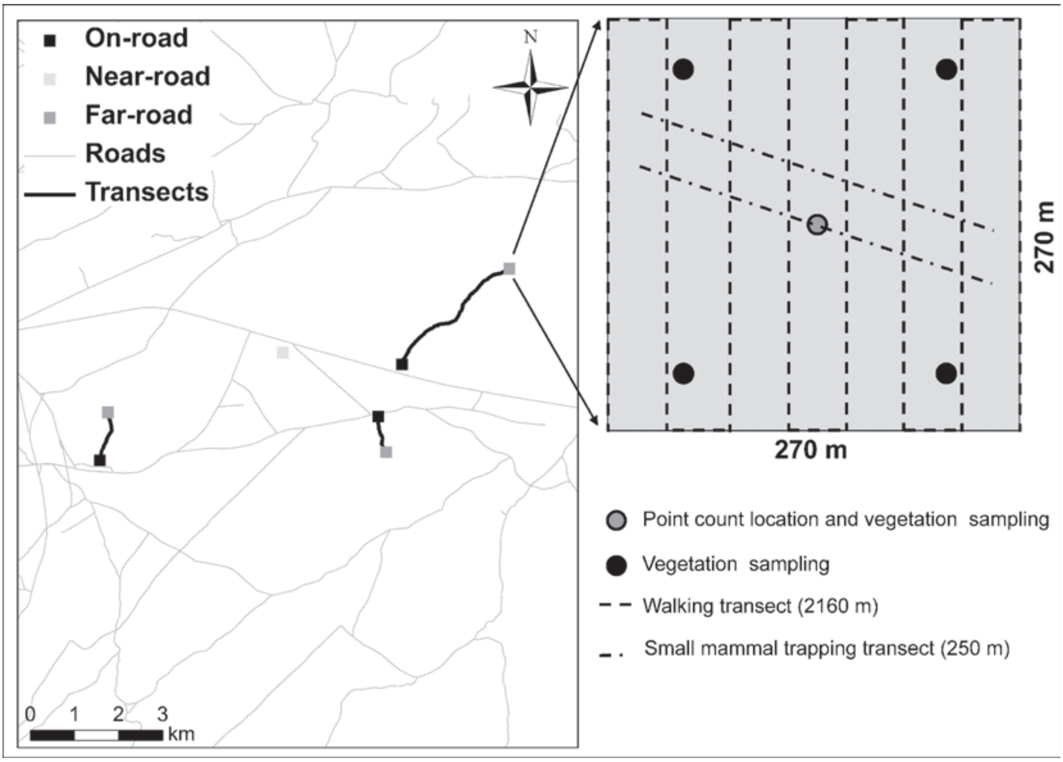

FIG. 4.3. Sampling layout within a survey block. Survey blocks were quadratic in shape with sides measuring 0.27 km. Points were used to survey vegetation (n = 5), with the center point used as songbird point count location. We used walking transects (2.16 km) to survey medium-sized mammals (grounds squirrels, prairie dogs, and chipmunks, lagomorphs), reptiles, and greater sage-grouse pellets. We surveyed small mammal diversity along two 0.25-km long transects (50 traps total); direction of transects was chosen randomly and transects were spaced 15 m apart.

veyed plant communities (shrub cover and composition, selected exotic forb and grass cover and composition, native annual and perennial forb and grass cover, and shrub height) in five 20-m radius (1,257 m^2) plots systematically located in the survey block at the center and 127.3 m from the center at 45º, 135º, 225º, and 315º azimuths (Fig. 4.3). For exotic plants, we sampled a subset of plant species deemed noxious and invasive by land management agencies (Appendix 4.3). We trapped small mammals at a subset of survey blocks using two parallel 0.25-km long transects centered on the survey block, but oriented randomly (Fig. 4.3). Detailed descriptions of specific sampling protocols are provided in chapters that follow.

We combined surveys throughout the field season to maximize sampling efficiency and minimize cost. Three field crews (two observers per team) worked independently throughout the field season. During the first round of surveys from 28 April – 31 May, all crews sampled medium to large-sized mammals on transects en route to survey blocks. Within survey blocks, crews sampled songbirds, pygmy rabbit signs, ant mounds, and medium-sized mammals (grounds squirrels [*Spermophilus* spp.], prairie dogs [*Cynomys* spp.], and chipmunks [*Tamius* spp.]). During the second round of sampling from 1 June – 2 July, all crews again sampled medium to large-sized mammals on transects en route to survey blocks; on survey

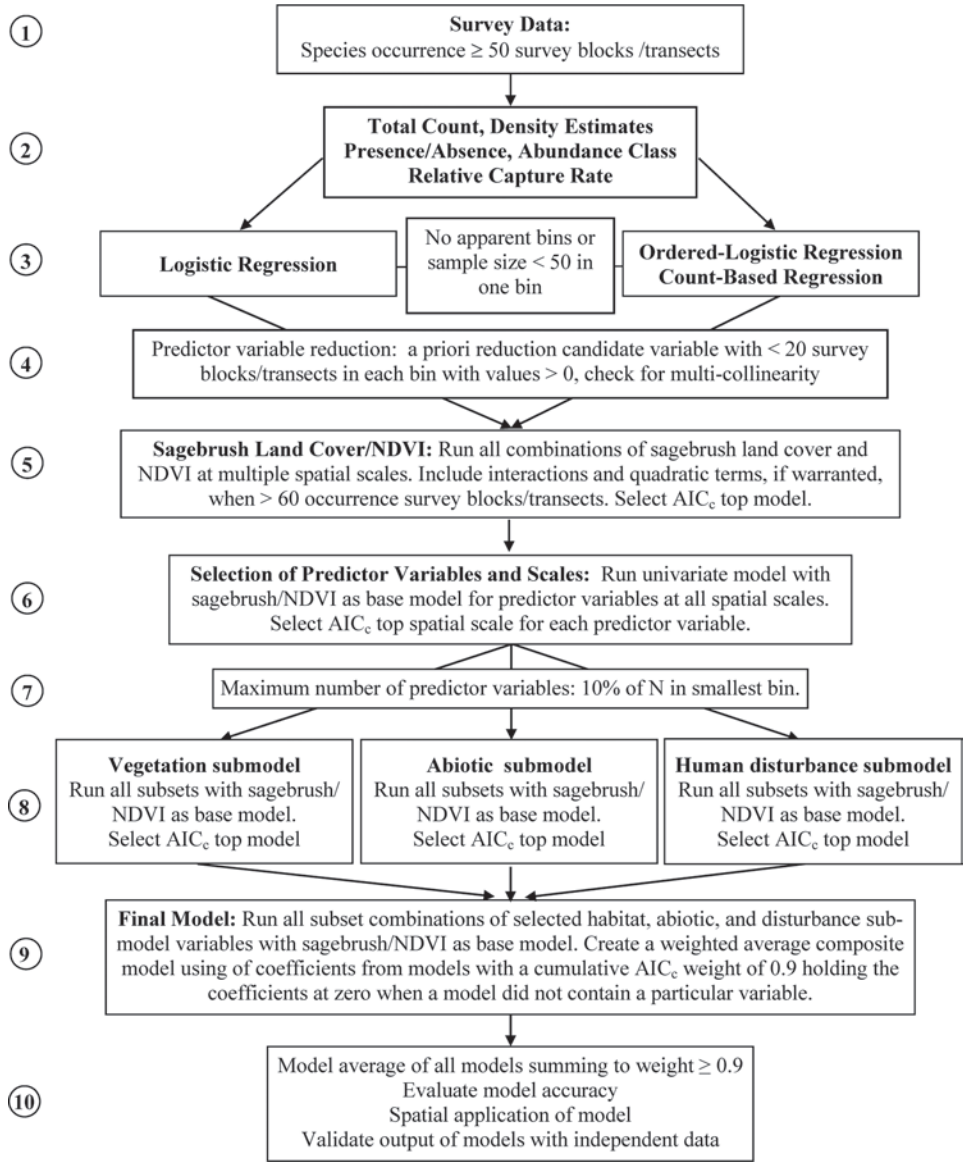

FIG. 4.4. Flow chart outlining hierarchical multi-stage modeling approach for floral and faunal presence/absence and abundance data.

blocks, song birds, and vegetation (species specific shrub and tree cover and height, exotic and native herbaceous cover, and ground cover) were sampled. During the last round of sampling between 6 July and 2 September, we only sampled on survey blocks. Crew one counted reptiles, mammals, and sage-grouse pellets; crew two measured vegetation and habitat characteristics (shrub cover, total, sagebrush [live, woody, and total], exotic and native herbaceous cover, dominant species by cover type, rock out-crop cover, and ground cover); and crew three trapped small mammals on a subset of survey blocks. We assigned field crews to sample the various taxonomic groups based on individual expertise.

ANALYSES

We developed species occurrence and abundance models based on habitat, abiotic and land use predictor variables (Franklin 2009). Our modeling procedure followed an Akaike Information Criterion (AIC) approach (Burnham and Anderson 2002); however, for most species we could not develop *a priori* candidate models because we lacked knowledge about species-specific responses to land use as well as appropriate spatial extents for assessing land cover conditions. As a result, our modeling effort was exploratory and followed a hierarchical analysis based on multiple steps to select the most plausible final models (Fig 4.4). We first selected the best extent and form of variables of interest and then chose top variables among competing variables within categories, of influence (Fig. 4.4). We used empirical information and/or our own knowledge to guide selection of predictor variables whenever possible but ultimately used AIC corrected for small sample sizes (AIC_c; Burnham and Anderson 2002) to select among competing predictor variables. Once predictor variables were selected within categories, we used all possible variable combinations within and across categories to develop candidate models. We used AIC_c to rank these models, produced a final model-averaged composite model based on a 90% confidence model set, and used independent data when possible to evaluate predictive capacity of final models. For all species, we modeled species presence/absence, abundance, or density, as summarized on survey blocks or transects, using a set of predictor variables consisting of a variety of environmental, habitat, and land-use covariates. Below, we outline detailed analytical approaches that apply to Chapters 5-9; methods used in Chapter 10 (exotic plants) deviate from this approach and are detailed in that chapter.

Predictor Variables

We used a suite of common GIS predictor variables consisting of land cover measured at different radii, land cover patch metrics, vegetation productivity, soil characteristics, terrain-derived variables, distance from water, climate, and density of and distance from anthropogenic features. Little is known about how sagebrush-associated species perceive ecological patterns. Therefore, we explored landscape perception of these species by selecting a range of circular moving window sizes based on the radius of seven model home range sizes that best represented 38 sagebrush steppe-associated species (Appendix 4.2). We evaluated land cover, vegetation productivity, and terrain-derived variables at six radii (0.27, 0.54, 1, 3, 5, and 18 km) and landscape metrics (contagion, edge density, mean patch size) at three radii (1, 3, 5 km). The 18-km radius reflected the recommended scale for habitat management around lek locations of migratory greater sage-grouse populations (Connelly et al. 2000). All predictor variable data sets are available on the SAGEMAP website (http://sagemap.wr.usgs.gov/wbea.aspx).

We modeled distance variables using exponential distance decay functions (value = $e^{(\text{Euclidean distance to feature (km)/-distance parameter})}$) with the distance parameter set at 0.25, 0.5, and 1 km (Nielsen et al. 2009, Carpenter et al. 2010), allowing for nonlinear responses of species to distance from water sources or anthropogenic features. For anthropogenic features such as power lines that attract synanthropic predators (predators that benefit from human features [Johnston 2001]), the asymptote of the 1-km distance decay function (~4.5 km) approximates the maximum home range size (≈ 54 km^2) for golden eagles (*Aquila chrysaetos*) breeding in the Intermountain West (Kochert et al. 2002); the asymptote of the 0.5-km distance decay function (~2.4 km) approximates the mean home range size (22.8 km^2) for golden eagles in southwest Idaho (Marzluff et al. 1997); and the asymptote of the 0.25-km distance decay function (~1.2 km) approximates the mean common raven (*Corvus corax*) feeding distance around nests in arid regions of California (0.57 km ± 0.71 SD [Boarman and Heinrich 1999]).

We initially identified a total of 154 candidate predictor variables likely to influence species occurrence and abundance; inclusion or exclusion of specific predictor variables are discussed in each chapter separately. We screened candidate predictor variables for sufficient representation of non-zero data values (i.e., values >0) across survey blocks and extents to avoid model fitting based on predictor variables dominated by zeros or having non-zero data values only at large extents. As a cut-off point, we only included predictor variables with non-zero data values on at least 20 survey blocks (6%, n = 326) or transects (14%, n = 141) at the smallest radius of 0.27-km. We omitted three land-cover variables (agriculture, n = 4 survey blocks with values > 0 [retained as a distance predictor variable]; juniper [*Juniperus* spp.], n = 2; and mountain shrub, n = 19) and one anthropogenic variable (oil and gas wells, n = 5 [retained as a distance predictor variable]). For distance to anthropogenic feature, we selected predictor variables with at least 20 survey blocks or transects located ≤1 km from a feature. We omitted three predictor variables as a result, including human populated area (n = 4 survey blocks within 1 km of feature), railroad (n = 2), and tower (n = 2). We were left with a total of 122 candidate predictor variables after this screening (Table 4.2).

Fifty-four of 122 candidate predictor variables consisted of nine land cover types (Table 4.2) evaluated at the six radii (0.27, 0.54, 1, 3, 5, and 18 km); these included four sagebrush land cover classes as well as coniferous forest (CFRST), grassland (GRASS), mixed shrubland (MIX), riparian (RIP), and salt-desert shrubland (SALT) land cover (Table 4.2). We used the LANDFIRE existing vegetation type (EVT) data layer (LANDFIRE 2007), reclassified per the cross-walk listed in Appendix 1.1, as our base land cover map and moving window analyses in ArcMap 9.2 (ESRI 2006) to calculate proportion of land cover class for each of six radii. For the all sagebrush species (ALLSAGE) land cover (all sagebrush species and subspecies combined), we calculated landscape metrics in FragStats (McGarigal et al. 2002) including patch size (PATCH), edge density (EDGE), and contagion (CONTAG), at three radii (1, 3, and 5 km).

We determined land cover productivity values for the plot center and computed mean values at six spatial extents (Table 4.2). Land cover productivity values were calculated for each pixel on the landscape using the maximum value of NDVI from all available data during the growing season (May through August in 2005 and 2006). NDVI values were derived from the 250-m resolution Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery (Carroll et al. 2006) re-sampled to 90-m resolution using cubic convolution for interpolation in ArcMap 9.2 (ESRI 2006).

We derived 18 abiotic variables (Table 4.2) based on terrain, soil, climate, and hydrography. Terrain variables were derived from 90-m DEM and consisted of compound topographic index (CTI) (Gessler et al. 1995), elevation (ELEV), slope (SLOPE), solar radiation index (SOLAR, developed using HILLSHADE analysis with parameters set to solar angle and direction at noon on the summer solstice, ESRI 2006), and topographic ruggedness index (TRI) (Riley et al. 1999). We derived TRI across the six radii in addition to the plot center. For soil variables, we used the conterminous United States multilayer soil characteristics dataset (Miller and White 1998) to develop spatial datasets for acidity (pH), available water capacity (AWC), bulk density (BULKd), clay content (CLAY), depth (SOIL_{cm}), salinity (SALIN), sand content (SAND), and silt content (SILT). For climate variables, we used climate normals from Parame-

TABLE 4.2. Descriptive statistics (mean, standard error, and range) for 38 independent candidate variables and associated spatial extents (n = 122 variables) measured on 330 survey blocks in the Wyoming Basins Ecoregional Assessment area. We used a subset of candidate predictive variables in the species models introduced in Chapters 5–10.

Category	Description	Radius/distance parameter (km)	Variable	Unit	$\bar{x}$	SE	Min	Max
Vegetation	All big sagebrush (Intermountain basins big sagebrush shrubland, Intermountain basins big sagebrush steppe, Intermountain basins montane sagebrush steppe, and *Artemisia tridentata* ssp. *vaseyana* shrubland alliance)[a]	0.27	ABIGSAGE_{270}	Proportion	0.75	0.02	0.00	1.00
Land cover		0.54	ABIGSAGE_{540}	Proportion	0.73	0.01	0.00	1.00
		1	ABIGSAGE_{1km}	Proportion	0.72	0.01	0.01	1.00
		3	ABIGSAGE_{3km}	Proportion	0.69	0.01	0.03	0.99
		5	ABIGSAGE_{5km}	Proportion	0.67	0.01	0.03	0.98
		18	ABIGSAGE_{18km}	Proportion	0.62	0.01	0.10	0.90
	All sagebrush species (All big sagebrush ecological systems, plus Colorado Plateau mixed low sagebrush shrubland, Columbia Plateau low sagebrush steppe, Wyoming basins dwarf sagebrush shrubland and steppe)[a]	0.27	ALLSAGE_{270}	Proportion	0.77	0.02	0.00	1.00
		0.54	ALLSAGE_{540}	Proportion	0.75	0.01	0.00	1.00
		1	ALLSAGE_{1km}	Proportion	0.74	0.01	0.01	1.00
		3	ALLSAGE_{3km}	Proportion	0.71	0.01	0.03	0.99
		5	ALLSAGE_{5km}	Proportion	0.69	0.01	0.03	0.99
		18	ALLSAGE_{18km}	Proportion	0.64	0.01	0.11	0.93
	Big sagebrush (Intermountain basins big sagebrush shrubland, and Intermountain basins big sagebrush steppe)[a]	0.27	BIGSAGE_{270}	Proportion	0.59	0.02	0.00	1.00
		0.54	BIGSAGE_{540}	Proportion	0.58	0.02	0.00	1.00
		1	BIGSAGE_{1km}	Proportion	0.58	0.02	0.00	1.00
		3	BIGSAGE_{3km}	Proportion	0.56	0.02	0.00	0.97
		5	BIGSAGE_{5km}	Proportion	0.55	0.02	0.00	0.94
		18	BIGSAGE_{18km}	Proportion	0.51	0.01	0.00	0.87
	Mountain sagebrush (Intermountain basins montane sagebrush steppe and *A. t.* spp. *vaseyana* shrubland alliance)[a]	0.27	MTNSAGE_{270}	Proportion	0.16	0.02	0.00	1.00
		0.54	MTNSAGE_{540}	Proportion	0.15	0.02	0.00	1.00
		1	MTNSAGE_{1km}	Proportion	0.15	0.01	0.00	0.95
		3	MTNSAGE_{3km}	Proportion	0.13	0.01	0.00	0.91
		5	MTNSAGE_{5km}	Proportion	0.13	0.01	0.00	0.87
		18	MTNSAGE_{18km}	Proportion	0.11	0.01	0.00	0.48

TABLE 4.2. Continued

Category	Description	Radius/distance parameter (km)	Variable	Unit	$\overline{x}$	SE	Min	Max
	Coniferous forest[a]	0.27	$CFRST_{270}$	Proportion	0.02	0.01	0.00	0.79
		0.54	$CFRST_{540}$	Proportion	0.03	0.01	0.00	0.72
		1	$CFRST_{1km}$	Proportion	0.04	0.01	0.00	0.74
		3	$CFRST_{3km}$	Proportion	0.05	0.01	0.00	0.73
		5	$CFRST_{5km}$	Proportion	0.05	0.01	0.00	0.71
		18	$CFRST_{18km}$	Proportion	0.08	0.01	0.00	0.53
	Grassland[a]	0.27	$GRASS_{270}$	Proportion	0.05	0.01	0.00	0.97
		0.54	$GRASS_{540}$	Proportion	0.05	0.01	0.00	0.84
		1	$GRASS_{1km}$	Proportion	0.05	0.01	0.00	0.74
		3	$GRASS_{3km}$	Proportion	0.04	<0.01	0.00	0.61
		5	$GRASS_{5km}$	Proportion	0.04	<0.01	0.00	0.43
		18	$GRASS_{18km}$	Proportion	0.04	<0.01	0.00	0.15
	Mixed shrubland[a]	0.27	MIX_{270}	Proportion	0.00	<0.01	0.00	0.28
		0.54	MIX_{540}	Proportion	0.01	<0.01	0.00	0.24
		1	MIX_{1km}	Proportion	0.01	<0.01	0.00	0.12
		3	MIX_{3km}	Proportion	0.01	<0.01	0.00	0.08
		5	MIX_{5km}	Proportion	0.01	<0.01	0.00	0.06
		18	MIX_{18km}	Proportion	0.01	<0.01	0.00	0.04
	Riparian[a]	0.27	RIP_{270}	Proportion	0.03	<0.01	0.00	0.79
		0.54	RIP_{540}	Proportion	0.03	<0.01	0.00	0.57
		1	RIP_{1km}	Proportion	0.03	<0.01	0.00	0.34
		3	RIP_{3km}	Proportion	0.04	<0.01	0.00	0.26
		5	RIP_{5km}	Proportion	0.04	<0.01	0.00	0.19
		18	RIP_{18km}	Proportion	0.04	<0.01	0.00	0.12

TABLE 4.2. Continued

Category	Description	Radius/distance parameter (km)	Variable	Unit	$\overline{x}$	SE	Min	Max
	Salt-desert shrubland[a]	0.27	$SALT_{270}$	Proportion	0.05	0.01	0.00	0.83
		0.54	$SALT_{540}$	Proportion	0.05	0.01	0.00	0.76
		1	$SALT_{1km}$	Proportion	0.05	0.01	0.00	0.69
		3	$SALT_{3km}$	Proportion	0.05	0.01	0.00	0.58
		5	$SALT_{5km}$	Proportion	0.06	0.01	0.00	0.58
		18	$SALT_{18km}$	Proportion	0.06	0.01	0.00	0.49
	All sagebrush species contagion	1	$CONTAG_{1km}$	%	39.51	1.45	0.55	97.64
		3	$CONTAG_{3km}$	%	36.15	1.31	2.01	97.90
		5	$CONTAG_{5km}$	%	29.61	1.00	3.27	91.38
	All sagebrush species edge density	1	$EDGE_{1km}$	m/ha	41.92	1.20	0.88	91.60
		3	$EDGE_{3km}$	m/ha	42.85	1.20	0.00	84.20
		5	$EDGE_{5km}$	m/ha	45.98	0.89	3.84	80.10
	All sagebrush species mean patch size	1	$PATCH_{1km}$	m^2	178.27	6.24	0.81	304.56
		3	$PATCH_{3km}$	m^2	718.45	47.66	1.55	2,745.09
		5	$PATCH_{5km}$	m^2	1,011.6	119.1	1.8	9,866.6
NDVI	Normalized Difference Vegetation Index	Plot center	NDVI	Cell value	0.32	0.01	0.13	0.76
		0.27	$NDVI_{270}$	Mean value	0.32	0.01	0.14	0.76
		0.54	$NDVI_{540}$	Mean value	0.32	0.01	0.15	0.75
		1	$NDVI_{1km}$	Mean value	0.32	0.01	0.17	0.76
		3	$NDVI_{3km}$	Mean value	0.33	0.01	0.18	0.77
		5	$NDVI_{5km}$	Mean value	0.34	0.01	0.19	0.76
		18	$NDVI_{18km}$	Mean value	0.35	0.01	0.20	0.74
Abiotic	Compound topographic index	Plot center	CTI	Value	8.87	0.12	4.96	19.64

TABLE 4.2. Continued

Category	Description	Radius/distance parameter (km)	Variable	Unit	$\overline{x}$	SE	Min	Max
Terrain	Elevation	Plot center	ELEV	m	2,102	18.5	1,286	3,161
	Slope	Plot center	SLOPE	Deg	4.27	0.27	0.00	32.15
	Solar radiation index	Plot center	SOLAR	Value	148.52	0.90	76.00	226.00
	Topographic ruggedness index	Plot center	TRI	Cell value	20.78	1.21	0.00	149.47
		0.27	TRI_{270}	Mean value	21.40	1.08	0.00	114.50
		0.54	TRI_{540}	Mean value	22.17	1.02	0.59	94.64
		1	TRI_{1km}	Mean value	22.65	0.98	2.12	96.76
		3	TRI_{3km}	Mean value	23.87	0.94	2.18	82.26
		5	TRI_{5km}	Mean value	24.03	0.93	2.63	86.94
		18	TRI_{18km}	Mean value	25.91	0.92	5.98	95.79
Abiotic Soil	Acidity	Plot center	pH	Value	6.73	0.04	2.87	8.74
	Available water capacity	Plot center	AWC	inches/inch	5.18	0.09	1.46	9.16
	Bulk density	Plot center	BULKd	g/cc	1.53	0.01	1.21	2.19
	Clay content	Plot center	CLAY	%	16.51	0.39	0.00	47.00
	Depth	Plot center	$SOIL_{cm}$	cm	100.90	1.58	38.00	152.00
	Salinity	Plot center	SALIN	mmhos/cm	2.28	0.09	0.00	9.53
	Sand content	Plot center	SAND	%	39.14	0.81	0.00	88.25
	Silt content	Plot center	SILT	%	26.70	0.54	0.00	58.38
Abiotic Climate	Mean annual maximum temperature	Plot center	Tmax	Deg C	12.24	0.12	4.49	16.46
	Mean annual minimum temperature	Plot center	Tmin	Deg C	-2.95	0.11	-7.37	1.22
	Precipitation	Plot center	PRECIP	cm	33.72	0.70	17.07	80.74

TABLE 4.2. Continued

Category	Description	Radius/distance parameter (km)	Variable	Unit	$\bar{x}$	SE	Min	Max
Abiotic	Decay distance from intermittent water	0.25	$iH2Od_{250}$	Probability	0.22	0.016	0.00	1.00
Water Sources		0.5	$iH2Od_{500}$	Probability	0.36	0.017	0.00	1.00
		1	$iH2Od_{1km}$	Probability	0.53	0.016	0.02	1.00
	Decay distance from permanent water	0.25	$pH2Od_{250}$	Probability	0.05	0.009	0.00	1.00
		0.5	$pH2Od_{500}$	Probability	0.11	0.011	0.00	1.00
		1	$pH2Od_{1km}$	Probability	0.20	0.014	0.00	1.00
Disturbance	Decay distance from agricultural land	0.25	AG_{250}	Probability	0.02	<0.01	0.00	0.45
Distance		0.5	AG_{500}	Probability	0.06	0.01	0.00	0.67
		1	AG_{1km}	Probability	0.13	0.01	0.00	0.82
	Decay distance from interstate highways, federal and state highways	0.25	$MjRD_{250}$	Probability	0.04	0.01	0.00	1.00
		0.5	$MjRD_{500}$	Probability	0.08	0.01	0.00	1.00
		1	$MjRD_{1km}$	Probability	0.13	0.01	0.00	1.00
	Decay distance from pipeline	0.25	$PIPE_{250}$	Probability	0.06	0.01	0.00	1.00
		0.5	$PIPE_{500}$	Probability	0.10	0.01	0.00	1.00
		1	$PIPE_{1km}$	Probability	0.15	0.02	0.00	1.00
	Decay distance from power line	0.25	$POWER_{250}$	Probability	0.04	0.01	0.00	1.00
		0.5	$POWER_{500}$	Probability	0.06	0.01	0.00	1.00
		1	$POWER_{1km}$	Probability	0.12	0.01	0.00	1.00
	Decay distance from secondary roads	0.25	$2RD_{250}$	Probability	0.41	0.02	0.00	1.00
		0.5	$2RD_{500}$	Probability	0.54	0.02	0.01	1.00
		1	$2RD_{1km}$	Probability	0.69	0.02	0.08	1.00
	Decay distance from oil and gas wells	0.25	$WELL_{250}$	Probability	0.01	<0.01	0.00	0.70
		0.5	$WELL_{500}$	Probability	0.03	0.01	0.00	0.84
		1	$WELL_{1km}$	Probability	0.07	0.01	0.00	0.91

TABLE 4.2. Continued

Category	Description	Radius/distance parameter (km)	Variable	Unit	$\bar{x}$	SE	Min	Max
Disturbance								
Density	Density of all roads (interstate highways, federal and state highways, and secondary roads)	0.27	RDdens_{270}	km/km^2	1.78	0.10	0.00	9.54
		0.54	RDdens_{540}	km/km^2	1.44	0.07	0.00	7.59
		1	RDdens_{1km}	km/km^2	1.28	0.06	0.00	6.24
		3	RDdens_{3km}	km/km^2	1.43	0.04	0.07	5.03
		5	RDdens_{5km}	km/km^2	1.43	0.03	0.35	4.19
		18	RDdens_{18km}	km/km^2	1.44	0.02	0.32	2.31

[a] Ecological systems reclassified from the LANDFIRE existing vegetation type data set (LANDFIRE 2007); see Ch. 1 for details.

ter-Elevation Regressions on Independent Slopes Model (PRISM) to estimate mean annual precipitation (PRECIP; PRISM Group 2006a), maximum temperature (Tmax; PRISM Group 2006b), and minimum temperature (Tmin; PRISM Group 2006c). Last, we developed hydrographic variables based on distance to perennial (pH2Od) and intermittent (iH2Od) water sources; as with other distance-based variables, we used exponential distance decay functions fit to 0.25-km, 0.50-km, and 1-km distance parameters.

We included seven anthropogenic feature types in our analyses. Spatial data sets for anthropogenic features were clipped from input data used to create the human footprint of the western U.S. (Leu et al. 2008) and updated with recent spatial data sets (see metadata for detailed information on data acquisition). We derived 18 anthropogenic proximity variables (Table 4.2) based on six anthropogenic features (agriculture [AG], interstate and state/federal highways [MjRD], pipelines [PIPE], power lines [POWER], secondary roads [2RD], and oil-gas wells as of August 2005 [WELL]) and exponential distance decay functions fit with three distance parameters (0.25 km, 0.50 km, 1 km). We also developed a road density (RDdens) (interstate highways, federal and state highways, and secondary roads combined) spatial data set evaluated at the six radii.

Modeling Approach

Step 1 – Candidate species selection

Our goal at the onset of this study was to develop occurrence or abundance models for all species surveyed during the breeding seasons of 2005 and 2006. However, many species were rare or difficult to detect (Ch. 5–10). We restricted development of models to species with occurrences on at least 50 survey blocks or transects (Fig. 4.4) because sample sizes below this threshold result in regression models with poor predictive capabilities (Coudun and

Gégout 2006). Only 43.2% (n = 37 species) of all species sampled in our study were detected on >50 survey blocks and only 10.0% (n = 10) on >50 transects. We present a complete list of species sampled on the 330 survey blocks or the 145 transects in following chapters.

Step 2 – Survey data

Our survey data consisted of four types: (1) counts on survey blocks for sage-grouse pellets, ant mounds, lagomorphs, medium-sized rodents, and reptiles; (2) counts with distance estimates for birds and large-bodied mammals (lagomorphs and ungulates); (3) relative capture rates for small mammals; and (4) plant composition and cover estimates (discussed separately in Ch. 10). We derived detection probabilities for species sampled when possible (Buckland et al. 2001) (Ch. 6-8).

Step 3 – Model structure

We used three modeling approaches to develop species occurrence or abundance models: count-based regressions, generalized ordered-logistic regressions, and logistic regressions (Fig. 4.4). The decision on which analysis to employ was based on (1) the sample size of survey blocks or transects with presences, and (2) whether data collected were counts or presence/absence. For species with counts, we used count-based models, investigating appropriate distributional form of the data (e.g, Poisson versus negative binomial), and also whether data were inherently zero-inflated. The expected output from count-based models is based on count estimates. We used ordered-logistic regression where the distribution of the counts prevented us from implementing count-based models (e.g., few counts over a broad range) or counts were an indicator rather than a direct measure of species abundance (e.g., sage-grouse pellets). For ordered-logistic regression models, we required a minimum of 50 observations within each count/abundance class. Classes were determined based on apparent break points in counts/density frequency distributions. For species with less than 50 observations in each count/abundance class, we simply reverted to a presence/absence model using logistic regression. The expected outcome from ordered-logistic regression and logistic-regression analyses is based on a probability of occurrence estimate. All analyses were conducted in STATA 10.1 (STATA Corporation, College Station, TX).

We followed a recently developed two-staged approach for count-based models that incorporates detectability into count-based regression models when distance was recorded for individual detections (see Buckland et al. 2009). We first modeled detectability using the Multiple Covariate Sampling Engine in Program DISTANCE (Thomas et al. 2006). We develop the detection-function model for all observations for a given species by identifying the best detection function and form using AIC. We did so only for species with a minimum of 60 detections, allowing for proper estimation of the species detection function (Buckland et al. 2001). Note that 60 distance estimates could be obtained even if occurrence was less than 50 survey blocks or transects. We used observer team, time of year, time of day, and a shrub volume index (based on field measured data) when possible to assess the influence of covariates on detectability and to adjust density estimates. We used the top detection function to predict density on each survey block or transect. We then developed a generalized linear model (GLM) for each species using observed counts as the response variable and an offset term that included detection probability (that varied among sites) and survey effort (constant across sites) (Buckland et al. 2009). We restricted raw counts based on the truncation distance as identified in Program DISTANCE (Buckland et al. 2001). We used the offset term in the GLM to model observed counts while incorporating detectability differences across sites (Buckland et al. 2009).

Count data are typically Poisson-distributed, but when data are over-dispersed, a negative binomial distribution (mixture distribution of Poisson and gamma) may be more appropriate. Although a negative binomial regression model may account for excess zeros, a zero-inflated model (type of mixture model) is typically required to properly account for excess zeros in the dataset (Hilbe 2007). We evaluated different model structures and assessed the fit of each structure using a Vuong test (Vuong 1989). We first conducted a Vuong test using an intercept only model to identify the most appropriate of four exponential model forms: Poisson, negative binomial, zero-inflated Poisson (ZIP), or zero-inflated negative binomial (ZINB). We used the identified model form to evaluate the sagebrush land cover/NDVI sub-model (Step 5 below). After the top sagebrush land cover/NDVI sub-model was identified, we re-ran the Vuong test to confirm the top model form with base covariates. When zero-inflated processes were warranted, we maintained candidate model variables in both count and inflated portions of the model. Otherwise, potential model combinations became too cumbersome to evaluate. When incorporating offsets, expected outcome from count-based models result in density estimates.

We used generalized ordered-logistic regression analyses (Willams 2006) when distribution of the counts made it difficult to estimate count-based models or if counts were an indicator of species abundance rather than density of individuals (Ch. 5 and 7). We binned data into high and low abundance classes (0 = absence, 1 = low-medium abundance, 2 = high abundance) according to natural breaks in frequency distributions. Ordered-logistic regression uses an ordered (from low to high) categorical dependent variable to simultaneously estimate multiple equations, resulting in separate intercepts for each level (number of abundance classes in the dependent variable minus one) and a single set of coefficients for each predictor variable. Unlike ordered-logistic regression, which assumes parallel regression lines of each abundance class, generalized ordered-logistic regression analyses relax this assumption (Willams 2006). We used the "GOLOGIT2" command in STATA 10 (STATA Corporation, College Station, TX), with the "autofit" option, which automatically relaxes the parallel constraint for those predictor variables that do not meet the parallel-line assumption and fits a separate slope for each abundance class.

We used logistic regression analyses (Hosmer and Lemeshow 2000) for those species whose survey data was an indicator of occurrence, no natural breaks in frequency distributions could be identified, or when count/abundance classes contained <50 survey blocks or transects. Survey blocks and transects were coded as presence if one or more individuals were detected.

Step 4 – Predictor variable reduction

We avoided perfect fit of predictor variables, variables containing almost exclusively zero-values, by screening each variable for presence of non-zero data values (Fig. 4.4). We set the threshold where at least 20 presence survey blocks or transects contained non-zero data values. We removed predictor variables from the standard candidate set if this criterion was not met. After we selected all candidate predictor variables, we checked for collinearity (Spearman rank correlation $r_s \geq |0.7|$) among the predictor variables. In cases where predictor variables were correlated, we retained variables at uncorrelated spatial scales or used *a priori* knowledge and ease of biological interpretation to select a single variable from the pair. We document the predictor variables, including descriptive statistics, used in each species distribution model in chapters to follow.

Step 5– Sagebrush land cover/NDVI sub-model

Our sampling design was based on presence of sagebrush-grassland land cover and NDVI. Thus, we first evaluated which combination of sagebrush land-cover class (0.27, 0.54, 1, 3, 5, and 18 km) and/or NDVI (0.27, 0.54, 1, 3, 5, and 18 km) had the best model fit when predicting species occurrence/abundance. We used *a priori* biological knowledge to select sagebrush land-cover classes to be included in this analysis. For example, if a species did not primarily inhabit mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) land cover, we excluded mountain sagebrush only land cover class (MTNSAGE) from the regression analyses. We included all radii of selected sagebrush types in the analyses because little is known about the scale of sagebrush land cover important to species. We used AIC_c for model selection and carried forward the AIC_c-selected top sagebrush, NDVI, or sagebrush-NDVI model (parameters (k) = 2–4 [intercept, sagebrush variable, NDVI variable, two variables for quadratic term or interaction]). We did not test interactions or quadratic terms if the sample size was ≤ 60 due to sample size limitations. We visually inspected presence/absence bi-plots and abundance scatter plots to evaluate whether interactions of sagebrush-NDVI or quadric terms for both sagebrush and NDVI were justified.

Step 6 – Selection of predictor variable scales

We used univariate regression models to determine the best scale for each predictor variable that explained species occurrence/abundance (Fig. 4.4). Each univariate model included the sagebrush-NDVI sub-model selected from Step 5, along with a predictor variable at the given radii. We carried forward the AIC_c-best scale for each predictor variable.

Step 7 – Number of predictor variables included in sub-models and final models

We limited the number of predictor variables to 10% (Hosmer and Lemshow 2000) of the smallest sample size in each abundance or presence/absence class to avoid model over-fitting in logistic, ordered logistic, negative binomial, zero-inflated negative binomial, Poisson and zero-inflated Poisson regression analyses (Fig. 4.4). For example, candidate models could only include a maximum of ten predictor variables if the presence sample size was 104 survey blocks, including the variables from the sagebrush-NDVI base model in submodels and final models.

Step 8 – Sub-model development for vegetation, abiotic, and anthropogenic disturbance variables

We developed three sub-models based on vegetation, abiotic, and anthropogenic disturbance variables (Fig 4.4). Our goal was to select the best combination of each predictor variable and extent within each sub-model group. Candidate models for each sub-model group consisted of the sagebrush-NDVI sub-model selected in Step 5 and all possible combinations of predictor variables in each category selected in Step 6, limited to the number of variables identified in Step 7. We carried forward the AIC_c-selected top sub-model to the next step.

Step 9 – Final model

We allowed all predictor variables within each of the AIC_c-best submodels for vegetation, abiotic, and anthropogenic disturbance categories (Step 8) to compete, both within and across submodels (Fig. 4.4). The sagebrush/NDVI submodel (Step 5) was again held constant in all models. All possible candidate models were competed; final models were ranked based on AIC_c, and model weights (w_i) were calculated. We incorporated model uncertainty into the final composite predictive model by using model-averaged coefficients based on weights from all candidate models within a cumulative AIC_c weight just ≥ 0.9 (Burnham and Anderson 2001). We set coefficients to zero when a model did not contain a particular variable.

Step 10 – Spatial application, dose response curves, and model evaluation

We develop maps of species occurrence or abundance at a 90-m cell size by spatially applying the final composite model using raster calculator in ArcMap 9.3.1 (ESRI 2006) (Fig. 4.4). We binned final model predictions for summary and display. Non-sagebrush habitats (areas with <3% sagebrush habitat in a 5-km radius) where we did not sample were masked, and no predictions were made to these areas.

We evaluated accuracy of generalized ordered logistic and logistic regression models using receiver operating characteristic (ROC) estimating the area under the curve (AUC, Metz 1978). AUC is a discrimination index based on likelihood for a presence to have a higher species occurrence probability when compared to a randomly selected absence point. We used this metric as one indicator of model performance, fully cognizant of potential problems if ROC is the only metric used to evaluate model performance (Lobo et al. 2008). We used the sensitivity-specificity equality approach (Liu et al. 2005) to determine the optimal cutoff threshold for predicting presence-absence of each species (habitat or non-habitat) and used this threshold to assess the predictive capacity for each model (Nielsen et al. 2004, Lobo et al. 2008).

We created dose response curves for each species by plotting predicted probability of occurrence or density relative to changes in sagebrush quantity. This permitted us to assess critical levels of sagebrush required for a species across the WBEA landscape, as well as characterize response to losses or fragmentation of sagebrush habitat. We used the Dose Response Calculator for ArcGIS (Hanser et al. 2011) to calculate the mean probability of occurrence or density from the spatial model output across one percent intervals of the sagebrush predictor variable, 0.01 intervals of NDVI, or distance intervals from anthropogenic features, where appropriate. We used the optimal cutoff or minimum densities to identify the sagebrush or productivity threshold values above which a species was likely to occur.

We used independent survey data when available to evaluate predictive outputs of species models (Pearce and Ferrier 2000, Strauss and Biederman 2007). We used three data sets to validate models: (1) Wyoming Fish and Game (pronghorn, Bob Oaklef pers. comm.; sage-grouse, Tom Christiansen pers. comm.), (2) Wyoming Natural Diversity Database (reptile models; Wyoming Natural Diversity Database 2009), and (3) Breeding Bird Survey (USGS Breeding Bird Survey Data, http://www.mbr-pwrc.usgs.gov/bbs/) data sets (songbird models). To examine performance of models based on logistic regression analyses, we first binned each model into 10 equal probability classes, and then counted presence locations and calculated area in each bin. We used this information to determine expected observations per bin and regressed proportion of expected against observed observations (Johnson et al. 2006). A model well supported by validation data will have (1) a slope not differing from one, (2) an intercept near zero, and (3) a high R^2 value (Nielsen et al. 2004). As a more general evaluation of songbird models (Ch. 6) we used BBS data from 2005–06 and compared mean counts across entire BBS routes with averaged model predictions (density or probability of occurrence) along each BBS survey route. Predictive models should have a significant and positive correlation with independent count data, even though BBS data do not account for differences in detectability.

DISCUSSION

Conducting floral and faunal sampling across large scales is a costly endeavor and logistically challenging (Franklin 2009). Given these hurdles, few studies to date have investigated how wildlife and plant communities respond to habitat-anthropogenic disturbance gradients across large scales (Franklin 2009). Moreover, most studies do not sample all possible habitat-anthropogenic disturbance combinations or gradients (e.g., low habitat suitability – high anthropogenic disturbance). Yet such field data are crucial when evaluating ecoregional assessment outcomes and predictions. To our knowledge, our study is one of a few that has sampled habitat-anthropogenic disturbance interactions across large spatial extents and covered the possible range of habitat-anthropogenic disturbance combinations.

An inherent problem of faunal surveys is to find trained field biologists capable of sampling a suite of species in different taxonomic groups (Noss et al. 1997). Although some taxonomic groups are easier to sample than others, we had difficulty training field technicians in identifying all possible bird species by sound. We recommend that a subset of bird species be sampled rather than a complete inventory of the avian community to minimize errors associated with identifying all breeding species that may possibly occur. This approach can be applied to any taxonomic group. Subsets of species should be selected according to habitat associations, life history traits, or sensitivity to perceived anthropogenic threats. Ultimately these species should be potential indicators of biodiversity (Mac Nally and Fleishman 2004). The cost of sampling and logistics associated with training field technicians can be reduced by having at least one well-trained technician per survey protocol in each team to assist in training inexperienced biological technicians.

Our hierarchical multi-stage modeling approach, although exploratory in nature, worked well in developing species occurrence and abundance models for sagebrush-associated species. Very little was known about how most species in our assessment responded to land cover composition and configuration and human disturbance and at which spatial extents these responses might be strongest. Therefore, field data collection and an exploratory analytical approach, as we have outlined here, was the first step in conducting statistically rigorous studies that investigate thresholds at which species occurrence and abundance are influenced by human disturbance.

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APPENDIX 4.1

Summary of literature review on effect area of various anthropogenic disturbances (if not reported in the metric system, units were converted from originally reported values). This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 4.2

Home range estimates for 40 species of concern in the Wyoming Basins Ecoregional Assessment area. Scientific names for species are provided in Chapter 2. The minimum and maximum home range or territory size are provided along with the corresponding citations, where available. Values other than the minimum and maximum are also provided. Where applicable we provide the citation if different from those used to obtain the minimum and maximum values. Values are in hectares unless specified otherwise. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 4.3

Exotic plants species sampled during 2005 and 2006 for the Wyoming Basins Ecoregional Assessment. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

Sagebrush Ecosystem Conservation and Management: 112–140, 2011

Chapter 5: Greater Sage-Grouse: General Use and Roost Site Occurrence with Pellet Counts as a Measure of Relative Abundance

Steven E. Hanser, Cameron L. Aldridge, Matthias Leu, Mary M. Rowland, Scott E. Nielsen, and Steven T. Knick

Abstract. Greater sage-grouse (*Centrocercus urophasianus*) have been declining both spatially and numerically throughout their range because of anthropogenic disturbance and loss and fragmentation of sagebrush (*Artemisia* spp.) habitats. Understanding how sage-grouse respond to these habitat alterations and disturbances, particularly the types of disturbances and extent at which they respond, is critical to designing management actions and prioritizing areas of conservation. To address these needs, we developed statistical models of the relationships between occurrence and abundance of greater sage-grouse and multi-scaled measures of vegetation, abiotic, and disturbance in the Wyoming Basins Ecoregional Assessment (WBEA) area. Sage-grouse occurrence was strongly related to the amount of sagebrush within 1 km for both roost site and general use locations. Roost sites were identified by presence of sage-grouse fecal pellet groups whereas general use locations had single pellets. Proximity to anthropogenic disturbance including energy development, power lines, and major roads was negatively associated with sage-grouse occurrence. Models of sage-grouse occurrence correctly predicted active lek locations with >75% accuracy. Our spatially explicit models identified areas of high occurrence probability in the WBEA area that can be used to delineate areas for conservation and refine existing conservation plans. These models can also facilitate identification of pathways and corridors important for maintenance of sage-grouse population connectivity.

Key words: abundance, anthropogenic disturbance, generalized ordered logistic regression, greater sage-grouse, habitat, occurrence.

Greater sage-grouse (sage-grouse hereafter, *Centrocercus urophasianus*) have undergone long-term declines throughout their range both spatially and numerically (Connelly and Braun 1997, Connelly et al. 2004, Garton et al. 2011). These declines have been attributed to the fragmentation and loss of sagebrush (*Artemisia* spp.) due to single and interacting effects of invasive grasses, fire, and increased human disturbances (Aldridge et al. 2008, Wisdom et al. 2011). As a result, sage-grouse were recently designated as a candidate species under the Endangered Species Act (U.S. Department of the Interior 2010); the biological data supported listing as endangered but immediate action was precluded by higher priorities. As a consequence, it is important to understand the environmental factors related to the distribution and abundance of sage-grouse both for management of current land uses but also for long-term conservation planning.

Sage-grouse have been studied extensively throughout their range (Schroeder et al. 1999, Connelly et al. 2004, Knick and Connelly 2011). Sage-grouse have extensive home ranges (up to 2,975 km^2; Connelly et al. 2000, 2004), and large expanses of sagebrush land cover are required to support viable populations (Patterson 1952, Wakkinen 1990, Connelly et al. 2000, Connelly et al. 2004). Wildfire (Connelly et al. 2000, Beck et al. 2009, Knick and Hanser

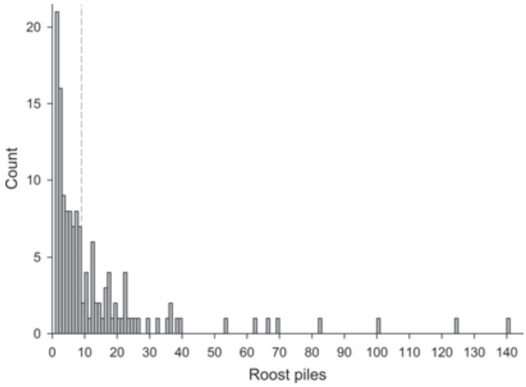

FIG. 5.1. Histogram of 137 survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for sage-grouse roost piles with >0 roost piles. Abundance at each survey block equates with total number of roost piles. Survey blocks with zero roost piles were classed as absent, survey blocks with 1-8 roost piles as low abundance, and >8 roost piles as high abundance. The dashed vertical line indicates the boundary between the low and high abundance classes.

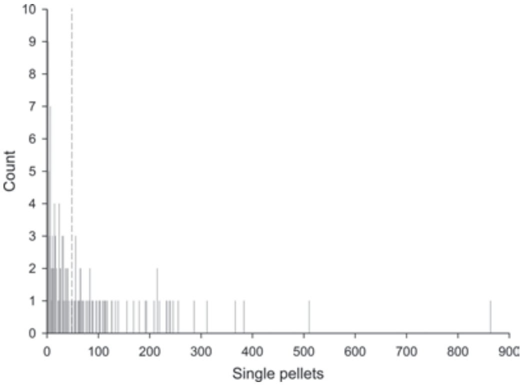

FIG. 5.2. Histogram of 149 survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for sage-grouse single pellets with >0 pellets. Abundance at each survey block equates with total number of single pellets. Survey blocks with zero pellets were classed as absent, 1-48 pellets as low abundance, and >48 pellets as high abundance. The dashed vertical line indicates the boundary between the low and high abundance classes.

2011), energy resource extraction (Naugle et al. 2011), and other anthropogenic infrastructure (Johnson et al. 2011) influence the distribution, movement patterns, and population trends of sage-grouse. However, habitat requirements and responses to disturbance may vary across spatial scales (Aldridge 2005, Aldridge and Boyce 2007, Walker et al. 2007, Carpenter et al. 2010, Connelly et al. 2011).

Knowledge of the response by sage-grouse populations to the multi-scale habitat and disturbance factors regulating their occurrence and abundance is needed for planning land use and conservation actions that mitigate these declines. Our objective was to develop spatially explicit models of occurrence and abundance for sage-grouse in the Wyoming Basins Ecoregional Assessment (WBEA) area. We conducted surveys throughout the WBEA area (Ch. 4) and used habitat and disturbance variables measured across multiple spatial scales to develop models of species occurrence and abundance. Such models may be particularly useful for assessing effects of proposed or future development across the WBEA on sage-grouse populations and aiding in the development of management practices to avoid or minimize these potential effects.

METHODS

Field Surveys

We conducted field surveys for sage-grouse between 6 July and 2 September, within 7.29-ha survey blocks (270 m x 270 m) sampled in 2005 and 2006 (Ch. 4). We used sage-grouse pellet-count surveys (Boyce 1981, Hanser and Knick 2011, Schroeder and Vander Haegen 2011) on each survey block walking parallel transects spaced 30 m apart (Fig. 4.2). We searched within 2 m of the walking transect to detect sage-grouse pellets. We did not assess detection rates for pellets; detectability along transects typically is high and detection of pellets does not vary dramatically between areas of different vegetation cover (Dahlgren et al. 2006). We counted roost piles (>1 pellet within a 30-cm diameter circle) and single pellets. To determine the average number of pellets per group across the entire study area, we counted total pellets within the first group

TABLE 5.1. Occurrence (abundance) of sage grouse pellets counted as single pellets and roost piles in relation to distance to road during 2005 and 2006 in the Wyoming Basins Ecoregional Assessment area.

Year	Survey block type	Single pellets	Roost piles	Occurrence (%)[a]
2005	On road[b]	32 (993)	28 (230)	54.1
	Near road[c]	22 (1,163)	18 (344)	46.0
	Far road[d]	17 (961)	18 (278)	39.6
	Total	71 (3,117)	64 (852)	47.2
2006	On road	30 (3,135)	28 (312)	55.0
	Near road	21 (2,782)	19 (213)	43.4
	Far road	27 (1,646)	26 (480)	58.8
	Total	78 (7,563)	73 (1,005)	52.4
Total	On road	62 (4,128)	56 (542)	54.5
	Near road	43 (3,945)	37 (557)	44.7
	Far road	44 (2,607)	44 (758)	49.5
	Total	149 (10,680)	137 (1,857)	49.8

[a] Percent occurrence based on number of survey blocks surveyed, by type, within each year. In 2005, 159 survey blocks were surveyed (58 on-road, 49 near-road, and 48 far-road) and in 2006, 164 were surveyed (63 on-road, 54 near-road, and 51 far-road) for a total of 323 survey blocks

[b] On-road survey blocks were centered on the road

[c] Near-road survey blocks were 0-0.75 km from the nearest road

[d] Far-road survey blocks were >0.75-3 km from the nearest road

encountered on each survey block. We used roost piles as an indicator of roost site locations and single pellets as a metric of general use (Dahlgren et al. 2006).

Abundance Categories

We classified abundance levels according to frequency histograms of study blocks versus number of roost piles or single pellets per survey block. Survey blocks with zero detections were categorized as absent. Histograms of survey blocks with roost piles counts > 0 (Fig. 5.1) and single pellet counts > 0 (Fig. 5.2) were used to categorize survey blocks into two abundance classes (low and high) of roost site and general use based on patterns in the frequency distribution.

Model Development

Variables considered in the selection of the sage-grouse models included the standard candidate predictor variables (Ch. 4) with the exclusion of mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), precipitation, and the eight soil variables (pH, soil depth, salinity, clay, sand, silt, bulk density, and available water capacity). These variables were excluded because sage-grouse use a variety of different sagebrush habitats (Connelly et al. 2011) and are not directly influenced by precipitation or soil characteristics. We calculated descriptive statistics for all predictor variables within each abundance class for both roost sites and general use. We also determined the number of survey blocks with predictor variable values > 0 within each abundance class and excluded from model development all variables/extents with <20 survey blocks in a class (Ch. 4).

We used a hierarchical multi-stage modeling approach (Ch. 4) assessing all model subsets using generalized ordered logistic

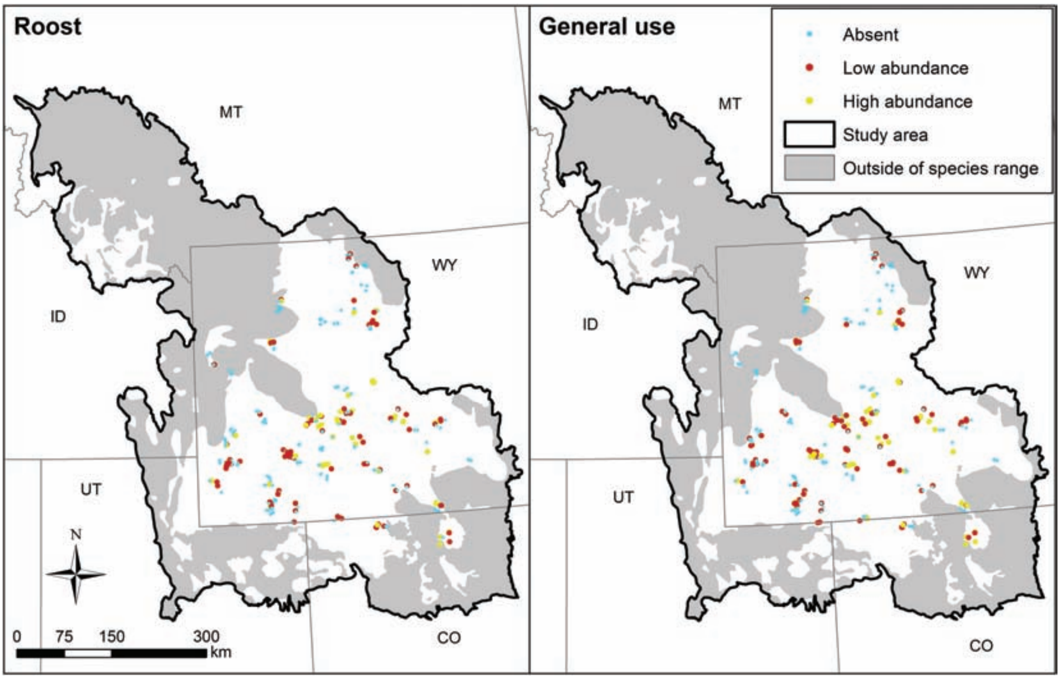

FIG. 5.3. Distribution of survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for sage-grouse pellets. Survey blocks were surveyed for both roost piles and single pellets. Roost piles were an indicator of roost locations and survey blocks were designated as absent (blue, zero roost piles), low abundance (red, 1-8 roost piles), or high abundance (yellow, >8 roost piles) for development of the roost model. Single pellets were used to develop the general habitat use model and survey blocks were designated as absent (blue, zero single pellets), low abundance (red, 1-48 single pellets), or high abundance (yellow, >48 single pellets). The gray shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004).

regression (GOLOGIT2 within Stata 10.1, Stata Corporation, College Station, TX, USA; Williams 2006). We first examined scatterplots and histograms of sagebrush, NDVI, and abiotic variables to look for non-linearities and interactions. If visual inspection indicated a potential non-linearity or interaction, these functions were tested in subsequent modeling steps. We used Akaike's Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002). We first evaluated each sagebrush and NDVI variable and identified circular moving window radii (extent) and combination of sagebrush and NDVI variables that had the strongest relationship to sage-grouse occurrence. We used these selected sagebrush/NDVI variables as a base model and tested the relationship between sage-grouse occurrence/abundance and all spatial extents for each vegetation, abiotic, and disturbance variable to identify the best spatial extent for each variable using AIC_c values. We then allowed the best spatial extent for each variable to compete with all possible combinations of other variables within the same category to identify the AIC_c-best model. We limited the number of variables in all competing models to 10% of the sample size in the lowest frequency class (Hosmer and Lemeshow 2000). After identifying the AIC_c-best model within vegetation, abiotic, and disturbance categories, we allowed variables within these models to compete both within and across submodels to develop the best overall composite model, holding the sagebrush/NDVI base constant. In order to incorporate model uncertainty, we used

TABLE 5.2. Results of AIC_c-based model selection for sage-grouse roost site selection in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI using generalized ordered logistic regression; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are presented in the table.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ALLSAGE_{1km}$	-294.43	3	594.93	0.00	0.10
2	$ALLSAGE_{1km}$ + $NDVI_{5km}$	-294.35	4	596.83	1.91	0.04
3	$ALLSAGE_{1km}$ + NDVI	-294.37	4	596.87	1.94	0.04
4	$ALLSAGE_{1km}$ + $NDVI_{3km}$	-294.38	4	596.88	1.95	0.04
5	$ALLSAGE_{1km}$ + $NDVI_{1km}$	-294.38	4	596.88	1.95	0.04
6	$ALLSAGE_{1km}$ + $NDVI_{270}$	-294.40	4	596.92	1.99	0.04

[a] Variable definitions provided in Table 4.2.

a weighted average of coefficients from models with a cumulative AIC_c weight of just ≥ 0.9 (Burnham and Anderson 2002) to create a composite model. Coefficients were set to zero when a model did not contain a particular variable. Accuracy of statistical models was evaluated with receiver operating characteristic (ROC) estimating the area under the curve (AUC, Metz 1978). We determined an optimal cutoff threshold for predicting the presence-absence of sage-grouse using a sensitivity-specificity equality approach (Liu et al. 2005) and applied this threshold to assess predictive capability for each model (Nielsen et al. 2004).

Spatial Application and Dose Response

We predicted species occurrence in a Geographic Information System (GIS) at a 90-m cell size using the final model coefficients in ArcGIS raster calculator (ESRI 2006). Final model predictions were binned into 10% probability classes for summary and display. Masks of non-sagebrush habitats (areas with <3% sagebrush habitat in a 5-km moving window) and those areas outside the known range of sage-grouse (Schroeder et al. 2004) were used to identify areas where predictions were either not possible or where it was not reasonable to extrapolate model predictions. Probability of occurrence maps were subsequently combined into a composite three-class abundance surface (absent, low, and high). The bin breakpoint separating absent from low/high abundance habitat was based on the sensitivity-specificity equality threshold to maximize prediction success for each model. Within low/high abundance habitat, the threshold was set at the point where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. This map allowed us to first assess the proportion of the WBEA area likely to contain sage-grouse, and then further delineate the WBEA into areas likely to support low or high abundance of sage-grouse.

Following development of both the roost and general use models, we plotted predicted probability of sage-grouse occurrence relative to changes in sagebrush quantity. This permitted us to assess levels of sagebrush required for sage-grouse presence, as well as to characterize response to losses or fragmentation of sagebrush habitat. We calculated these values using the Dose Response Calculator for ArcGIS tool (Hanser et al. 2011). We used the optimal cut-off threshold from the sensitivity-specificity analysis to identify the sagebrush threshold value above which the species was likely to occur.

TABLE 5.3. Evaluation statistics from AIC$_c$-based univariate model selection for sage-grouse roost site selection in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and Akaike weight [w_i]). We ran generalized ordered logistic models with all sagebrush within 1 km as a base model for all variables tested. We used AIC$_c$ to identify the spatial extent at which sage-grouse respond to individual variables.

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	CFRST$_{3km}$	-293.92	4	595.96	0.00	0.38
	CFRST$_{5km}$	-293.94	4	596.00	0.05	0.37
	CFRST$_{18km}$	-294.33	4	596.79	0.83	0.25
	GRASS$_{18km}$	-293.87	4	595.87	0.00	0.46
	GRASS$_{3km}$	-294.42	4	596.96	1.10	0.27
	GRASS$_{5km}$	-294.42	4	596.96	1.10	0.27
	MIX$_{3km}$	-291.57	4	591.26	0.00	0.73
	MIX$_{5km}$	-293.08	4	594.28	3.02	0.16
	MIX$_{1km}$	-294.05	4	596.22	4.96	0.06
	MIX$_{18km}$	-294.42	4	596.96	5.70	0.04
	RIP$_{1km}$	-290.75	4	589.63	0.00	0.67
	RIP$_{540}$	-292.05	4	592.22	2.60	0.18
	RIP$_{5km}$	-292.85	4	593.83	4.21	0.08
	RIP$_{3km}$	-293.33	4	594.78	5.15	0.05
	RIP$_{18km}$	-294.30	4	596.72	7.09	0.02
	SALT$_{18km}$	-294.39	4	596.91	0.00	0.34
	SALT$_{3km}$	-294.40	4	596.93	0.02	0.33
	SALT$_{5km}$	-294.40	4	596.93	0.02	0.33
	EDGE$_{5km}$	-292.95	4	594.02	0.00	0.48
	CONTAG$_{5km}$	-293.62	4	595.37	1.34	0.25
	CONTAG$_{3km}$	-294.18	4	596.49	2.47	0.14
	EDGE$_{3km}$	-294.27	4	596.67	2.65	0.13
Abiotic	CTI[b]	-292.09	5	594.36	0.00	0.61
	CTI	-293.58	4	595.29	0.92	0.39
	ELEV	-292.91	4	593.95	0.00	0.67
	ELEV[b]	-292.57	5	595.32	1.38	0.33
	iH2Od$_{250}$[c]	-293.96	4	596.04	0.00	0.37
	iH2Od$_{500}$[c]	-294.09	4	596.30	0.25	0.33
	iH2Od$_{1km}$[c]	-294.19	4	596.51	0.47	0.30
	pH2Od$_{250}$[c]	-292.41	4	592.95	0.00	0.52
	pH2Od$_{500}$[c]	-292.97	4	594.06	1.11	0.30
	pH2Od$_{1km}$[c]	-293.45	4	595.02	2.07	0.18
	SOLAR[b]	-290.24	5	590.67	0.00	0.96
	SOLAR	-294.33	4	596.78	6.12	0.04

TABLE 5.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	Tmin	-294.40	4	596.92	0.00	1.00
	TRI_{270}	-282.53	4	573.19	0.00	0.48
	TRI_{540}	-282.55	4	573.22	0.03	0.47
	TRI	-285.32	4	578.77	5.58	0.03
	TRI_{1km}	-285.59	4	579.30	6.11	0.02
	TRI_{3km}	-291.81	4	591.75	18.56	0.00
	TRI_{5km}	-292.71	4	593.55	20.36	0.00
	TRI_{18km}	-294.06	4	596.25	23.06	0.00
Disturbance	AG_{1km}^{c}	-294.14	4	596.41	0.00	0.39
	AG_{500}^{c}	-294.33	4	596.78	0.37	0.32
	AG_{250}^{c}	-294.41	4	596.95	0.54	0.29
	$MjRD_{1km}^{c}$	-290.38	4	588.89	0.00	0.45
	$MjRD_{500}^{c}$	-290.44	4	589.00	0.11	0.42
	$MjRD_{250}^{c}$	-291.65	4	591.44	2.55	0.13
	$PIPE_{500}^{c}$	-291.87	4	591.87	0.00	0.39
	$PIPE_{1km}^{c}$	-292.09	4	592.31	0.44	0.31
	$PIPE_{250}^{c}$	-292.12	4	592.36	0.49	0.30
	$POWER_{500}^{c}$	-289.46	4	587.05	0.00	0.43
	$POWER_{1km}^{c}$	-289.46	4	587.05	0.00	0.42
	$POWER_{250}^{c}$	-290.51	4	589.14	2.09	0.15
	$RDdens_{3km}$	-293.42	4	594.96	0.00	0.22
	$RDdens_{5km}$	-293.71	4	595.54	0.58	0.16
	$RDdens_{1km}$	-293.88	4	595.89	0.93	0.14
	$RDdens_{540}$	-294.39	4	596.90	1.94	0.08
	$RDdens_{18km}$	-294.43	4	596.98	2.02	0.08
	$RDdens_{270}$	-294.43	4	596.98	2.02	0.08
	$2RD_{250}^{c}$	-294.37	4	596.86	1.91	0.08
	$2RD_{1km}^{c}$	-294.40	4	596.93	1.97	0.08
	$2RD_{500}^{c}$	-294.43	4	596.98	2.02	0.08
	$WELL_{1km}^{c}$	-290.50	4	589.12	0.00	0.68
	$WELL_{500}^{c}$	-291.64	4	591.41	2.29	0.22
	$WELL_{250}^{c}$	-292.34	4	592.81	3.70	0.11

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function ($e^{(\text{Euclidean distance from feature/-distance parameter})}$)

TABLE 5.4. Results of AIC_c-based submodel selection for sage-grouse roost site selection in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ALLSAGE_{1km} + CFRST_{3km} + MIX_{3km} + RIP_{1km} + EDGE_{5km}$	-283.71	7	581.78	0.00	0.24
	2	$ALLSAGE_{1km} + MIX_{3km} + RIP_{1km} + EDGE_{5km}$	-284.79	6	581.84	0.06	0.23
	3	$ALLSAGE_{1km} + MIX_{3km} + RIP_{1km} + EDGE_{5km} + SALT_{18km}$	-284.33	7	583.01	1.23	0.13
Abiotic	1	$ALLSAGE_{1km} + ELEV + Tmin + TRI_{270}$	-274.85	6	561.96	0.00	0.41
	2	$ALLSAGE_{1km} + ELEV + iH2Od_{250} + Tmin + TRI_{270}$	-274.32	7	563.00	1.05	0.24
	3	$ALLSAGE_{1km} + ELEV + pH2Od_{250} + Tmin + TRI_{270}$	-274.50	7	563.35	1.40	0.21
Disturbance	1	$ALLSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500}$	-282.50	6	577.27	0.00	0.33
	2	$ALLSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + PIPE_{1km}$	-282.29	7	578.94	1.67	0.15
	3	$ALLSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + AG_{1km}$	-282.30	7	578.95	1.69	0.14

[a] Variable definitions provided in Table 4.2

Model Evaluation

We evaluated roost and general use models using sage-grouse lek data obtained from the Wyoming Game and Fish lek count database (unpublished data on file). Although lek locations represent one portion of the annual life cycle of sage-grouse, these locations are generally in or adjacent to nesting habitats (Connelly et al. 2011). Standardized lek survey protocols (Connelly et al. 2003) and the point-based nature of lek counts provided an ideal data set for validating our models; lek data are often used to assess population trajectories because they represent abundance in a region (Fedy and Aldridge 2011, Garton et al. 2011). We evaluated model predictions by assessing the proportion of active leks that were correctly classified as low or high abundance areas, using the pixel value intersected with each lek site (point). We then compared observed proportion of lek locations in each probability bin against expected proportion of locations from the model, using regression analysis to evaluate model fit (Johnson et al. 2006). A model with good fit should have a high R^2 value, a slope not different from 1.0, and an intercept not different from zero (Johnson et al. 2006). We also compared predicted model probabilities within each 10% probability class to (1) mean maximum count of male sage-grouse (2003-2006) as an abundance metric and (2) proportion of total leks identified as inactive (counts with zero birds during the same time frame). Finally, we calculated the same metrics for the three abundance classes (absent, low, and high).

RESULTS

Field Surveys

We counted sage-grouse pellets on 323 survey blocks (n = 159 in 2005 and 164 in 2006). For both years combined, 50% of survey blocks contained single pellets or roost piles. Sage-grouse use generally was highest on on-road survey blocks, medium

TABLE 5.5. Results of AIC$_c$-based model selection for combined sage-grouse roost site selection models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and cumulative Akaike weight [Σw_i]). Models were developed from a combination of vegetation, abiotic and disturbance variables using generalized ordered logistic regression. The generalized ordered logistic regression models resulted in parallel lines with a separate intercept value for the low (Present) and high (High) abundance categories. Models shown with cumulative Akaike weight (w_i) of just $\geq$ 0.9.

Rank	Intercept	ALLSAGE$_{1km}$	RIP$_{1km}$	TRI$_{270}$	MjRD$_{1km}$	POWER$_{500}$
1	Present: -1.34 (0.65) High: -2.94 (0.67)	2.72 (0.71)	7.59 (2.39)	-0.05 (0.01)	-1.59 (0.59)	-2.19 (0.91)
2	Present: -3.54 (1.03) High: -5.14 (1.06)	2.45 (0.67)	7.23 (2.37)	-0.06 (0.01)	-1.97 (0.59)	
3	Present: -1.38 (0.66) High: -2.99 (0.67)	2.84 (0.72)	7.36 (2.37)	-0.05 (0.01)	-2.02 (0.59)	
4	Present: -3.75 (1.03) High: -5.35 (1.06)	2.62 (0.68)	7.25 (2.36)	-0.05 (0.01)		-2.73 (0.94)
5	Present: -4.78 (1.19) High: -6.39 (1.21)	2.36 (0.63)		-0.06 (0.01)	-2.04 (0.59)	
6	Present: -1.71 (0.65) High: -3.3 (0.67)	3.03 (0.73)	7.42 (2.37)	-0.05 (0.01)		-2.71 (0.92)
7	Present: -0.83 (0.6) High: -2.44 (0.62)	2.51 (0.67)		-0.05 (0.01)	-1.71 (0.59)	-2.2 (0.88)
8	Present: -3.09 (1.01) High: -4.69 (1.03)	2.21 (0.62)		-0.06 (0.01)	-1.62 (0.59)	-2.13 (0.9)
9	Present: -3.14 (1.03) High: -4.74 (1.05)	2.34 (0.63)		-0.06 (0.01)	-2.04 (0.59)	
10	Present: -4.87 (1.17) High: -6.47 (1.2)	2.48 (0.63)		-0.06 (0.01)		-2.76 (0.93)
11	Present: -1.6 (0.66) High: -3.19 (0.68)	2.69 (0.72)	8.13 (2.39)	-0.05 (0.01)	-1.92 (0.59)	
12	Present: -3.35 (1.02) High: -4.94 (1.04)	2.48 (0.64)		-0.05 (0.01)		-2.66 (0.91)
13	Present: -5.58 (1.2) High: -7.17 (1.23)	2.85 (0.69)	7.87 (2.37)	-0.06 (0.01)		
14	Present: -1.77 (0.7) High: -3.36 (0.71)	3.18 (0.78)	8.02 (2.40)	-0.06 (0.01)	-1.95 (0.59)	
15	Present: -1.89 (0.66) High: -3.47 (0.68)	2.87 (0.73)	8.20 (2.40)	-0.05 (0.01)		-2.7 (0.93)
16	Present: -3.78 (1.07) High: -5.38 (1.09)	2.13 (0.62)		-0.05 (0.01)	-1.92 (0.59)	
17	Present: -1.43 (0.65) High: -3.01 (0 .67)	2.70 (0.71)	7.63 (2.38)	-0.05 (0.01)	-1.93 (0.59)	

[a] Variable definitions provided in Table 4.2

[b] Coefficients and standard errors multiplied by 10^2

TABLE 5.5. Extended

$ELEV^b$	$WELL_{500}$	Tmin	MIX_{3km}	$CFRST_{3km}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
					-267.09	7	548.55	0.00	0.153
0.12 (0.04)					-267.23	7	548.82	0.27	0.287
	-1.97 (0.78)				-267.30	7	548.97	0.42	0.412
0.11 (0.04)					-267.79	7	549.95	1.4	0.488
0.23 (0.06)		0.24 (0.09)			-267.89	7	550.15	1.6	0.557
	-1.87 (0.78)				-267.94	7	550.25	1.71	0.622
	-2.11 (0.79)				-268.06	7	550.49	1.95	0.680
0.12 (0.04)					-268.28	7	550.92	2.38	0.727
0.12 (0.04)	-1.96 (0.77)				-268.29	7	550.94	2.39	0.773
0.22 (0.06)		0.23 (0.09)			-268.75	7	551.87	3.33	0.802
			16.86 (9.36)		-269.25	7	552.87	4.32	0.820
0.11 (0.04)	-1.85 (0.77)				-269.29	7	552.95	4.4	0.837
0.22 (0.06)		0.25 (0.09)			-269.41	7	553.19	4.64	0.852
				3.54 (1.95)	-269.48	7	553.32	4.77	0.866
			16.85 (9.27)		-269.51	7	553.38	4.83	0.880
0.14 (0.04)			20.02 (9.8)		-269.73	7	553.82	5.27	0.891
					-270.87	6	554.02	5.48	0.901

on far-road survey blocks, and lowest on near-road survey blocks (Table 5.1). Annual differences in occurrence were evident with the highest occurrence on on-road survey blocks in 2005 and far-road survey blocks in 2006. Total single pellet counts (general use model) were highest on on-road survey blocks, medium on near-road survey blocks, and lowest on far-road survey blocks. Total roost piles had the opposite relationship with the highest count at far-road survey blocks, medium at near-road survey blocks, and lowest at on-road survey blocks.

We detected single pellets at 46.1% and roost piles at 42.4% of all sampled survey blocks. We counted 10,680 single pellets and 1,857 roost piles across both years. The maximum count at any given survey block was 864 single pellets and 141 roost piles. Based on the total pellet size within the first roost pile encountered on each survey block, mean (SE) group size per root pile was 23.0 (1.3) pellets ($n = 137$).

Abundance Categories

The frequency distribution illustrates patterns observed in abundance of sage-grouse pellets on survey block locations (Figs. 5.1 and 5.2). Survey blocks with zero roost pile detections were classified as absent whereas those with 1–8 roost piles were classified as low abundance, and those with >8 piles were assigned a high abundance value for modeling purposes (Fig. 5.3). Survey blocks were classified using a similar three class abundance scheme for single pellet detections; zero detection survey blocks were classified as absent, 1–48 single pellets as low abundance, and >48 single pellets as high abundance (Fig. 5.3).

Model Development

Eight predictor variables were excluded because they had <20 survey blocks with values > 0 in the least frequent abundance category (high) for both roost sites and general use. These variables included proportion of coniferous forest (0.27-, 0.54-, and 1-km radii), grassland (0.27 km), mixed shrubland (0.27 and 0.54 km), salt desert shrubland (0.27 km), and riparian (0.27 km). We excluded highly correlating variables ($r_s \geq 0.7$) from the candidate set in both models: sagebrush mean patch size (1 and 3 km), all sagebrush contagion (1 km), mean annual maximum temperature, and slope. Additional variables excluded from the roost model because of correlation included all sagebrush mean patch size (5 km) and all sagebrush edge density (1 km). Several variables caused instability in the generalized ordered logistic regression procedure and were removed from submodel development. These variables included salt desert shrubland (0.54, 1, 3, and 5 km), solar radiation, and 0.25-km distance decay from power lines for the general use model; and grassland (0.54 and 1 km) and salt desert shrubland (0.54 and 1 km) for the roost model.

Roost model

All sagebrush (*Artemisia* spp.) within 1 km ($ALLSAGE_{1km}$) was the only predictor variable in the AIC_c-selected top sagebrush/NDVI model when predicting roost site occurrence (Table 5.2). All models with $\Delta AIC_c \leq 2$ contained $ALLSAGE_{1km}$, as the sagebrush component, and NDVI at multiple spatial extents. There was 14.9% more $ALLSAGE_{1km}$ at high abundance roost sites (83.3%, SE = 2.38) and 14.6% more at low abundance use sites (83.0%, SE = 1.96) when compared with unused sites (68.5%, SE = 1.85; Appendix 5.1).

After assessing individual covariates (Table 5.3) within model subgroups, the top roost site vegetation submodel consisted of three land cover variables (riparian within 1 km [RIP_{1km}], conifer forest within 3 km [$CFRST_{3km}$], and mixed shrubland within 3 km [MIX_{3km}]) and all sagebrush edge density within 5 km ($EDGE_{5km}$), in addition to the sagebrush base model (Table 5.4). Important abiotic predictors of sage-grouse roost site locations included elevation (ELEV), topographic ruggedness within 0.27 km (TRI_{270}), and minimum yearly temperature (Tmin) (Table 5.4). Three disturbance factors, 1-km distance decay from interstates/major highways ($MjRD_{1km}$), 0.5-km distance decay from power lines ($POWER_{500}$), and 1-km distance decay from oil/gas wells ($WELL_{1km}$), were included in the top disturbance model (Table 5.4).

The AIC_c-selected top sage-grouse roost site model was a combination of vegetation, abiotic, and disturbance factors. Sage-grouse roost sites were positively associated with large expanses of sagebrush and riparian habitat and negatively associated with rugged terrain and proximity to major roads (interstates and major highways) and power lines (Table 5.5). However, the low Akaike weight ($w_i = 0.15$) indicated there were other suitable candidate models. An examination of variables in the other candidate models with a cumulative Akaike weight of just ≥ 0.9 indicated that sage-grouse roost site locations were positively associated with mixed shrubland, conifer forest, increased elevation, and higher minimum yearly temperatures, and negatively associated with proximity to oil/gas wells (Table 5.5). The final composite model-averaged linear predictors of occurrence for the low (Eq. 5.1) and high (Eq. 5.2) abundance categories are listed below.

$$Prob_{low} = 1 / (1 + (exp(-(-2.81 + 2.66 * ALLSAGE_{1km} + 5.15 * RIP_{1km} - 0.05 * TRI_{270} - 1.08 * MjRD_{1km} - 1.34 * POWER_{500} - 0.28 * WELL_{1km} + 0.06 * Tmin + 0.0008 * ELEV + 4.45 * MIX_{3km} + 0.26 * CFRST_{3km}))) \tag{5.1}$$

$$Prob_{high} = 1 / (1 + (exp(-(-4.40 + 2.66 * ALLSAGE_{1km} + 5.15 * RIP_{1km} - 0.05 * TRI_{270} - 1.08 * MjRD_{1km} - 1.34 * POWER_{500} - 0.28 * WELL_{1km} + 0.06 * Tmin + 0.0008 * ELEV + 4.45 * MIX_{3km} + 0.26 * CFRST_{3km})))) \tag{5.2}$$

The AIC_c-selected top model had good accuracy in predicting both sage-grouse roost site presence (ROC AUC = 0.79) and high abundance roost site areas (ROC AUC = 0.74). The composite model of sage-grouse roost occurrence was an improvement over the top model with excellent model accuracy for presence (ROC AUC = 0.81) and good model accuracy for high density (ROC AUC = 0.78). Our model of sage-grouse roost occurrence had an optimal sensitivity-specificity equality threshold of 0.48 when determining presence/absence, which resulted in the correct classification of 74.7% of survey block locations.

General use model

All big sagebrush (*A. tridentata*) within 1 km ($ABIGSAGE_{1km}$) was the AIC_c-selected top sagebrush/NDVI model when predicting sage-grouse general use (Table 5.6). All models with $\Delta AIC_c < 2$ contained $ABIGSAGE_{1km}$ or $ALLSAGE_{1km}$, as the sagebrush component, and NDVI at all spatial extents. $ABIGSAGE_{1km}$ increased with increasing use class. There was 18.0% more $ABIGSAGE_{1km}$ at high abundance general use sites (83.8% SE = 1.83) and 13.2% more at low abundance general use sites (79.0% SE = 2.13) when compared with unused sites (65.8% SE = 1.88; Appendix 5.2).

After assessing individual covariates (Table 5.7) within model subgroups, the top general use vegetation submodel consisted of RIP_{1km}, MIX_{3km}, coniferous forest within 5 km ($CFRST_{5km}$) and all sagebrush edge density within 1 km ($EDGE_{1km}$), in addition to the sagebrush base model (Table 5.8). ELEV, TRI_{270}, and Tmin were selected as important abiotic predictors of sage-grouse general use locations (Table 5.8). Distance decay from three disturbance factors, $MjRD_{1km}$, $POWER_{500}$, and $WELL_{1km}$, were included in the top disturbance submodel (Table 5.8).

The AIC_c-selected top sage-grouse general use model was a combination of vegetation, abiotic, and disturbance factors. Sage-grouse general use was positively associated with large expanses of all big sagebrush and higher elevations and negatively associated with rugged terrain and proximity to interstates and major highways, power lines, and oil/gas wells (Table 5.9). Although the weight of evidence was high for the top model (w_i = 0.58), there were other suitable candidate models. An examination of variables in the other eight candidate models with cumulative Akaike weight of just ≥ 0.9 showed that sage-grouse general use was also positively associated with mixed shrubland and riparian land cover, and higher minimum yearly temperatures (Table 5.9). The final composite model-averaged linear predictor of occurrence for the low (Eq. 5.3) and high (Eq. 5.4) abundance categories are listed below.

$$\text{Prob}_{\text{low}} = 1 / (1 + (\exp(-(-3.56 + 2.57 * \text{ABIGSAGE}_{\text{1km}} - 0.07 * \text{TRI}_{270} + 0.002 * \text{ELEV} - 1.75 * \text{WELL}_{\text{1km}} - 2.44 * \text{MjRD}_{\text{1km}} - 2.12 * \text{POWER}_{500} + 0.04 * \text{Tmin} + 0.25 * \text{RIP}_{\text{1km}} + 0.99 * \text{MIX}_{\text{3km}})))) \tag{5.3}$$

$$\text{Prob}_{\text{high}} = 1 / (1 + (\exp(-(-5.26 + 2.57 * \text{ABIGSAGE}_{\text{1km}} - 0.07 * \text{TRI}_{270} + 0.002 * \text{ELEV} - 1.75 * \text{WELL}_{\text{1km}} - 2.44 * \text{MjRD}_{\text{1km}} - 2.12 * \text{POWER}_{500} + 0.04 * \text{Tmin} + 0.25 * \text{RIP}_{\text{1km}} + 0.99 * \text{MIX}_{\text{3km}})))) \tag{5.4}$$

The AIC_c-selected top model had excellent model accuracy predicting sage-grouse general use occurrence (ROC AUC = 0.82) and good accuracy when predicting high density general use areas (ROC AUC = 0.75). The composite model of sage-grouse general use occurrence had improved model accuracy compared to the top single model for both presence (ROC AUC = 0.83) and high density areas (ROC AUC = 0.81). Our model of sage-grouse general use had an optimal sensitivity and specificity equality threshold of 0.49 when determining presence/absence, which resulted in 75.2% survey blocks locations correctly classified.

Spatial Application and Dose Response

Sage-grouse roost site and general use occurrence was predicted to be highest in the central part of the WBEA area (Figs. 5.4, 5.5). We estimated that the WBEA contained approximately 52,979 km^2 (32.4%) of suitable sage-grouse roost habitat and 63,784 km^2 (39.2%) of suitable sage-grouse general use habitat, much of which was overlapping. Where sage-grouse were predicted to be present, high-quality habitat based on density of pellets was much smaller for both roosting (4,170 km^2; 7.9%; Fig. 5.6) and general use (16,760 km^2; 26.2%; Fig. 5.7). Sage-grouse were more likely to roost in areas with at least 88% (61% at +1SD) all sagebrush habitat within 1 km (Fig. 5.8) and general use areas with at least 81% (51% at +1SD) all big sagebrush habitat, also within 1 km (Fig. 5.9).

Model Evaluation

Our final composite models of sage-grouse occurrence correctly classified active sage-grouse lek locations as occurrence locations with 75.2% accuracy for the roost site model and 79.5% for the general use model. Both models also validated well with slope of observed versus expected values not differing from 1.0, the intercept not differing from zero for roosting (slope = 1.31, 95% CI = 0.15-2.47; intercept = -0.03, 95% CI = -0.16-0.99; r_s = 0.92, $p < 0.001$) and general use (slope = 1.73, 95% CI=-0.45-3.01; intercept = -0.07, 95% CI = -0.21-0.64; r_s = 0.77 p = 0.009). The mean maximum count (2003-2006) of sage-grouse at active leks increased, and the percentage of inactive leks decreased, with increasing predicted probability of occurrence for both roost and general use models (Figs. 5.10, 5.11). When probability of occurrence was transformed into three abundance classes this same relationship

TABLE 5.6. Results of AIC_c-based model selection for sage-grouse general use in the Wyoming Basins Ecoregional Assessment area.in relation to multi-scale sagebrush and NDVI using generalized ordered logistic regression; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{1km}$	-303.43	3	612.93	0.00	0.05
2	$ABIGSAGE_{1km} + NDVI_{3km}$	-302.41	4	612.95	0.02	0.05
3	$ABIGSAGE_{1km} + NDVI_{5km}$	-302.42	4	612.96	0.04	0.05
4	$ABIGSAGE_{1km} + NDVI_{540}$	-302.80	4	613.72	0.80	0.03
5	$ALLSAGE_{1km} + NDVI_{3km}$	-302.80	4	613.73	0.81	0.03
6	$ALLSAGE_{1km} + NDVI_{5km}$	-302.81	4	613.74	0.81	0.03
7	$ABIGSAGE_{1km} + NDVI_{1km} + NDVI_{1km}^2$	-299.74	7	613.84	0.91	0.03
8	$ABIGSAGE_{1km} + NDVI_{1km}$	-302.86	4	613.85	0.92	0.03
9	$ABIGSAGE_{1km} + NDVI_{270}$	-302.87	4	613.86	0.94	0.03
10	$ALLSAGE_{1km}$	-303.92	3	613.91	0.98	0.03
11	$ABIGSAGE_{1km} + NDVI_{18km}$	-302.96	4	614.05	1.12	0.03
12	$ABIGSAGE_{1km} + NDVI$	-302.98	4	614.09	1.16	0.03
13	$ABIGSAGE_{1km} + NDVI + NDVI^2$	-301.99	5	614.17	1.24	0.02
14	$ABIGSAGE_{1km} + NDVI_{270} + NDVI_{270}^2$	-302.16	5	614.51	1.59	0.02
15	$ALLSAGE_{1km} + NDVI_{540}$	-303.20	4	614.52	1.60	0.02
16	$ALLSAGE_{1km} + NDVI_{18km}$	-303.23	4	614.58	1.65	0.02
17	$ALLSAGE_{1km} + NDVI_{1km}$	-303.28	4	614.68	1.75	0.02
18	$ALLSAGE_{1km} + NDVI_{270}$	-303.28	4	614.69	1.76	0.02
19	$ABIGSAGE_{1km} + NDVI_{540} + NDVI_{540}^2$	-302.28	5	614.76	1.83	0.02
20	$ABIGSAGE_{1km} + NDVI_{18km} + NDVI_{18km}^2$	-300.21	7	614.77	1.84	0.02
21	$ALLSAGE_{1km} + NDVI_{18km} + NDVI_{18km}^2$	-300.28	7	614.91	1.98	0.02

[a] Variable definitions provided in Table 4.2

held true for the predicted density classes (Tables 5.10, 5.11), suggesting both our low and high density models captured trends in lek attendance by sage-grouse.

DISCUSSION

Sage-grouse occurrence was variable throughout the known range in the WBEA area (Schroeder et al. 2004), with the highest probabilities of occurrence throughout central Wyoming. Models describing sage-grouse general use and roost sites had strong positive relationships with the amount of sagebrush habitat within a 1-km radius; this spatial scale is similar to winter habitats selected in Wyoming (1.13-km radius; Doherty et al. 2008) and nest, brood, and winter habitat selection in Alberta (0.564-km radius; Aldridge and Boyce 2007, Carpenter et al. 2010). Amount of sagebrush habitat surrounding lek locations is an important determinant of lek population trend (Johnson et al. 2011). Sage-grouse select intact sagebrush landscapes that may provide protection against predation and enhance nesting success (Aldridge and Boyce 2007), thus contrib-

TABLE 5.7. Evaluation statistics from AIC$_c$-based univariate model selection for sage-grouse general use in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and Akaike weight [w_i]). We ran generalized ordered logistic regression models with the all big sagebrush (1-km radius) variable as a base model for all variables tested. We used AIC$_c$ to identify the spatial extent at which sage-grouse respond to individual variables.

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	CFRST$_{5km}$	-302.36	4	612.97	0.00	0.35
	CFRST$_{3km}$	-302.37	4	613.00	0.03	0.35
	CFRST$_{1km}$	-302.97	4	614.19	1.22	0.19
	CFRST$_{18km}$	-303.56	4	615.37	2.40	0.11
	GRASS$_{18km}$	-302.33	4	612.92	0.00	0.40
	GRASS$_{540}$	-303.07	4	614.39	1.47	0.19
	GRASS$_{3km}$	-303.35	4	614.95	2.03	0.14
	GRASS$_{5km}$	-303.37	4	615.00	2.08	0.14
	GRASS$_{1km}$	-303.54	4	615.32	2.40	0.12
	MIX$_{3km}$	-301.84	4	611.93	0.00	0.46
	MIX$_{540}$	-302.62	4	613.49	1.56	0.21
	MIX$_{5km}$	-302.88	4	614.02	2.09	0.16
	MIX$_{1km}$	-303.45	4	615.14	3.21	0.09
	MIX$_{18km}$	-303.61	4	615.47	3.54	0.08
	RIP$_{1km}$	-302.01	4	612.27	0.00	0.39
	RIP$_{540}$	-302.72	4	613.70	1.43	0.19
	RIP$_{5km}$	-302.80	4	613.85	1.58	0.17
	RIP$_{3km}$	-302.84	4	613.93	1.66	0.17
	RIP$_{18km}$	-303.54	4	615.33	3.06	0.08
	EDGE$_{1km}$	-300.52	4	609.28	0.00	0.66
	EDGE$_{5km}$	-302.16	4	612.57	3.29	0.13
	EDGE$_{3km}$	-301.61	5	613.60	4.32	0.08
	PATCH$_{5km}$	-302.88	4	614.01	4.73	0.06
	CONTAG$_{5km}$	-303.12	4	614.48	5.20	0.05
	CONTAG$_{3km}$	-303.56	4	615.37	6.09	0.03
	SALT$_{18km}$	-301.95	5	614.28	0.00	1.00
Abiotic	CTI[b]	-299.77	5	609.93	0.00	0.87
	CTI	-302.71	4	613.66	3.73	0.13
	ELEV	-301.14	4	610.53	0.00	1.00
	pH2Od$_{250}$[c]	-302.45	4	613.15	0.00	0.35
	pH2Od$_{500}$[c]	-302.48	4	613.21	0.05	0.34
	pH2Od$_{1km}$[c]	-302.57	4	613.40	0.25	0.31
	iH2Od$_{250}$[c]	-302.86	4	613.98	0.00	0.43

TABLE 5.7. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	iH2Od$_{500}^{c}$	-303.14	4	614.54	0.56	0.32
	iH2Od$_{1km}^{c}$	-303.42	4	615.08	1.10	0.25
	Tmin	-303.49	4	615.23	0.00	1.00
	TRI$_{270}$	-287.69	4	583.62	0.00	0.34
	TRI$_{540}$	-287.69	4	583.64	0.02	0.34
	TRI$_{270}^{b}$	-287.60	5	585.59	1.96	0.13
	TRI$_{540}^{b}$	-287.68	5	585.75	2.12	0.12
	TRI	-289.85	4	587.95	4.32	0.04
	TRI$_{1km}$	-290.52	4	589.29	5.67	0.02
	TRI^{b}	-289.74	5	589.87	6.24	0.01
	TRI$_{1km}^{b}$	-290.52	5	591.42	7.79	0.01
	TRI$_{3km}$	-297.70	4	603.65	20.02	0.00
	TRI$_{3km}^{b}$	-297.19	5	604.77	21.14	0.00
	TRI$_{5km}$	-298.81	4	605.88	22.25	0.00
	TRI$_{5km}^{b}$	-298.41	5	607.19	23.57	0.00
	TRI$_{18km}$	-301.69	4	611.63	28.01	0.00
	TRI$_{18km}^{b}$	-301.66	5	613.69	30.07	0.00
Disturbance	AG$_{1km}^{c}$	-302.93	4	614.11	0.00	0.46
	AG$_{500}^{c}$	-303.35	4	614.95	0.84	0.30
	AG$_{250}^{c}$	-303.57	4	615.39	1.28	0.24
	PIPE$_{1km}^{c}$	-300.90	4	610.05	0.00	0.48
	PIPE$_{500}^{c}$	-301.26	4	610.78	0.73	0.33
	PIPE$_{250}^{c}$	-301.82	4	611.88	1.83	0.19
	POWER$_{500}^{c}$	-297.32	4	602.88	0.00	0.59
	POWER$_{1km}^{c}$	-297.67	4	603.58	0.70	0.41
	MjRD$_{1km}^{c}$	-296.24	4	600.73	0.00	0.67
	MjRD$_{500}^{c}$	-297.12	4	602.49	1.75	0.28
	MjRD$_{250}^{c}$	-298.91	4	606.07	5.33	0.05
	RDdens$_{3km}$	-300.43	4	609.11	0.00	0.42
	RDdens$_{5km}$	-300.93	4	610.11	1.00	0.26
	RDdens$_{1km}$	-301.61	4	611.47	2.36	0.13
	2RD$_{250}^{c}$	-301.36	5	613.11	4.00	0.06
	2RD$_{500}^{c}$	-301.63	5	613.63	4.52	0.04
	RDdens$_{540}$	-303.19	4	614.64	5.53	0.03
	RDdens$_{270}$	-303.26	4	614.78	5.67	0.02

TABLE 5.7. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	RDdens$_{18km}$	-303.28	4	614.81	5.70	0.02
	2RD$_{1km}$[c]	-303.60	4	615.46	6.35	0.02
	WELL$_{1km}$[c]	-298.69	4	605.63	0.00	0.67
	WELL$_{500}$[c]	-299.74	4	607.73	2.11	0.23
	WELL$_{250}$[c]	-300.65	4	609.55	3.92	0.09

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function ($e^{(\text{Euclidian distance from feature/-distance parameter})}$)

uting to increased recruitment and population trends based on attendance at leks.

Sage-grouse also were more likely to occur in areas near riparian zones. Riparian habitats provide higher cover and diversity of forbs and insects that are important for sage-grouse broods (Drut et al. 1994a, 1994b; Johnson and Boyce 1991; Sveum et al. 1998), and lek population trends in the Wyoming Basin sage-grouse management zone exhibited a positive association with increased riparian habitat (Johnson et al. 2011). This relationship is most likely related to mesic habitats characterized by landscape-scale measures of riparian habitat. Riparian habitat can be more risky for sage-grouse broods because chicks experience reduced survival in this habitat type (Aldridge and Boyce 2007). The association of sage-grouse with mixed shrubland and conifer forest land cover within a 3-km radius may be due to the proximity of these habitat types to favorable conditions or conditions within the habitat type itself. Sage-grouse use shrubs in the mixed shrubland land cover (i.e., rabbitbrush [*Chrysothamnus* spp. and *Ericameria* spp.] and horsebrush [*Tetradymia* spp.]) as both nesting and hiding cover, and birds may also occupy sagebrush habitat with some conifer nearby (Connelly et al. 2011). However, the effect of conifer in our roost site model was weak, only occurring in one of the 17 models in the top AIC$_c$-selected set (w_i = 0.02, Table 5.5).

Sage-grouse avoided areas with rugged terrain in our study area, selecting for flat valleys and rolling hills with low topographic ruggedness, which is typical of sage-grouse habitat (Eng and Schladweiler 1972, Connelly et al. 1991, Gregg et al. 1994). Sage-grouse seek out habitats with less rugged terrain during winter (Beck 1977, Doherty et al. 2008, Carpenter et al. 2010) and avoid rugged terrain for nesting habitat in central Wyoming (Jensen 2006).

Sage-grouse were more likely to occur at higher elevations in the Wyoming Basins, which may be related to seasonal movements where birds track vegetation phenology and use habitats with increased forb availability at higher elevations throughout summer (Klebenow 1969, Wallestad 1971, Connelly et al. 2011). Sage-grouse occurrence increased in warmer areas as identified by higher minimum temperatures. Sage-grouse require access to sagebrush exposed above snow for food and shelter (Connelly et al. 2011). South or southwest-facing aspects and windswept ridges or draws and swales (Beck 1977, Crawford et al. 2004) are common habitat characteristics of sage-grouse winter habitat. South and southwest-facing aspects often have high-

Table 5.8. Results of AIC_c-based submodel selection for sage-grouse general use in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + MIX_{3km} + RIP_{1km}$	-293.71	7	601.78	0.00	0.15
	2	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + MIX_{3km} + RIP_{1km} + SALT_{18km}$	-291.78	9	602.13	0.35	0.13
	3	$ABIGSAGE_{1km} + EDGE_{1km} + MIX_{3km} + RIP_{1km} + SALT_{18km}$	-293.05	8	602.55	0.77	0.10
	4	$ABIGSAGE_{1km} + EDGE_{1km} + MIX_{3km} + RIP_{1km}$	-295.63	6	603.53	1.75	0.06
	5	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + GRASS_{18km} + MIX_{3km} + RIP_{1km}$	-293.56	8	603.57	1.79	0.06
	6	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + MIX_{3km}$	-295.73	6	603.72	1.94	0.06
Abiotic	1	$ABIGSAGE_{1km} + Tmin + TRI_{270} + ELEV$	-279.19	6	570.64	0.00	0.25
	2	$ABIGSAGE_{1km} + Tmin + TRI_{270} + ELEV + iH2Od_{250}$	-278.54	7	571.43	0.79	0.17
	3	$ABIGSAGE_{1km} + TRI_{270} + ELEV$	-281.05	5	572.30	1.66	0.11
	4	$ABIGSAGE_{1km} + Tmin + TRI_{270} + ELEV + pH2Od_{250}$	-279.13	7	572.62	1.98	0.09
Disturbance	1	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500}$	-286.46	6	585.18	0.00	0.28
	2	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + AG_{1km}$	-285.91	7	586.16	0.98	0.17
	3	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + PIPE_{1km}$	-286.09	7	586.52	1.34	0.14
	4	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + RDdens_{3km} + POWER_{500}$	-286.18	7	586.72	1.54	0.13

[a] Variable definitions provided in Table 4.2

TABLE 5.9. Results of AIC_c-based model selection for combined sage-grouse general use models[a] in the Wyoming Basins Ecoregional Assessment area.; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [$\sum w_i$]). Models were developed from a combination of vegetation, abiotic and disturbance variables using generalized ordered logistic regression. The generalized ordered logistic regression models resulted in parallel lines with a separate intercept value for the low (Present) and high (High) abundance categories. Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Intercept	$ABIGSAGE_{1km}$	TRI_{270}	ELEV[b]	$MjRD_{1km}$	$POWER_{500}$
1	Present: -3.24 (1.03) High: -4.95 (1.05)	2.58 (0.62)	-0.07 (0.01)	0.14 (0.04)	-2.40 (0.62)	-2.51 (0.97)
2	Present: -4.63 (1.17) High: -6.32 (1.2)	2.54 (0.61)	-0.07 (0.01)	0.24 (0.06)	-2.35 (0.62)	-2.52 (1.00)
3	Present: -4.51 (1.19) High: -6.2 (1.21)	2.65 (0.62)	-0.07 (0.01)	0.23 (0.06)	-2.82 (0.62)	
4	Present: -3.83 (1.07) High: -5.52 (1.1)	2.49 (0.62)	-0.07 (0.01)	0.17 (0.04)	-2.73 (0.62)	
5	Present: -3.64 (1.03) High: -5.32 (1.06)	2.63 (0.64)	-0.07 (0.01)	0.15 (0.04)	-2.25 (0.61)	-2.54 (1.00)
6	Present: -3.64 (1.04) High: -5.32 (1.07)	2.75 (0.65)	-0.07 (0.01)	0.15 (0.04)	-2.75 (0.63)	
7	Present: -3.76 (1.06) High: -5.45 (1.08)	2.36 (0.61)	-0.07 (0.01)	0.16 (0.04)	-2.24 (0.61)	-2.5 (0.99)
8	Present: -3.4 (1.03) High: -5.08 (1.05)	2.53 (0.62)	-0.07 (0.01)	0.15 (0.04)	-2.76 (0.62)	
9	Present: -3.38 (1.02) High: -5.06 (1.04)	2.40 (0.61)	-0.07 (0.01)	0.15 (0.04)	-2.27 (0.61)	-2.49 (0.98)

[a] Variable definitions provided in Table 4.2

[b] Coefficients and standard errors multiplied by 10^2

er temperatures due to solar radiation. Although we tested solar radiation as a predictor, temperature (modeled from Doggett et al. 2004) incorporates additional environmental characteristics and therefore may better capture local variation than solar radiation alone.

Sage-grouse occurrence was negatively affected by anthropogenic features. Areas near interstates and major highways, power lines, and oil and gas well locations had lower probability of sage-grouse occurrence (roost and general use). Direct and indirect effects of roads negatively affect both distribution and abundance of sage-grouse (Lyon and Anderson 2003, Connelly et al. 2004, Holloran and Anderson 2005, Aldridge and Boyce 2007). Sage-grouse no longer occupied leks within 2 km of Interstate 80 in Wyoming; leks within 7.5 km of the interstate had greater rates of population decline (based on lek attendance) than leks between 7.5 and 15 km of the interstate (Connelly et al. 2004). At range-wide scales, lek count trends were lower on leks with >20 linear km of interstate, federal, or state highways within 18 km (Johnson et al. 2011). Ef-

TABLE 5.9. Extended

$WELL_{1km}$	Tmin	MIX_{3km}	RIP_{1km}	LL	K	AIC_c	ΔAIC_c	Σw_i
-2.24 (0.80)				-261.08	8	538.62	0.00	0.577
	0.20 (0.09)			-262.72	8	541.91	3.29	0.688
-2.00 (0.79)	0.17 (0.09)			-263.35	8	543.17	4.55	0.748
-2.24 (0.79)		16.19 (9.72)		-263.95	8	544.35	5.73	0.781
			3.88 (2.29)	-263.99	8	544.45	5.84	0.812
-2.16 (0.79)			3.71 (2.29)	-264.07	8	544.59	5.97	0.841
		14.72 (9.59)		-264.23	8	544.91	6.29	0.866
-2.18 (0.79)				-265.37	7	545.09	6.47	0.888
				-265.42	7	545.19	6.58	0.910

fects of oil and gas development on sage-grouse have been extensively investigated in Wyoming (Lyon 2000, Braun et al. 2002, Lyon and Anderson 2003, Holloran 2005, Walker et al. 2007, Doherty et al. 2008) and Alberta (Braun et al. 2002, Aldridge and Boyce 2007, Carpenter et al. 2010). Maximum counts of males/lek within 3.2 km of a drilling rig declined 32%, compared to a 2% decline on areas >6.5 km from a rig (Holloran and Anderson 2005). Any drilling <6.5 km from a sage-grouse lek could have indirect (noise disturbance) or direct (mortality) negative effects on sage-grouse populations. In the Powder River Basin, sage-grouse declined 82% within gas fields compared to 12% outside (Naugle et al. 2011). Sage-grouse had lower nest initiation rates and moved longer distances from the lek to nesting sites for hens from "disturbed leks" (leks ≤3 km of a well pad or road) compared to hens from control leks (leks >3 km away from pad or road) in southwestern Wyoming (Lyon and Anderson (2003). The longer movements from disturbed leks may have been a response to light (<12 vehicles/day) traffic at these sites during the breeding season.

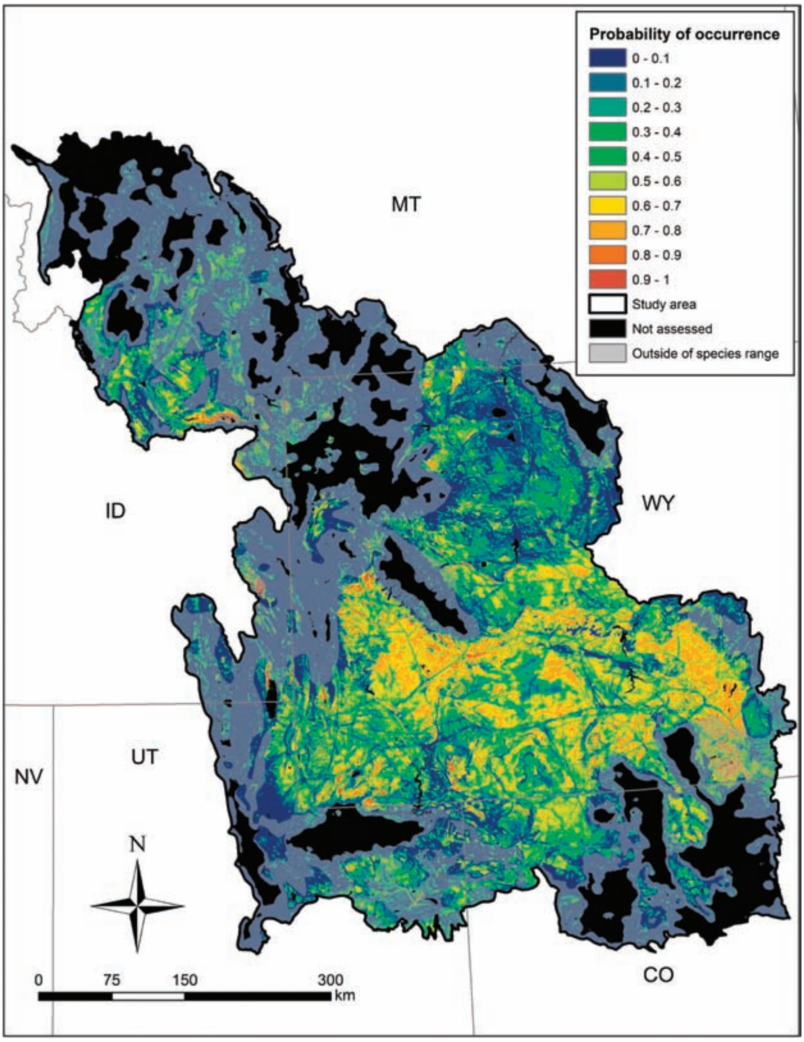

FIG. 5.4. Probability of sage-grouse roost site occurrence in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Sage-grouse roost sites are likely to occur in areas with probability > 0.48.

In the Powder River Basin of Wyoming/ Montana, all leks <200 m from active oil and gas wells were abandoned (Braun et al. 2002). Sage-grouse within the Powder River Basin also avoided coal bed methane (CBM) developments (4-km^2 scale) when selecting winter habitat (Doherty et al. 2008), and attendance at leks within CBM developments was 46% lower than outside from 2002 to 2005 (Walker et al. 2007). In guidelines for mitigation related to oil and gas activity, the Wyoming Game and Fish Department (2004) suggested that oil and gas development at >16 wells or >80 acres (0.32 km^2) of disturbance per section (2.56 km^2) in sage-grouse nesting and early brood-rearing habitat would constitute an "extreme" impact. A density of 1-4 well locations per section (1–4 wells/2.56 km^2), or <20 acres/section (0.08 km^2/2.56 km^2) of disturbance, was deemed a moderate impact. In Alberta, a density

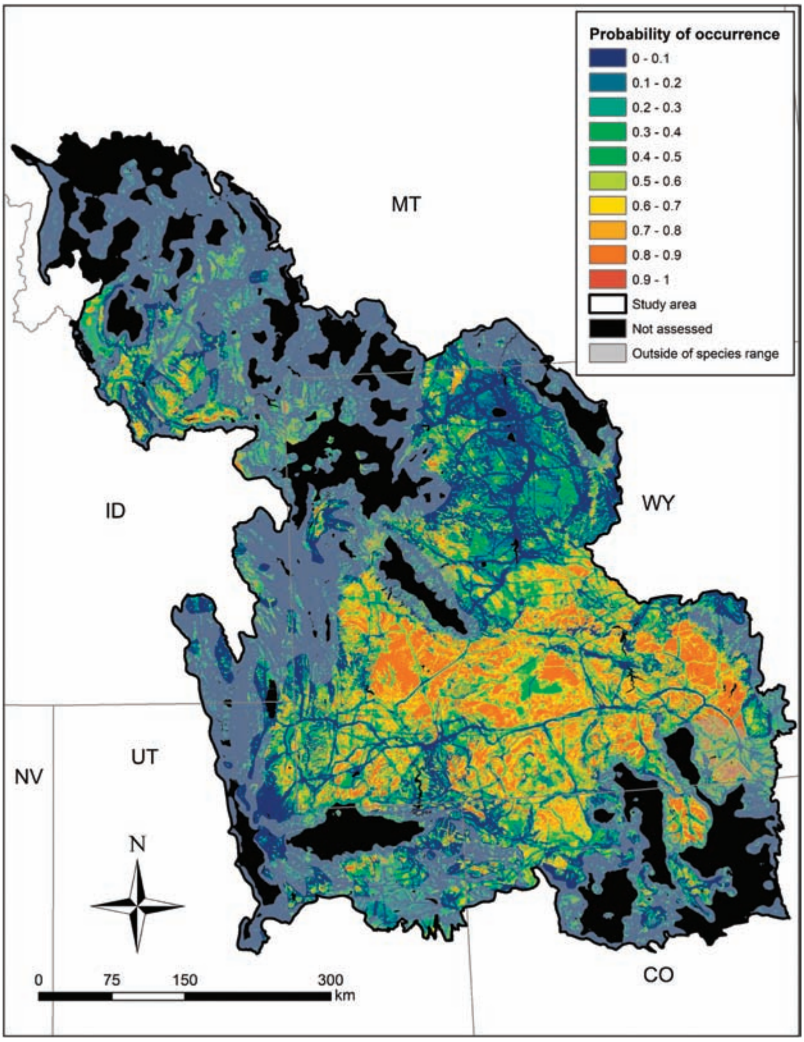

FIG. 5.5. Probability of sage-grouse general use in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Sage-grouse general use is likely to occur in areas with probability > 0.49.

of 3 wells/km^2 was associated with steep declines in sage-grouse lek attendance (Braun et al. 2002). Birds in this population avoided energy developments within a minimum of 564 m from habitats during nesting, brood-rearing, and wintering; and increased development was correlated with reduced chick survival (Aldridge and Boyce 2007, Carpenter et al. 2010).

Interstates and major highways, power lines, and oil and gas well locations, all of which were avoided by sage-grouse in our study, are of particular importance to sage-grouse conservation given the ongoing development of energy resources within the Wyoming Basins (Ch. 3, Knick et al. 2011, Naugle et al. 2011). Future planning and assessments can use the strength of these measured responses of sage-grouse to the proximity of individual disturbance factors or the density of developments to avoid disruption of exist-

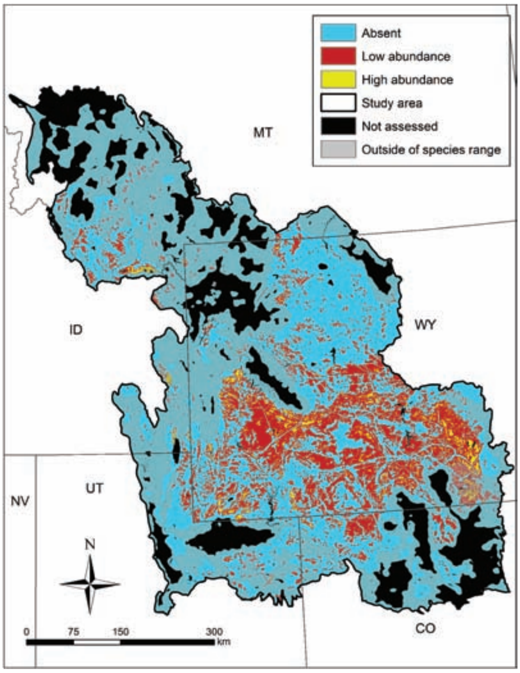

FIG. 5.6. Predicted absent, low, and high abundance sage-grouse roost site areas in the Wyoming Basins Ecoregional Assessment area. Sage-grouse were predicted to occur in areas with a probability above the sensitivity-specificity equality threshold (0.48). Within low/high abundance habitat, the threshold was set at the point where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

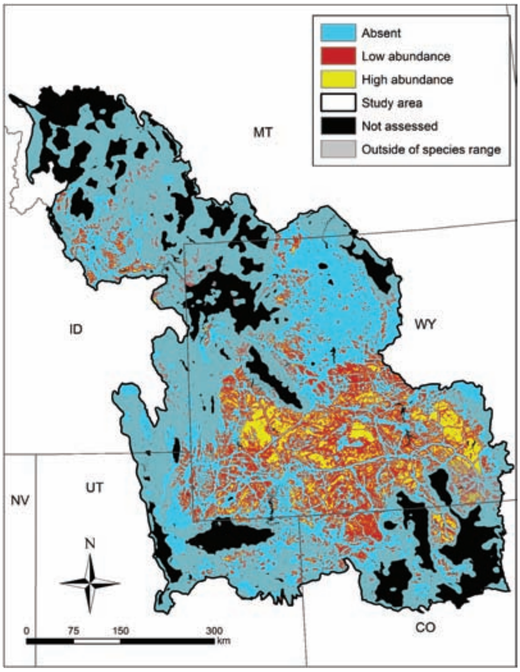

FIG. 5.7. Predicted absent, low, and high abundance sage-grouse general use areas in the Wyoming Basins Ecoregional Assessment area. Sage-grouse were predicted to occur in areas with probability above the sensitivity-specificity equality threshold (0.49). Within low/high abundance habitat, the threshold was set at the point where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

ing high quality habitats and inform sighting and mitigation efforts.

Our models of sage-grouse probability of occurrence/abundance, based on pellet count surveys, correctly classified habitat as occupied at >75% of active leks in Wyoming. Variables in these models were based on relatively large-scale effects, potentially capturing habitat surrounding leks. As predicted probability of occurrence and abundance increased in our models, the number of male sage-grouse at active leks increased and the proportion of inactive leks decreased, suggesting that our models captured multi-seasonal habitat use patterns associated with individual lek sites. The ordered logistic regression probability of occurrence models accurately identified key sage-grouse habitat across large landscapes and also provided important information on abundance (Nielsen et al. 2005), allowing for more refined management planning.

Our spatially explicit models predicting roost and general use can be used in efforts to conserve and improve habitat for sage-grouse within the WBEA area. Current mapping efforts to identify core areas (Doherty et al. 2011) of sage-grouse populations within the region may be improved or refined through an examination of over-

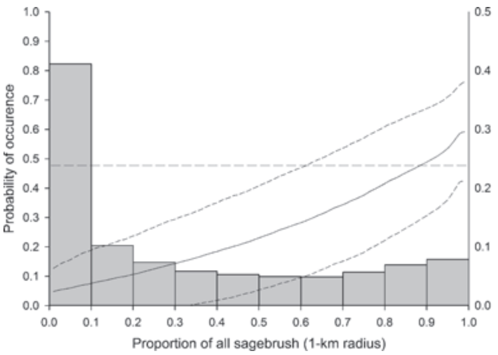

FIG. 5.8. Predicted probability of occurrence for greater sage-grouse roost locations within the Wyoming Basins Ecoregional Assessment area based on proportion of all sagebrush (*Artemisia* spp.) at a 1 km radius moving window. Mean probability of occurrence (±1 SD) values were calculated in each one percent increment of all sagebrush within a 1-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.48) above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10 % segment of all sagebrush with 1 km.

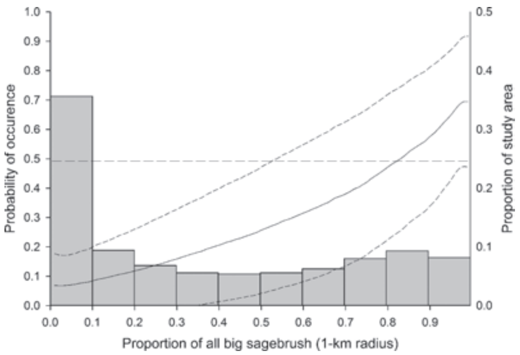

FIG. 5.9. Predicted probability of occurrence for greater sage-grouse general use locations within the Wyoming Basins Ecoregional Assessment area based on proportion of all big sagebrush (*Artemisia tridentata*) at a 1-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. Probability values are the mean predicted values in each one percent increment of all big sagebrush within a 1 km radius moving window. Dashed line represents the optimal cutoff threshold (0.49) above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 1 km.

lap between core areas and our models of year-round occurrence probability and abundance; core areas are currently based only on breeding density. Our models can identify habitat conditions within the existing core areas, highlight high-quality habitats on the periphery of existing core areas that could be considered for protection, and identify high-quality habitat not currently included in a designated core area. This spatially explicit knowledge of existing sage-grouse distribution can help inform and prioritize areas for application of future conservation and management actions in the region (Aldridge et al. 2008, Meinke et al. 2009) and thus maximize the effectiveness of limited but precious conservation resources.

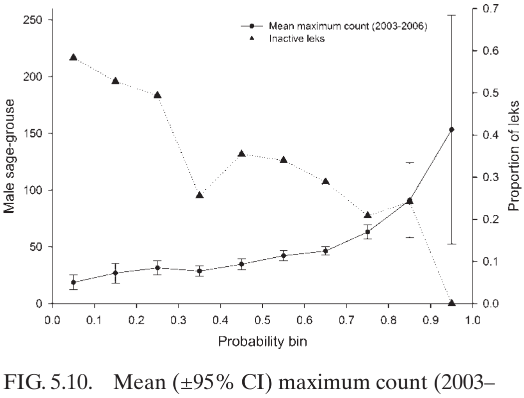

FIG. 5.10. Mean (±95% CI) maximum count (2003–2006) of male sage-grouse at active lek locations and proportion of inactive leks in Wyoming by probability bin in each 10% probability of occurrence bin for the Wyoming Basins Ecoregional Assessment roost model.

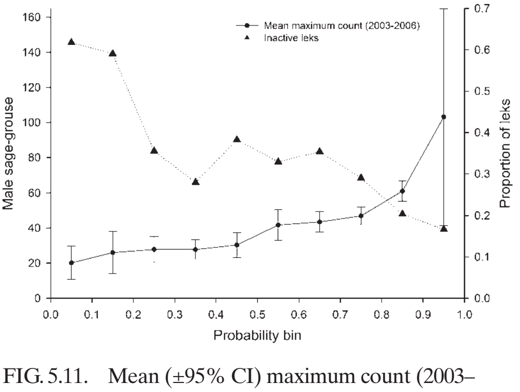

FIG. 5.11. Mean (±95% CI) maximum count (2003–2006) of male sage-grouse at active lek locations and proportion of inactive leks in Wyoming by probability bin in each 10% probability of occurrence bin for the Wyoming Basins Ecoregional Assessment general use model.

TABLE 5.10. Evaluation results for the sage-grouse roost site selection model in relation to lek characteristics in Wyoming including the number of active leks, total leks, extirpated leks (%), and mean count (SD).

Class	Leks Active	Leks Total	Leks Extirpated (%)	Count $\bar{x}$ (SD)
Absent	287	459	37.47	19.16 (27.66)
Low	728	1,037	29.79	34.44 (44.98)
High	140	170	17.64	57.11 (64.08)

TABLE 5.11. Evaluation results for the sage-grouse general use model in relation to lek characteristics in Wyoming including the number of active leks, total leks, extirpated leks (%), and mean count (SD).

Class	Leks Active	Leks Total	Leks Extirpated (%)	Count $\bar{x}$ (SD)
Absent	237	388	38.92	17.57 (26.26)
Low	487	722	32.55	29.75 (40.46)
High	431	556	22.48	46.61 (55.01)

Our regional models may also help identify pathways and corridors between priority areas important for maintaining population connectivity (Aldridge and Boyce 2007, Knick and Hanser 2011). Small isolated populations at the periphery of the sage-grouse distribution are at greater risk for extirpation than those within the core distribution (Aldridge et al. 2008, Wisdom et al. 2011). The explicit protection of areas such as those espoused by the core areas concept (Doherty et al. 2011) may institutionalize a disjunct or isolated view of sage-grouse populations in the region. Institutionalization of this type of population structure may be problematic to long-term conservation of this species because breeding habitats (leks) with lower connectivity inherently have a lower likelihood of persistence (Knick and Hanser 2011). Therefore, it is important to address issues of connectivity both within and between priority areas. Our models provide a means by which to identify areas that may currently serve as important connections between populations and areas that, if targeted for habitat improvements, could serve to improve connectivity.

Our sampling design and modeling approach provides a baseline for monitoring sage-grouse habitat use within the WBEA. The pellet survey technique used to develop these models is a rapid assessment and requires minimal training of field crews. The ability for surveys to be conducted year-round makes this a valuable field technique when conducting large landscape-scale studies and could be easily applied within other ecoregional assessments. Use of this survey methodology coupled with spatially explicit models will facilitate future research and monitoring of habitat-use by sage-grouse throughout its range.

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APPENDIX 5.1

Descriptive statistics for explanatory variables used to model sage-grouse roost occurrence in the Wyoming Basins Ecoregional Assessment area. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 5.2

Descriptive statistics for explanatory variables used to model sage-grouse general use occurrence in the Wyoming Basins Ecoregional Assessment area. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

Sagebrush Ecosystem Conservation and Management: 141–220, 2011

Chapter 6: Detectability Adjusted Count Models of Songbird Abundance

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Abstract. Sagebrush (*Artemisia* spp.) steppe ecosystems have experienced recent changes resulting not only in the loss of habitat but also fragmentation and degradation of remaining habitats. As a result, sagebrush-obligate and sagebrush-associated songbird populations have experienced population declines over the past several decades. We examined landscape-scale responses in occupancy and abundance for six focal songbird species at 318 survey sites across the Wyoming Basins Ecoregional Assessment (WBEA) area. Occupancy and abundance models were fit for each species using datasets developed at multiple moving window extents to assess landscape-scale relationships between abiotic, habitat, and anthropogenic factors. Anthropogenic factors had less influence on species occupancy or abundance than abiotic and habitat factors. Sagebrush measures were strong predictors of occurrence for sagebrush-obligate species, such as Brewer's sparrows (*Spizella breweri*), sage sparrows (*Amphispiza belli*) and sage thrashers (*Oreoscoptes montanus*), as well as green-tailed towhees (*Pipilo chlorurus*), a species associated with mountain shrub communities. Occurrence for lark sparrows (*Chondestes grammacus*) and vesper sparrows (*Pooecetes gramineus*), considered shrub steppe-associated species, was also related to big sagebrush communities, but at large spatial extents. Although relationships between anthropogenic variables and occurrence were weak for most species, the consistent relationship with sagebrush habitat variables suggests direct habitat loss and not edge or additional fragmentation effects are causing declines in the avifauna examined in the WBEA area. Thus, natural and anthropogenic disturbances that result in loss of critical habitats are the biggest threats to these species. We applied our models spatially across the WBEA area to identify and prioritize key areas for conservation.

Key words: count-based models, energy development, habitat, occurrence, point counts, sagebrush, songbirds, Wyoming.

There is a growing body of research on habitat relationships for sagebrush (*Artemisia* spp.)-obligate birds at both local (Wiens and Rotenberry 1985, Vander Haegen et al. 2000, Erickson 2011) and landscape (Knick and Rotenberry 1995, 1997, 2000; Vander Haegen et al. 2000) scales. Relationships with anthropogenic developments, however, are less well understood (Rotenberry and Knick 1995, Braun et al. 2002, Inglefinger and Anderson 2004). Concerns over loss and degradation of sagebrush habitats have been raised for sagebrush-obligate songbirds because of population declines (Braun et al. 1976, Knick et al. 2003, Dobkin and Sauder 2004). However, consequences of current land-use activities on non-obligate or sagebrush-associated species are poorly understood because research addressing the effects of habitat loss and degradation is limited to a few species.

Oil and natural gas energy development and associated infrastructure, including roads, power lines, pumps, and water storage ponds all result in the loss and fragmentation of habitat (Walston et al. 2009, Ch. 3). This development has been rapidly increasing in recent decades with more wells proposed for development than are currently on the landscape (Naugle et al. 2011). Potential negative ecological consequences for songbirds due to energy development, beyond habitat loss and fragmentation, include: (1) disturbance due to increased noise levels associated with drilling, well operations, and vehicle traffic (Bayne et al. 2008); (2) subsidization of avian nest predators, such as common ravens (*Corvus corax*), through the creation of perches, nest sites, and increased refuse (Andrén 1992, Chalfoun et al. 2002, Bui et al. 2010); and (3) spread of exotic plants (Ch. 10, Knick et al. 2011). Indeed, localized negative effects of energy development on songbird abundance have recently been shown for sagebrush-obligate songbirds (Gilbert and Chalfoun 2011), but landscape scale assessments are lacking.

Ongoing development of energy resources in the Wyoming Basins Ecoregional Assessment (WBEA) area (Ch. 3) highlights the importance of understanding relationships between sagebrush-obligate and sagebrush-associated songbird abundance, current habitat conditions, and anthropogenic activities. Our objectives were two-fold: (1) determine whether anthropogenic disturbances, including energy development, affect occupancy and abundance for a suite of songbirds in sagebrush habitats across the WBEA area; and (2) develop spatially explicit empirical models of songbird occurrence and abundance using data from point count surveys to identify priority conservation areas in the WBEA area. We used count-based models (Hilbe 2007) while accounting for detectability (Buckland et al. 2009) for those species with sufficient observations (Ch. 4). Statistical models were developed for each species to assign habitat associations and gauge impacts of anthropogenic activities, as well as to map the distribution of species habitat for the sagebrush ecosystem across the WBEA area.

METHODS

Field Surveys

Survey blocks (7.29 ha) within the sagebrush ecosystem of the WBEA were chosen using a stratified sampling design (Ch. 4). Point counts were used to survey songbirds (Rosenstock et al. 2002); surveys were conducted at the center of each survey block. Each block was visited twice within a season, once in both May and June, in order to capture phenological differences between migratory species and to further reduce observer bias by switching observers between sampling periods. For each detected bird, we recorded observation type (visual, aural, or both) and estimated the distance to the individual using a laser range finder (Bushnell Yardage Pro Legend) to estimate detectability (Buckland et al. 2001, 2004). Point counts were conducted for 5 minutes at each survey block during calm (<12 km/hr winds) and rainless (light drizzle allowed) days. Counts began at sunrise, and on cold days, particularly following rain, point counts were conducted until 1100 hr (depending on the activity of the bird community). Counts were terminated at ~0900 hr on hot and sunny days. Once observers navigated to a point count using a hand-held global position system (Fig. 4.1), they remained quiet and still for 3 minutes before beginning the survey. Individual detections were mapped to avoid double counting of birds.

Prior to field visits, we selected 23 species of birds for possible inclusion in the assessment (Table 6.1). These included sagebrush-obligate species, such as Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), and sage thrasher (*Oreoscoptes montanus*); sagebrush-associated species, such as western meadowlark (*Sturnella neglecta*), lark sparrow (*Chondestes grammacus*), and vesper sparrow (*Pooecetes gramineus*); grassland-associated species, such as savannah sparrow (*Passerculus sandwichensis*) and grasshopper sparrow (*Ammodramus savannarum*);

juniper (*Juniperus* spp.) and mountain shrub-associated species, such as gray flycatcher (*Empidonax wrightii*) and green-tailed towhee (*Pipilo chlorurus*); and synanthropic species (species associated with humans), such as European starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), and corvids (e.g., black-billed magpie [*Pica hudsonia*], common raven [*Corvus corax*], and American crow [*Corvus brachyrhynchos*]).

Analytical Approaches

We used count-based generalized linear models (GLM) with a Poisson or negative binomial error distribution and a log-link function to model bird abundance (Hilbe 2007; Ch. 4). We included an offset term in the GLM to account for detectability (Buckland et al. 2009), whereby site-specific detectability for each species can be incorporated into the GLM after estimation in Program DISTANCE (Thomas et al. 2006). When count models could not be developed due to limitations in the number of observations (Ch. 4, Fig. 4.4), we modeled probability of occurrence using logistic regression (Hosmer and Lemeshow 2000). We describe these specific model building approaches in the general analytical methods presented in Chapter 4.

Detection probability

We used program DISTANCE 5.0 Release 2 (Thomas et al. 2006) to calculate detection probabilities for species with a minimum of 60 observations using distance estimates recorded for each individual detection (Ch. 4). We considered half-normal and hazard rate key functions using simple polynomial and cosine series expansions and an information theoretic approach (Burnham and Anderson 2002) to select the top model based on Akaike's Information Criterion (AIC). We right-truncated observations to remove large distance outliers and assessed overall model fit using standard goodness of fit tests and visual plots of the data (Thomas et al. 2006, 2010). We then used the Multiple Covariate Distance-Sampling engine (Thomas et al. 2006) to model detection probabilities by bird species using covariates. We considered covariates representing (1) observer effect (team or detection type [auditory versus visual]), (2) time (start time or Julian date), and (3) vegetation obstruction cover, based on a multiplicative index of local shrub height and cover measured at all sites (Ch. 4, Ch. 10). We identified the top model in each of the three categories using AIC and then evaluated candidate models, including all combinations of variables from top models. We predicted species density across all survey sites as a function of covariates in the top AIC-selected model.

Model development and selection

To model bird abundance (density), we developed a GLM for each species using observed counts as the response variable and an offset term that included detection probability (varied among sites) and effort (constant across sites) (Buckland et al. 2009). This approach allowed us to model observed counts while incorporating detectability differences to assess how covariates might affect bird density (birds/ha). We restricted raw counts for regression models based on the truncation distance identified in program DISTANCE (Buckland et al. 2001). When no detections for a given species occurred at a site, we applied the mean offset value for sites with detections (Buckland et al. 2009). Most count data are Poisson distributed, but a negative binomial distribution may be more appropriate when data are overdispersed (Hilbe 2007). Negative binomial regression models may account for excess zeros, but often a zero-inflated model (type of mixture model) is required to properly account for excess zeros in the dataset (Hilbe 2007). We evaluated different model structures, and assessed the fit of each using a Vuong test (Vuong 1989). We first conducted a Voung test using an

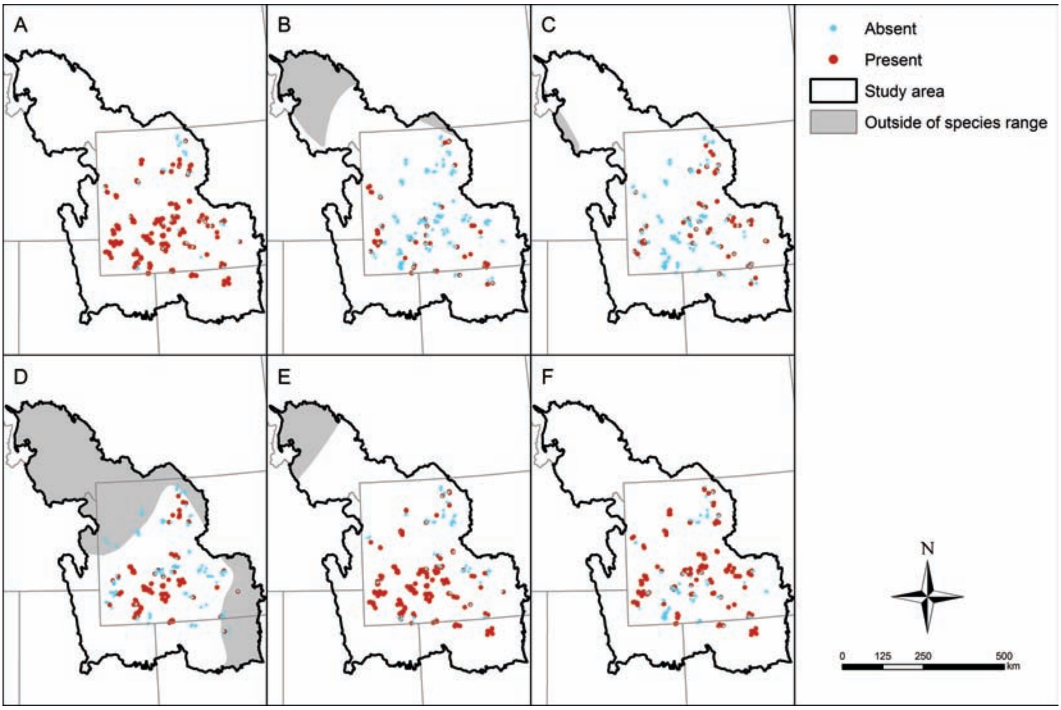

FIG. 6.1. Distribution of survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for Brewer's sparrow (A), green-tailed towhee (B), lark sparrow (C), sage sparrow (D), sage thrasher (E), and vesper sparrow (F). Survey blocks were designated as absent (blue, zero detections) and present (red) for model development. Grey shades indicate areas of the Wyoming Basins Ecoregional Assessment that are outside the range of each species.

intercept-only model to identify the most appropriate exponential model form: Poisson, negative binomial (NB), zero-inflated Poisson (ZIP), or zero-inflated negative binomial (ZINB). The top-selected model form was used to evaluate the sagebrush univariate variables (Ch. 4, see below). Where zero-inflated processes were warranted, we maintained candidate model forms for both count and inflated portions of the model; otherwise potential model combinations became too cumbersome to evaluate. Final count model predictions resulted in an estimate of abundance (density) that we report as birds/ha, which includes the joint model processes of occurrence and abundance. We present coefficient estimates for both processes; however, these estimates are dependent on the entire model.

We considered all variables in the standard candidate predictor set (Ch. 4, Table 4.2) for bird models with the exception of the eight soil-related variables (pH, salinity, bulk density, sand, silt, clay, soil depth, and available water capacity) and precipitation. Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana;* moderately correlated with elevation and NDVI), was only considered for the green-tailed towhee. We also evaluated solar radiation and temperature (min or max) for inclusion in each bird species model when determined relevant. We calculated descriptive statistics for all predictor variables within presence/absence classes for each species, identifying survey blocks with predictor variable values > 0 within each abundance class and excluding variables/scales with <20 survey blocks in a class from model building. Correlated predictor variables were removed from potential analyses prior to model development (Ch. 4). In some cases, particularly with zero-inflated models, we ran into convergence issues for a few of the candidate models. In such cases, these models were dropped from consideration.

We followed a hierarchical multi-stage modeling approach where we assessed all model subsets using count-based GLMs or logistic regression occurrence models in Stata 10.1 (Stata Corporation, College Station, Texas, USA). We used Akaike's Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002). Our sampling design was stratified by sagebrush and productivity (NDVI, Ch. 4). Therefore, we first evaluated each sagebrush and NDVI variable and identified the circular moving window radius (extent) and combinations of sagebrush and NDVI variables that had the strongest relationship to species occurrence/abundance. Selected sagebrush/NDVI variables formed a base model for assessing all spatial extents for each variable within the vegetation, abiotic, and disturbance subgroups to identify the best spatial extent for each variable using AIC_c values. For each variable, we examined data using scatterplots and histograms to look for nonlinearities. Potential interactions were investigated between sagebrush and NDVI variables and included when appropriate. We then allowed selected spatial extents for each variable to compete with all possible combinations of other variables within the same category to identify the AIC_c-selected top model within that category. To avoid overfitting, we limited the number of variables in all competing models to 10% of the sample size in the lowest frequency class (presence or absence; 1 variable per 10 survey blocks in lowest class; Hosmer and Lemeshow 2000). All variables from the top model within vegetation, abiotic, and disturbance submodel categories were allowed to compete with variables both within and across submodels to identify the top overall composite model; the sagebrush/NDVI base model, however, was held constant for all subsequent models. We model-averaged coefficients from all models with a cumulative AIC_c weight of just ≥ 0.9 to incorporate model uncertainty and generate model averaged spatial predictions (Burnham and Anderson 2002). Coefficients were set to zero when a model did not contain a particular variable.

Accuracy of logistic regression occurrence models was evaluated with receiver operating characteristic (ROC) plots estimating the area under the curve (AUC, Metz 1978). We determined an optimal cutoff threshold for predicting presence-absence of each species (i.e., habitat or non-habitat) using a sensitivity-specificity equality approach (Liu et al. 2005) and applied this threshold to assess the predictive capacity for each model (Nielsen et al. 2004).

Spatial Application and Dose Response

We predicted species occurrence or abundance in a GIS at a 90-m resolution (pixel size) applying the final model-averaged coefficients in ArcGIS using the raster calculator function (ESRI 2006). For abundance (count) models, we predicted the count of individuals occurring within a 1-ha area, effectively making our predictions density estimates. Final model predictions were displayed in 10 equal-area density classes for count-based models or 10% probability classes when species occurrence (presence/absence) was modeled. A non-sagebrush habitat mask (areas with <3% sagebrush habitat in a 5-km moving window) was used to exclude areas without significant sagebrush habitat for prediction. Areas outside the known range of each species (Ch. 2; Ridgely et al. 2003) were also used to restrict prediction to the range of the species. Probability of occurrence maps were converted to binary presence/absence maps based on the sensitivity-specificity equality threshold to

TABLE 6.1. Survey results for 23 songbird species on 318 survey blocks during May and June of 2005 and 2006 in the Wyoming Basins Ecoregional Assessment area. Shown are number sites with occurrences (percent), aural detections (percent), total detections, and detection distance (m; $\bar{x}$ [SE]).

Species	Scientific Name	Occurrence # sites (%)	Total detections (% aural detection)		Total Detections Both Years	Detection distance (m; $\bar{x}$ [SE])	
			2005	2006		2005	2006
American crow	*Corvus brachyrhynchos*	3 (0.9)	1 (0)	11 (27)	7	100	165 (9)
Black-billed magpie	*Pica hudsonia*	24 (7.5)	20 (30)	24 (63)	38	184 (18)	218 (35)
Brewer's blackbird	*Euphagus cyanocephalus*	25 (7.9)	63 (14)	29 (37)	85	90 (7)	100 (9)
Brewer's sparrow[a]	*Spizella breweri*	236 (74.2)	429 (90)	383 (89)	818	81 (2)	85 (3)
Brown-headed cowbird	*Molothrus ater*	18 (5.7)	7 (17)	17 (1)	20	81 (29)	71 (9)
Common raven	*Corvus corax*	29 (9.1)	22 (36)	66 (71)	36	301 (40)	237 (33)
European starling	*Sturnus vulgaris*	2 (0.6)	0	5 (40)	5	na	100 (30)
Grasshopper sparrow	*Ammodramus savannarum*	10 (3.1)	1 (100)	14 (86)	14	80	58 (7)
Gray flycatcher	*Empidonax wrightii*	24 (7.5)	3 (0)	27 (89)	30	59 (39)	60 (7)
Green-tailed towhee[a]	*Pipilo chlorurus*	59 (18.6)	86 (83)	65 (89)	152	84 (4)	66 (4)
Horned lark	*Eremophila alpestris*	235 (73.9)	683 (67)	551 (71)	1,221	68 (1)	78 (2)
House sparrow	*Passer domesticus*	4 (1.3)	0	4 (100)	5	na	43 (6)
House finch	*Carpodacus mexicanus*	1 (0.3)	0	4 (100)	4	na	190 (0)
Lark sparrow[a]	*Chondestes gramnacus*	67 (21.1)	99 (88)	34 (82)	133	76 (3)	63 (9)
Lark bunting	*Calamospiza melanocorys*	28 (8.8)	48 (81)	4 (100)	52	86 (5)	103 (27)
Loggerhead shrike	*Lanius ludovicianus*	15 (4.7)	10 (30)	12 (75)	22	66 (19)	90 (12)
Rock wren	*Salpinctes obsoletus*	49 (15.4)	20 (90)	101 (95)	125	125 (13)	135 (9)
Sage sparrow[a]	*Amphispiza belli*	114 (35.8)	192 (84)	117 (93)	307	86 (3)	109 (6)
Sage thrasher[a]	*Oreoscoptes montanus*	199 (62.6)	191 (93)	230 (95)	421	108 (3)	121 (5)
Savannah sparrow	*Passerculus sandwichensis*	25 (7.9)	5 (100)	45 (73)	50	68 (16)	83 (8)
Vesper sparrow[a]	*Pooecetes gramineus*	168 (52.8)	277 (75)	229 (87)	512	81 (2)	87 (3)
Western meadowlark	*Sturnella neglecta*	143 (45.0)	356 (78)	180 (83)	537	97 (2)	105 (6)
White-crowned sparrow	*Zonotrichia leucophrys*	7 (2.2)	0	14 (57)	14	na	80 (9)

[a] Species for which models were developed

TABLE 6.2. Results of AIC_c-based model selection for Brewer's sparrow negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{1km} + NDVI_{270} + NDVI_{270}^2$	-662.90	5	1336.18	0.00	0.07
2	$ABIGSAGE_{1km} + NDVI + NDVI^2$	-663.11	5	1336.41	0.23	0.06
3	$ABIGSAGE_{540} + NDVI_{270} + NDVI_{270}^2$	-663.24	5	1336.68	0.50	0.05
4	$ABIGSAGE_{540} + NDVI + NDVI^2$	-663.35	5	1336.89	0.71	0.05
5	$ABIGSAGE_{1km} + NDVI_{270}$	-664.48	4	1337.09	0.91	0.04
6	$ABIGSAGE_{1km} + NDVI$	-664.50	4	1337.13	0.95	0.04
7	$ABIGSAGE_{1km} + NDVI_{540} + NDVI_{540}^2$	-663.54	5	1337.27	1.08	0.04
8	$ABIGSAGE_{540} + NDVI_{540} + NDVI_{540}^2$	-663.69	5	1337.57	1.39	0.03
9	$ABIGSAGE_{1km} + NDVI_{540}$	-664.79	4	1337.71	1.53	0.03

[a] Variable definitions provided in Table 4.2

maximize prediction success for each model (Liu et al. 2005). For abundance models, we identified areas where predicted density exceeded that required to support ≥1 individual for each species, based on the largest recorded territory size (lowest density) required by each species, as reported in the "Spacing and Territoriality" section of the Birds of North America (BNA) species accounts (Poole 2005).

For each species, we plotted either density or predicted probability of occurrence relative to changes in sagebrush metrics to assess critical levels of sagebrush habitat required for a species to be present and characterize responses to loss or fragmentation of sagebrush habitat. We used the Dose Response Calculator for ArcGIS tool (Hanser et al. 2011) and plotted the occupancy threshold to identify the critical sagebrush requirement for species occupancy.

Model Evaluation

We evaluated model fit for species using independent data from the Breeding Bird Survey (BBS, Sauer et al. 2011) collected in 2005 and 2006, concurrent with our field sampling. The BBS data were not ideal because counts are conducted along roadsides rather than random transects. Although counts are conducted at discreet locations along a BBS route, the lack of availability of the specific coordinates required the use of aggregated summary data to compare to spatial model results. We used route-level (50 counts spaced 0.8 km apart along the 40-km route unadjusted for detectability) summaries for each of 96 BBS routes within the WBEA to compare summed counts with predicted species density or probability of occurrence averaged across the BBS route (mean of all pixel predictions within 200 m of the route). Model density/probability predictions should have a significant and positive correlation (Spearman Rho) with BBS counts (averaged over the two years).

RESULTS

Field Surveys

We sampled 318 survey blocks in both May and June during the 2005 or 2006 field season (n = 155 in 2005 and 163 in 2006; Table 6.1). Detections varied across species, with as many as 1,221 detections for horned lark (*Eremophila alpestris*) and as

TABLE 6.3. Evaluation statistics from AIC_c-based univariate model selection for Brewer's sparrow negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran models with all big sagebrush (1-km radius) and NDVI (0.27-km radius; quadratic) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which Brewer's sparrows respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-658.83	4	1,329.92	0.00	0.75
	$CFRST_{540}$	-660.14	4	1,332.54	2.62	0.20
	$CFRST_{270}$	-661.60	4	1,335.47	5.54	0.05
	$GRASS_{540}$	-659.91	4	1,332.09	0.00	0.29
	$GRASS_{5km}$	-660.19	4	1,332.66	0.56	0.22
	$GRASS_{3km}$	-660.45	4	1,333.17	1.08	0.17
	$GRASS_{1km}$	-660.54	4	1,333.34	1.25	0.16
	$GRASS_{270}$	-660.94	4	1,334.15	2.06	0.10
	$GRASS_{18km}$	-661.67	4	1,335.61	3.51	0.05
	MIX_{18km}	-659.40	4	1,331.07	0.00	0.47
	MIX_{5km}	-659.68	4	1,331.64	0.57	0.35
	MIX_{3km}	-661.18	4	1,334.63	3.56	0.08
	MIX_{1km}	-661.56	4	1,335.38	4.31	0.05
	MIX_{540}	-662.21	4	1,336.70	5.63	0.03
	MIX_{270}	-662.42	4	1,337.12	6.05	0.02
	RIP_{540}	-657.21	4	1,326.69	0.00	0.41
	RIP_{1km}	-657.32	4	1,326.91	0.22	0.37
	RIP_{270}	-658.06	4	1,328.39	1.70	0.18
	RIP_{3km}	-660.33	4	1,332.94	6.25	0.02
	RIP_{18km}	-660.37	4	1,333.00	6.32	0.02
	RIP_{5km}	-660.90	4	1,334.07	7.38	0.01
	$SALT_{18km}$	-662.47	4	1,337.20	0.00	0.23
	$SALT_{1km}$	-662.74	4	1,337.75	0.55	0.18
	$SALT_{3km}$	-662.89	4	1,338.05	0.84	0.15
	$SALT_{540}$	-662.90	4	1,338.08	0.87	0.15
	$SALT_{270}$	-662.94	4	1,338.15	0.95	0.14
	$SALT_{5km}$	-662.94	4	1,338.16	0.96	0.14
	$CONTAG_{5km}$	-661.62	4	1,335.51	0.00	0.35
	$PATCH_{3km}$	-661.88	4	1,336.04	0.53	0.27
	$PATCH_{5km}$	-662.21	4	1,336.69	1.18	0.19
	$EDGE_{5km}$	-662.88	4	1,338.03	2.53	0.10
	$CONTAG_{3km}$	-662.99	4	1,338.26	2.75	0.09

TABLE 6.3. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Abiotic	CTI	-662.80	4	1,337.88	0.00	1.00
	ELEV^{2b}	-652.80	5	1,319.97	0.00	0.96
	ELEV	-657.12	4	1,326.51	6.54	0.04
	iH2Od$_{250}$^{c}	-662.18	4	1,336.63	0.00	0.36
	iH2Od$_{500}$^{c}	-662.19	4	1,336.66	0.02	0.36
	iH2Od$_{1km}$^{c}	-662.42	4	1,337.11	0.48	0.28
	pH2Od$_{1km}$^{c}	-662.88	4	1,338.04	0.00	0.36
	pH2Od$_{250}$^{c}	-662.98	4	1,338.24	0.20	0.32
	pH2Od$_{500}$^{c}	-662.99	4	1,338.26	0.22	0.32
	SOLAR^{2b}	-653.84	5	1,322.04	0.00	1.00
	SOLAR	-660.99	4	1,334.25	12.21	0.00
	TRI$_{18km}$	-650.01	4	1,312.28	0.00	0.81
	TRI$_{5km}$	-651.62	4	1,315.52	3.23	0.16
	TRI$_{3km}$	-654.29	4	1,320.85	8.57	0.01
	TRI$_{1km}$	-654.60	4	1,321.48	9.20	0.01
	TRI$_{540}$	-655.66	4	1,323.59	11.30	0.00
	TRI$_{270}$	-656.81	4	1,325.88	13.60	0.00
	TRI	-656.84	4	1,325.94	13.66	0.00
Disturbance	AG$_{250}$^{c}	-661.58	4	1,335.43	0.00	0.42
	AG$_{500}$^{c}	-661.77	4	1,335.80	0.37	0.35
	AG$_{1km}$^{c}	-662.22	4	1,336.71	1.27	0.22
	MjRD$_{250}$^{c}	-662.92	4	1,338.11	0.00	0.34
	MjRD$_{500}$^{c}	-662.94	4	1,338.15	0.04	0.34
	MjRD$_{1km}$^{c}	-662.99	4	1,338.26	0.15	0.32
	PIPE$_{1km}$^{c}	-662.44	4	1,337.15	0.00	0.46
	PIPE$_{500}$^{c}	-662.94	4	1,338.15	1.01	0.28
	PIPE$_{250}$^{c}	-662.96	4	1,338.20	1.05	0.27
	POWER$_{1km}$^{c}	-662.77	4	1,337.81	0.00	0.38
	POWER$_{250}$^{c}	-662.96	4	1,338.19	0.38	0.31
	POWER$_{500}$^{c}	-662.99	4	1,338.24	0.44	0.31
	RDdens$_{18km}$	-661.05	4	1,334.36	0.00	0.29
	RDdens$_{270}$	-661.88	4	1,336.03	1.66	0.13
	2RD$_{500}$^{c}	-661.99	4	1,336.25	1.89	0.11
	2RD$_{250}$^{c}	-662.02	4	1,336.30	1.94	0.11
	2RD$_{1km}$^{c}	-662.04	4	1,336.35	1.99	0.11
	RDdens$_{540}$	-662.07	4	1,336.40	2.04	0.10

TABLE 6.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{1km}$	-662.77	4	1,337.80	3.44	0.05
	$RDdens_{5km}$	-662.78	4	1,337.82	3.46	0.05
	$RDdens_{3km}$	-662.97	4	1,338.21	3.85	0.04
	$WELL_{250}{}^{c}$	-661.96	4	1,336.19	0.00	0.46
	$WELL_{500}{}^{c}$	-662.30	4	1,336.88	0.69	0.32
	$WELL_{1km}{}^{c}$	-662.70	4	1,337.66	1.47	0.22

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function ($e^{(\text{Euclidian distance from feature/-distance parameter})}$)

few as four detections for house finch (*Carpodacus mexicanus*; Table 6.1). Only eight species met our criteria with detection on >50 survey blocks (see Ch. 4; Fig. 6.1), including Brewer's sparrow, green-tailed towhee, horned lark, lark sparrow, sage sparrow, sage thrasher, vesper sparrow, and western meadowlark (Table 6.1). Models for the two grassland species, horned lark and western meadowlark, resulted in non-sensible spatial predictions, possibly as a result of our biased sampling design that targeted sagebrush habitats, and were therefore dropped from further consideration. Of the remaining six species modeled, Brewer's sparrow was most abundant, occurring on 74% of the 318 survey blocks (Table 6.1). Sage thrasher, vesper sparrow, and sage-sparrow were present at more than 1/3 of survey blocks (63%, 53%, and 36%, respectively), with lark sparrow (21%) and green-tailed towhee (19%) having the lowest occurrences of species we modeled (Table 6.1). Total detections across both survey years for modeled species ranged from 133 for lark sparrow to 818 for Brewer's sparrow (Table 6.1).

Detection Probability

Brewer's sparrow

A hazard rate model with a simple polynomial adjustment, 20-m grouping and aggregation of detections <40 m, combined with a truncation distance of 200 m, provided the best fit to the distance data for Brewer's sparrow ($\chi^2_5 = 4.069$, $p = 0.54$). This resulted in 799 detections being used at 232 of the 318 survey blocks. The top AIC-selected detection model included the base model with covariates for shrub index, observer group, detection type, and survey start time. All other models had ΔAIC values ranging from 1.33 to 72.5. A goodness of fit test could not be estimated for this top Brewer's sparrow model due to limited degrees of freedom. Brewer's sparrow detection probability was low (0.23; 95% CI = 0.22-0.26). The overall density estimate was 0.87 (95% CI = 0.77-0.98) birds/ha. Where present, mean Brewer's sparrow density was 1.19 birds/ha (range: 0.90-5.16).

Green-tailed towhee

The best distance model for green-tailed towhee was a hazard rate model with a simple polynomial adjustment and 25-m groupings. No truncation was required with the farthest detection at 174 m. We used 150 detections occurring at 59 of the 318 survey blocks for this model. The green-tailed towhee model with no covariates had good fit ($\chi^2_3 = 3.04$, $p = 0.39$), and based on AIC, outcompeted all other distance models fit with covariates; ΔAIC values ranged from 4.38 to 8.33. Detectability was 0.25 (95% CI = 0.20–

TABLE 6.4. Results of AIC_c-based submodel selection for Brewer's sparrow negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + MIX_{18km} + RIP_{540m} + EDGE_{3km}$	-646.74	8	1,314.20	0.00	0.23
	2	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + MIX_{18km} + RIP_{540m} + EDGE_{3km} + SALT_{18km}$	-646.36	9	1,315.58	1.38	0.12
	3	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + MIX_{18km} + EDGE_{3km}$	-648.78	7	1,316.14	1.95	0.09
	4	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + RIP_{540m} + EDGE_{3km}$	-648.80	7	1,316.18	1.98	0.09
Abiotic	1	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CTI + ELEV + ELEV^2 + iH2Od_{500} + SOLAR + SOLAR^2 + TRI_{18km}$	-635.23	10	1,295.48	0.00	0.24
	2	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + ELEV + ELEV^2 + pH2Od_{1km} + SOLAR + SOLAR^2 + TRI_{18km}$	-636.74	9	1,296.34	0.86	0.16
	3	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + ELEV + ELEV^2 + iH2Od_{500} + pH2Od_{1km} + SOLAR + SOLAR^2 + TRI_{18km}$	-635.90	10	1,296.83	1.35	0.12
	4	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CTI + ELEV + ELEV^2 + SLOPE + SOLAR + SOLAR^2 + TRI_{18km}$	-636.03	10	1,297.09	1.61	0.11
	5	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CTI + ELEV + ELEV^2 + iH2Od_{500} + pH2Od_{1km} + SOLAR + SOLAR^2 + TRI_{18km}$	-635.10	11	1,297.40	1.92	0.09
Disturbance	1	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + RDdens_{18km}$	-659.16	5	1,332.68	0.00	0.11
	2	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + RDdens_{18km} + WELL_{250}$	-658.65	6	1,333.76	1.08	0.06
	3	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + POWER_{1km} + RDdens_{18km}$	-658.83	6	1,334.13	1.45	0.05
	4	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + PIPE_{1km} + RDdens_{18km}$	-658.94	6	1,334.35	1.67	0.05
	5	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + RDdens_{18km}$	-661.05	4	1,334.36	1.68	0.05
	6	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + MjRD_{250} + RDdens_{18km}$	-658.97	6	1,334.41	1.73	0.04

[a] Variable definitions provided in Table 4

TABLE 6.5. Results of AIC_c-based model selection for the combined Brewer's sparrow negative binomial abundance models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [$\sum w_i$]). Models shown with cumulative Akaike weight (w_i) just ≥ 0.9.

Rank	Intercept	$ABIGSAGE_{1km}$	$NDVI_{270}$	$NDVI_{270}^2$	$ELEV^b$	$ELEV^{2c}$	SOLAR	$SOLAR^{2d}$	TRI_{18km}	$CFRST_{1km}$
1	-11.65 (4.03)	0.82 (0.36)	3.36 (3.51)	0.03 (4.09)	0.26 (0.20)	-0.42 (0.50)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.31 (1.22)
2	-11.49 (4.05)	0.57 (0.39)	2.91 (3.52)	0.39 (4.10)	0.23 (0.20)	-0.35 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.45 (1.22)
3	-10.10 (3.87)	0.98 (0.34)	3.93 (3.49)	-0.73 (4.07)	0.22 (0.20)	-0.34 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.09 (1.21)
4	-12.59 (4.03)	0.35 (0.37)	4.48 (3.40)	-1.11 (4.02)	0.28 (0.20)	-0.48 (0.50)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	-2.78 (1.21)
5	-9.86 (3.88)	0.76 (0.38)	3.53 (3.50)	-0.42 (4.07)	0.19 (0.20)	-0.26 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.22 (1.21)
6	-11.78 (4.01)	0.79 (0.36)	3.78 (3.51)	-0.87 (4.14)	0.29 (0.20)	-0.51 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.05 (1.22)
7	-12.95 (4.01)	0.60 (0.34)	5.24 (3.38)	-1.75 (4.01)	0.32 (0.20)	-0.59 (0.49)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.65 (1.22)
8	-11.61 (4.02)	0.56 (0.39)	3.33 (3.52)	-0.46 (4.16)	0.26 (0.20)	-0.43 (0.51)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.21 (1.23)
9	-12.69 (4.00)	0.34 (0.37)	4.88 (3.40)	-1.96 (4.07)	0.31 (0.20)	-0.57 (0.50)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	-2.51 (1.22)
10	-10.12 (3.85)	0.97 (0.34)	4.33 (3.50)	-1.56 (4.13)	0.24 (0.20)	-0.41 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-1.86 (1.22)
11	-12.29 (3.75)	1.21 (0.32)	4.78 (3.46)	-2.42 (3.95)	0.33 (0.19)	-0.63 (0.47)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
12	-9.37 (3.90)	0.91 (0.34)	3.77 (3.48)	-0.44 (4.06)	0.20 (0.20)	-0.30 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.30 (1.22)
13	-9.03 (3.91)	0.66 (0.38)	3.32 (3.49)	-0.07 (4.06)	0.16 (0.20)	-0.21 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.46 (1.22)
14	-13.04 (3.98)	0.58 (0.33)	5.61 (3.38)	-2.65 (4.05)	0.35 (0.20)	-0.68 (0.50)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.36 (1.22)
15	-13.71 (3.91)	1.02 (0.33)	4.76 (3.46)	-2.79 (3.98)	0.39 (0.19)	-0.79 (0.48)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
16	-10.64 (4.10)	0.51 (0.40)	2.80 (3.50)	0.60 (4.08)	0.20 (0.20)	-0.30 (0.50)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.63 (1.23)
17	-12.02 (3.71)	1.16 (0.32)	5.17 (3.46)	-3.23 (3.98)	0.34 (0.19)	-0.67 (0.47)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	
18	-11.62 (4.09)	0.29 (0.37)	4.29 (3.39)	-0.82 (4.01)	0.25 (0.20)	-0.43 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.96 (1.22)
19	-10.93 (4.09)	0.78 (0.36)	3.28 (3.49)	0.20 (4.08)	0.24 (0.20)	-0.39 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.45 (1.23)
20	-13.83 (3.96)	1.09 (0.33)	4.37 (3.47)	-1.93 (3.96)	0.37 (0.19)	-0.73 (0.47)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
21	-11.96 (4.06)	0.79 (0.36)	3.67 (3.53)	-0.33 (4.11)	0.27 (0.20)	-0.46 (0.50)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.26 (1.22)
22	-12.87 (4.04)	0.34 (0.37)	4.74 (3.40)	-1.43 (4.02)	0.29 (0.20)	-0.51 (0.50)	0.11 (0.04)	-0.37 (0.14)	-0.02 (0.01)	-2.69 (1.21)
23	-9.89 (3.86)	0.76 (0.38)	3.92 (3.52)	-1.19 (4.14)	0.21 (0.20)	-0.32 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.00 (1.22)
24	-11.79 (4.07)	0.55 (0.39)	3.22 (3.54)	0.04 (4.12)	0.24 (0.20)	-0.38 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.41 (1.22)
25	-10.40 (3.89)	0.96 (0.34)	4.25 (3.52)	-1.09 (4.09)	0.23 (0.20)	-0.37 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.05 (1.21)
26	-12.24 (3.76)	1.03 (0.35)	4.46 (3.47)	-2.23 (3.95)	0.30 (0.19)	-0.57 (0.47)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
27	-11 (4.06)	0.74 (0.36)	3.70 (3.49)	-0.72 (4.13)	0.27 (0.20)	-0.48 (0.50)	0.09 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.20 (1.23)
28	-9.35 (3.87)	0.89 (0.34)	4.18 (3.48)	-1.31 (4.11)	0.23 (0.20)	-0.37 (0.50)	0.07 (0.04)	-0.26 (0.13)	-0.02 (0.01)	-2.06 (1.23)
29	-13.23 (4.02)	0.59 (0.33)	5.50 (3.38)	-2.09 (4.01)	0.33 (0.20)	-0.62 (0.49)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.56 (1.21)
30	-11.68 (4.05)	0.28 (0.37)	4.69 (3.39)	-1.69 (4.06)	0.28 (0.20)	-0.51 (0.50)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.70 (1.22)
31	-3.96 (2.16)	0.96 (0.34)	4.80 (3.43)	-1.73 (3.98)	0.15 (0.19)	-0.16 (0.49)			-0.03 (0.01)	-2.80 (1.15)
32	-10.72 (4.07)	0.50 (0.40)	3.23 (3.51)	-0.28 (4.14)	0.23 (0.20)	-0.39 (0.51)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.39 (1.23)
33	-13.86 (3.97)	0.89 (0.36)	4.02 (3.48)	-1.72 (3.96)	0.34 (0.19)	-0.67 (0.47)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
34	-12.12 (4.08)	0.57 (0.34)	5.09 (3.37)	-1.52 (4.00)	0.30 (0.20)	-0.55 (0.49)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.80 (1.23)
35	-13.74 (3.93)	0.84 (0.36)	4.43 (3.47)	-2.57 (3.99)	0.37 (0.19)	-0.74 (0.48)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
36	-10.15 (3.91)	0.74 (0.38)	3.84 (3.53)	-0.77 (4.10)	0.20 (0.20)	-0.29 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.17 (1.21)
37	-9.02 (3.88)	0.66 (0.38)	3.73 (3.50)	-0.89 (4.12)	0.19 (0.20)	-0.28 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.24 (1.23)
38	-12.03 (4.03)	0.77 (0.36)	4.04 (3.53)	-1.15 (4.16)	0.30 (0.20)	-0.53 (0.51)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.02 (1.22)
39	-11.99 (3.72)	1.00 (0.35)	4.86 (3.47)	-3.02 (3.98)	0.32 (0.19)	-0.62 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
40	-11.81 (4.09)	0.28 (0.37)	4.56 (3.39)	-1.16 (4.01)	0.26 (0.20)	-0.45 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.88 (1.21)
41	-10.81 (3.90)	0.52 (0.36)	5.87 (3.36)	-2.73 (3.96)	0.24 (0.20)	-0.40 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.58 (1.21)
42	-12.15 (4.04)	0.54 (0.34)	5.47 (3.37)	-2.43 (4.04)	0.33 (0.20)	-0.63 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.52 (1.23)

TABLE 6.5. Extended

MIX$_{18km}$	RIP$_{540m}$	RDdens$_{18km}$	GRASS$_{540m}$	AG$_{250}$	EDGE$_{3km}^{b}$	iH2Od$_{500}$	LL	K	AIC$_c$	ΔAIC$_c$	Σw_i
-24.50 (7.98)	1.61 (0.92)	0.29 (0.18)					-625.58	12	1,280.56	0.00	0.028
-23.57 (8.00)	1.43 (0.92)	0.30 (0.18)	-1.07 (0.76)				-624.56	13	1,280.71	0.15	0.051
-23.34 (7.97)	1.96 (0.89)						-626.79	11	1,280.78	0.23	0.073
-24.96 (8.00)		0.37 (0.18)	-1.23 (0.76)				-625.78	12	1,280.94	0.38	0.094
-22.41 (7.98)	1.81 (0.90)		-1.01 (0.76)				-625.89	12	1,281.16	0.61	0.113
-24.10 (7.97)	1.55 (0.91)	0.31 (0.18)		1.13 (0.90)			-624.79	13	1,281.18	0.62	0.131
-26.26 (7.99)		0.37 (0.18)					-627.14	11	1,281.48	0.92	0.147
-23.27 (7.98)	1.39 (0.92)	0.32 (0.18)	-1.00 (0.76)	1.02 (0.90)			-623.91	14	1,281.63	1.07	0.162
-24.61 (7.98)		0.39 (0.18)	-1.15 (0.76)	1.08 (0.91)			-625.07	13	1,281.73	1.17	0.176
-22.90 (7.95)	1.93 (0.89)			0.99 (0.90)			-626.18	12	1,281.74	1.18	0.189
-24.42 (7.97)	2.17 (0.89)						-628.36	10	1,281.74	1.19	0.203
-22.11 (8.03)	1.87 (0.89)				-0.30 (0.28)		-626.20	12	1,281.79	1.24	0.217
-20.97 (8.05)	1.70 (0.90)		-1.09 (0.76)		-0.34 (0.28)		-625.14	13	1,281.88	1.32	0.230
-25.77 (7.98)		0.39 (0.18)		1.21 (0.91)			-626.25	12	1,281.90	1.34	0.243
-24.88 (7.98)	1.79 (0.90)	0.28 (0.18)		1.38 (0.90)			-626.26	12	1,281.92	1.36	0.255
-22.29 (8.08)	1.38 (0.92)	0.27 (0.19)	-1.13 (0.76)		-0.28 (0.28)		-624.07	14	1,281.95	1.39	0.268
-23.72 (7.96)	2.11 (0.88)			1.23 (0.89)			-627.39	11	1,281.97	1.42	0.280
-23.49 (8.10)		0.34 (0.18)	-1.29 (0.76)		-0.30 (0.28)		-625.21	13	1,282.00	1.45	0.292
-23.43 (8.07)	1.57 (0.91)	0.26 (0.19)			-0.24 (0.28)		-625.22	13	1,282.02	1.46	0.304
-25.51 (8.00)	1.89 (0.91)	0.25 (0.18)					-627.47	11	1,282.13	1.58	0.316
-24.50 (7.97)	1.50 (0.92)	0.29 (0.18)				0.14 (0.18)	-625.30	13	1,282.19	1.63	0.327
-24.85 (7.98)		0.37 (0.18)	-1.21 (0.76)			0.17 (0.18)	-625.32	13	1,282.23	1.67	0.338
-22.08 (7.97)	1.79 (0.89)		-0.94 (0.76)	0.89 (0.90)			-625.40	13	1,282.38	1.82	0.348
-23.57 (7.98)	1.33 (0.93)	0.30 (0.18)	-1.06 (0.76)			0.13 (0.18)	-624.29	14	1,282.39	1.83	0.358
-23.34 (7.96)	1.85 (0.90)					0.13 (0.18)	-626.52	12	1,282.42	1.86	0.368
-23.63 (7.99)	2.06 (0.89)		-0.90 (0.76)				-627.65	11	1,282.51	1.95	0.377
-22.92 (8.05)	1.51 (0.91)	0.28 (0.19)		1.17 (0.90)	-0.26 (0.28)		-624.36	14	1,282.52	1.97	0.387
-21.56 (8.02)	1.84 (0.89)			1.06 (0.89)	-0.32 (0.28)		-625.50	13	1,282.58	2.02	0.396
-26.12 (7.97)		0.36 (0.18)				0.18 (0.18)	-626.63	12	1,282.64	2.08	0.405
-23.06 (8.08)		0.36 (0.18)	-1.21 (0.76)	1.12 (0.90)	-0.32 (0.28)		-624.43	14	1,282.68	2.12	0.413
-22.81 (8.02)	2.02 (0.90)						-629.91	9	1,282.69	2.14	0.422
-21.92 (8.06)	1.34 (0.92)	0.29 (0.19)	-1.06 (0.76)	1.06 (0.90)	-0.29 (0.28)		-623.36	15	1,282.77	2.21	0.430
-24.72 (8.01)	1.76 (0.91)	0.25 (0.18)	-0.94 (0.77)				-626.69	12	1,282.77	2.21	0.438
-25.02 (8.09)		0.34 (0.18)			-0.26 (0.28)		-626.71	12	1,282.80	2.24	0.447
-24.20 (7.99)	1.67 (0.91)	0.28 (0.18)	-0.85 (0.76)	1.30 (0.90)			-625.62	13	1,282.83	2.27	0.455
-22.41 (7.97)	1.70 (0.91)		-1.00 (0.76)			0.13 (0.18)	-625.63	13	1,282.85	2.29	0.463
-20.56 (8.03)	1.68 (0.89)		-1.02 (0.76)	0.95 (0.89)	-0.36 (0.28)		-624.57	14	1,282.95	2.39	0.470
-24.12 (7.96)	1.46 (0.92)	0.31 (0.18)		1.08 (0.90)		0.12 (0.18)	-624.58	14	1,282.96	2.40	0.478
-23.05 (7.97)	2.01 (0.89)		-0.82 (0.76)	1.16 (0.89)			-626.80	12	1,282.99	2.44	0.485
-23.20 (8.07)		0.33 (0.18)	-1.27 (0.76)		-0.34 (0.28)	0.20 (0.18)	-624.60	14	1,283.01	2.45	0.493
-23.90 (8.03)			-1.20 (0.76)				-627.94	11	1,283.08	2.52	0.500
-24.42 (8.07)		0.36 (0.18)		1.25 (0.91)	-0.28 (0.28)		-625.75	13	1,283.08	2.53	0.507

TABLE 6.5. Continued

Rank	Intercept	ABIGSAGE$_{1km}$	NDVI$_{270}$	NDVI$_{270}^{2}$	ELEV^{b}	ELEV^{2c}	SOLAR	SOLAR^{2d}	TRI$_{18km}$	CFRST$_{1km}$
43	-9.65 (3.91)	0.88 (0.35)	4.13 (3.50)	-0.85 (4.07)	0.21 (0.20)	-0.33 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.27 (1.22)
44	-12.92 (4.01)	0.34 (0.37)	5.09 (3.41)	-2.21 (4.07)	0.32 (0.20)	-0.58 (0.50)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	-2.45 (1.22)
45	-12.57 (3.76)	1.19 (0.32)	5.11 (3.49)	-2.78 (3.97)	0.34 (0.19)	-0.66 (0.47)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
46	-4.26 (2.17)	0.94 (0.34)	5.15 (3.43)	-2.56 (4.03)	0.18 (0.19)	-0.24 (0.49)			-0.03 (0.01)	-2.53 (1.16)
47	-13.28 (3.99)	0.57 (0.33)	5.83 (3.38)	-2.90 (4.05)	0.36 (0.20)	-0.69 (0.50)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.30 (1.22)
48	-9.78 (3.92)	0.43 (0.36)	5.45 (3.35)	-2.16 (3.96)	0.21 (0.20)	-0.34 (0.50)	0.08 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.84 (1.22)
49	-11.94 (3.75)	1.18 (0.32)	4.73 (3.45)	-2.34 (3.94)	0.32 (0.19)	-0.63 (0.46)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
50	-11.60 (3.71)	1.12 (0.32)	5.13 (3.45)	-3.19 (3.96)	0.34 (0.19)	-0.67 (0.47)	0.09 (0.04)	-0.32 (0.13)	-0.02 (0.01)	
51	-10.89 (4.11)	0.48 (0.40)	3.15 (3.52)	0.20 (4.10)	0.22 (0.20)	-0.33 (0.50)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.60 (1.23)
52	-11.86 (4.04)	0.54 (0.39)	3.58 (3.54)	-0.74 (4.17)	0.27 (0.20)	-0.46 (0.51)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.18 (1.22)
53	-11.18 (4.10)	0.74 (0.36)	3.63 (3.51)	-0.20 (4.10)	0.25 (0.20)	-0.42 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.42 (1.23)
54	-11.21 (3.89)	0.77 (0.33)	6.60 (3.34)	-3.35 (3.95)	0.29 (0.20)	-0.52 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.03 (0.01)	-2.46 (1.22)
55	-3.50 (2.19)	0.88 (0.35)	4.64 (3.42)	-1.46 (3.97)	0.13 (0.19)	-0.13 (0.49)			-0.03 (0.01)	-3.01 (1.17)
56	-10.38 (3.87)	0.95 (0.34)	4.59 (3.52)	-1.84 (4.15)	0.25 (0.20)	-0.43 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-1.83 (1.22)
57	-4.39 (2.19)	0.84 (0.36)	4.39 (3.44)	-1.19 (4.00)	0.18 (0.19)	-0.22 (0.49)			-0.03 (0.01)	-2.98 (1.16)
58	-13.97 (3.93)	0.99 (0.33)	5.03 (3.48)	-3.07 (4.00)	0.40 (0.19)	-0.81 (0.48)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
59	-14.13 (3.97)	1.06 (0.33)	4.70 (3.49)	-2.29 (3.98)	0.38 (0.19)	-0.76 (0.47)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
60	-12.27 (3.73)	1.14 (0.32)	5.43 (3.48)	-3.51 (4.00)	0.35 (0.19)	-0.70 (0.47)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	
61	-13.26 (3.94)	1.00 (0.33)	4.77 (3.45)	-2.80 (3.97)	0.38 (0.19)	-0.78 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
62	-15.58 (3.86)	0.81 (0.32)	7.09 (3.30)	-5.23 (3.84)	0.48 (0.19)	-1.04 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
63	-12.31 (4.08)	0.55 (0.34)	5.37 (3.37)	-1.87 (4.00)	0.31 (0.20)	-0.57 (0.49)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.72 (1.22)
64	-4.78 (2.21)	0.81 (0.36)	4.73 (3.44)	-2.04 (4.04)	0.21 (0.20)	-0.32 (0.50)			-0.03 (0.01)	-2.71 (1.16)
65	-3.78 (2.19)	0.86 (0.35)	5.01 (3.42)	-2.32 (4.01)	0.16 (0.19)	-0.21 (0.49)			-0.03 (0.01)	-2.75 (1.17)
66	-3.52 (2.21)	0.79 (0.38)	4.56 (3.44)	-1.58 (3.98)	0.13 (0.20)	-0.10 (0.49)			-0.03 (0.01)	-2.94 (1.16)
67	-11.85 (4.05)	0.27 (0.37)	4.92 (3.39)	-1.95 (4.05)	0.29 (0.20)	-0.53 (0.50)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.64 (1.22)
68	-11.85 (3.76)	0.98 (0.35)	4.39 (3.46)	-2.14 (3.93)	0.30 (0.19)	-0.57 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
69	-13.46 (3.99)	1.07 (0.33)	4.36 (3.46)	-1.91 (3.95)	0.36 (0.19)	-0.72 (0.47)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
70	-15.46 (3.87)	0.62 (0.35)	6.52 (3.33)	-4.76 (3.85)	0.45 (0.19)	-0.96 (0.47)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
71	-12.51 (3.77)	1.00 (0.35)	4.78 (3.49)	-2.58 (3.97)	0.31 (0.19)	-0.60 (0.47)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
72	-10.31 (3.91)	0.70 (0.33)	6.27 (3.33)	-2.87 (3.94)	0.26 (0.20)	-0.47 (0.49)	0.08 (0.04)	-0.29 (0.14)	-0.03 (0.01)	-2.69 (1.23)
73	-10.05 (3.93)	0.41 (0.36)	5.71 (3.34)	-2.48 (3.95)	0.22 (0.20)	-0.37 (0.50)	0.08 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.76 (1.21)
74	-9.59 (3.88)	0.87 (0.34)	4.49 (3.50)	-1.64 (4.13)	0.24 (0.20)	-0.40 (0.50)	0.07 (0.04)	-0.27 (0.13)	-0.02 (0.01)	-2.05 (1.23)
75	-11.22 (4.07)	0.72 (0.36)	4.01 (3.51)	-1.05 (4.14)	0.28 (0.20)	-0.50 (0.50)	0.09 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.18 (1.23)
76	-10.14 (3.88)	0.74 (0.38)	4.18 (3.54)	-1.47 (4.16)	0.22 (0.20)	-0.35 (0.51)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-1.97 (1.22)
77	-12.32 (4.04)	0.52 (0.34)	5.70 (3.36)	-2.70 (4.04)	0.34 (0.20)	-0.65 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.46 (1.22)
78	-11.13 (3.91)	0.51 (0.36)	6.13 (3.36)	-3.05 (3.97)	0.26 (0.20)	-0.44 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.49 (1.21)
79	-11.54 (3.72)	0.94 (0.35)	4.81 (3.46)	-2.97 (3.97)	0.31 (0.19)	-0.62 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
80	-10.83 (3.88)	0.52 (0.36)	6.25 (3.37)	-3.51 (4.03)	0.27 (0.20)	-0.47 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.35 (1.22)
81	-14.15 (3.99)	0.86 (0.37)	4.34 (3.50)	-2.07 (3.98)	0.36 (0.19)	-0.70 (0.48)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
82	-9.77 (3.89)	0.43 (0.36)	5.85 (3.35)	-2.98 (4.02)	0.24 (0.20)	-0.41 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.61 (1.23)
83	-11.22 (3.86)	0.76 (0.33)	6.97 (3.34)	-4.18 (4.01)	0.31 (0.20)	-0.59 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.03 (0.01)	-2.21 (1.22)
84	-15.69 (3.93)	0.66 (0.35)	6.18 (3.34)	-3.95 (3.83)	0.43 (0.19)	-0.90 (0.46)	0.12 (0.04)	-0.44 (0.15)	-0.02 (0.01)	
85	-15.82 (3.91)	0.88 (0.32)	6.81 (3.32)	-4.42 (3.83)	0.46 (0.18)	-0.98 (0.46)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
86	-4.19 (2.19)	0.94 (0.34)	5.09 (3.46)	-2.07 (4.01)	0.17 (0.19)	-0.19 (0.49)			-0.03 (0.01)	-2.76 (1.15)
87	-2.97 (2.23)	0.69 (0.39)	4.37 (3.42)	-1.26 (3.97)	0.10 (0.19)	-0.05 (0.49)			-0.03 (0.01)	-3.20 (1.17)

TABLE 6.5. Extended

MIX_{18km}	RIP_{540m}	$RDdens_{18km}$	$GRASS_{540m}$	AG_{250}	$EDGE_{3km}{}^{b}$	$iH2Od_{500}$	LL	K	AIC_c	ΔAIC_c	Σw_i
-21.98 (8.01)	1.73 (0.90)				-0.33 (0.28)	0.16 (0.18)	-625.80	13	1,283.19	2.63	0.514
-24.53 (7.97)		0.38 (0.18)	-1.13 (0.76)	1.01 (0.91)		0.16 (0.18)	-624.69	14	1,283.19	2.64	0.520
-24.39 (7.96)	2.05 (0.90)					0.15 (0.18)	-628.02	11	1,283.23	2.68	0.527
-22.32 (7.99)	1.99 (0.90)			1.12 (0.89)			-629.11	10	1,283.24	2.68	0.533
-25.67 (7.96)		0.38 (0.18)		1.14 (0.91)		0.16 (0.18)	-625.84	13	1,283.27	2.72	0.540
-22.10 (8.11)			-1.28 (0.76)		-0.39 (0.28)		-626.96	12	1,283.31	2.75	0.546
-23.62 (8.03)	2.13 (0.89)				-0.21 (0.27)		-628.06	11	1,283.32	2.76	0.552
-22.74 (8.01)	2.06 (0.88)			1.30 (0.89)	-0.25 (0.27)		-626.97	12	1,283.34	2.78	0.559
-22.16 (8.06)	1.25 (0.93)	0.27 (0.18)	-1.13 (0.76)		-0.31 (0.28)	0.16 (0.18)	-623.69	15	1,283.42	2.86	0.565
-23.29 (7.97)	1.30 (0.93)	0.32 (0.18)	-0.99 (0.76)	0.98 (0.90)		0.12 (0.18)	-623.70	15	1,283.44	2.88	0.571
-23.29 (8.05)	1.44 (0.92)	0.26 (0.18)			-0.27 (0.28)	0.16 (0.18)	-624.83	14	1,283.46	2.91	0.576
-25.19 (8.03)							-629.23	10	1,283.47	2.92	0.582
-21.50 (8.08)	1.93 (0.90)				-0.33 (0.28)		-629.23	10	1,283.48	2.92	0.588
-22.92 (7.95)	1.83 (0.90)			0.94 (0.90)		0.12 (0.18)	-625.96	13	1,283.51	2.95	0.594
-23.60 (8.03)	1.77 (0.92)	0.21 (0.18)					-629.26	10	1,283.54	2.98	0.600
-24.88 (7.97)	1.68 (0.91)	0.28 (0.18)		1.33 (0.90)		0.13 (0.18)	-626.01	13	1,283.60	3.05	0.605
-25.49 (7.99)	1.76 (0.92)	0.25 (0.18)				0.15 (0.18)	-627.11	12	1,283.61	3.06	0.610
-23.72 (7.95)	2.00 (0.89)			1.18 (0.89)		0.13 (0.18)	-627.14	12	1,283.66	3.10	0.616
-24.06 (8.06)	1.77 (0.90)	0.26 (0.19)		1.42 (0.90)	-0.19 (0.28)		-626.03	13	1,283.66	3.10	0.621
-27.02 (7.99)		0.37 (0.18)		1.53 (0.91)			-628.23	11	1,283.67	3.11	0.626
-24.68 (8.06)		0.33 (0.18)			-0.30 (0.28)	0.21 (0.18)	-626.05	13	1,283.69	3.14	0.632
-23.16 (8.00)	1.71 (0.92)	0.23 (0.18)		1.24 (0.89)			-628.29	11	1,283.77	3.22	0.637
-20.90 (8.05)	1.89 (0.89)			1.19 (0.88)	-0.35 (0.28)		-628.32	11	1,283.83	3.28	0.641
-22.11 (8.04)	1.91 (0.91)		-0.75 (0.76)				-629.41	10	1,283.85	3.29	0.646
-22.81 (8.06)		0.34 (0.18)	-1.19 (0.76)	1.05 (0.90)	-0.35 (0.28)	0.18 (0.18)	-623.92	15	1,283.88	3.33	0.651
-22.70 (8.05)	2.00 (0.89)		-0.94 (0.76)		-0.24 (0.27)		-627.28	12	1,283.95	3.39	0.656
-24.85 (8.08)	1.88 (0.91)	0.23 (0.19)			-0.15 (0.28)		-627.31	12	1,284.02	3.46	0.660
-26.04 (8.00)		0.37 (0.18)	-1.02 (0.76)	1.42 (0.91)			-627.32	12	1,284.02	3.47	0.665
-23.61 (7.98)	1.93 (0.90)		-0.89 (0.76)			0.15 (0.18)	-627.33	12	1,284.04	3.48	0.669
-23.61 (8.10)					-0.35 (0.28)		-628.43	11	1,284.06	3.51	0.673
-21.84 (8.08)			-1.26 (0.76)		-0.43 (0.28)	0.21 (0.18)	-626.24	13	1,284.07	3.52	0.678
-21.47 (8.00)	1.71 (0.90)			1.01 (0.89)	-0.35 (0.28)	0.15 (0.18)	-625.16	14	1,284.13	3.57	0.682
-22.82 (8.04)	1.39 (0.92)	0.28 (0.19)		1.12 (0.90)	-0.29 (0.28)	0.14 (0.18)	-624.05	15	1,284.13	3.58	0.686
-22.10 (7.96)	1.70 (0.90)		-0.94 (0.76)	0.84 (0.90)		0.12 (0.18)	-625.19	14	1,284.18	3.62	0.690
-24.14 (8.05)		0.34 (0.18)		1.18 (0.91)	-0.32 (0.28)	0.19 (0.18)	-625.20	14	1,284.21	3.66	0.694
-23.81 (8.01)			-1.17 (0.76)			0.18 (0.18)	-627.41	12	1,284.21	3.66	0.698
-21.97 (8.03)	1.94 (0.89)		-0.86 (0.76)	1.23 (0.89)	-0.27 (0.27)		-626.32	13	1,284.22	3.67	0.702
-23.56 (8.02)			-1.13 (0.76)	0.91 (0.91)			-627.43	12	1,284.24	3.69	0.706
-24.70 (8.00)	1.63 (0.92)	0.26 (0.18)	-0.93 (0.76)			0.15 (0.18)	-626.35	13	1,284.29	3.73	0.710
-21.65 (8.10)			-1.21 (0.76)	0.99 (0.90)	-0.41 (0.28)		-626.36	13	1,284.30	3.75	0.714
-24.70 (8.01)				1.04 (0.91)			-628.56	11	1,284.32	3.77	0.718
-26.71 (8.03)		0.34 (0.18)	-1.12 (0.77)				-628.56	11	1,284.32	3.77	0.721
-27.86 (8.02)		0.34 (0.18)					-629.66	10	1,284.35	3.79	0.725
-22.81 (8.01)	1.92 (0.91)					0.12 (0.18)	-629.68	10	1,284.38	3.83	0.729
-20.62 (8.10)	1.80 (0.91)		-0.84 (0.76)		-0.35 (0.28)		-623.05	16	1,284.38	3.83	0.733

TABLE 6.5. Continued

Rank	Intercept	$ABIGSAGE_{1km}$	$NDVI_{270}$	$NDVI_{270}^2$	$ELEV^b$	$ELEV^{2c}$	SOLAR	$SOLAR^{2d}$	TRI_{18km}	$CFRST_{1km}$
88	-11.54 (3.90)	0.76 (0.33)	6.86 (3.34)	-3.68 (3.95)	0.30 (0.20)	-0.55 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.03 (0.01)	-2.37 (1.21)
89	-13.25 (3.96)	0.81 (0.37)	4.43 (3.46)	-2.56 (3.98)	0.36 (0.19)	-0.73 (0.48)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
90	-9.26 (3.89)	0.63 (0.38)	4.04 (3.51)	-1.22 (4.14)	0.20 (0.20)	-0.31 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.23 (1.23)
91	-13.99 (3.94)	0.82 (0.37)	4.70 (3.49)	-2.84 (4.00)	0.38 (0.19)	-0.76 (0.48)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
92	-13.44 (4.01)	0.87 (0.36)	4.00 (3.47)	-1.69 (3.95)	0.34 (0.19)	-0.66 (0.47)	0.11 (0.04)	-0.40 (0.14)	-0.02 (0.01)	
93	-3.85 (2.22)	0.79 (0.38)	4.93 (3.44)	-2.38 (4.03)	0.16 (0.20)	-0.18 (0.50)			-0.03 (0.01)	-2.68 (1.16)
94	-3.96 (2.23)	0.66 (0.40)	4.14 (3.45)	-1.01 (4.00)	0.15 (0.20)	-0.16 (0.50)			-0.03 (0.01)	-3.14 (1.17)
95	-12.20 (3.76)	1.14 (0.32)	5.10 (3.47)	-2.74 (3.95)	0.33 (0.19)	-0.66 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
96	-3.93 (2.23)	0.79 (0.36)	4.30 (3.43)	-1.01 (3.99)	0.16 (0.19)	-0.19 (0.49)			-0.03 (0.01)	-3.15 (1.17)
97	-12.23 (3.74)	0.98 (0.35)	5.12 (3.49)	-3.29 (4.00)	0.33 (0.19)	-0.64 (0.47)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
98	-10.58 (3.92)	0.68 (0.33)	6.52 (3.32)	-3.19 (3.94)	0.27 (0.20)	-0.50 (0.49)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.61 (1.22)
99	-10.27 (3.88)	0.68 (0.33)	6.65 (3.33)	-3.73 (4.00)	0.29 (0.20)	-0.54 (0.50)	0.08 (0.04)	-0.27 (0.14)	-0.03 (0.01)	-2.43 (1.23)
100	-4.30 (2.24)	0.75 (0.36)	4.65 (3.42)	-1.88 (4.02)	0.19 (0.20)	-0.28 (0.50)			-0.03 (0.01)	-2.88 (1.17)
101	-15.78 (3.86)	0.80 (0.32)	7.29 (3.30)	-5.43 (3.83)	0.49 (0.19)	-1.05 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
102	-11.84 (3.72)	1.09 (0.32)	5.45 (3.46)	-3.51 (3.98)	0.35 (0.19)	-0.70 (0.47)	0.09 (0.04)	-0.32 (0.13)	-0.02 (0.01)	
103	-3.73 (2.20)	0.85 (0.35)	5.00 (3.44)	-1.85 (3.99)	0.15 (0.19)	-0.16 (0.49)			-0.03 (0.01)	-2.99 (1.16)
104	-3.29 (2.24)	0.68 (0.39)	4.75 (3.42)	-2.10 (4.01)	0.13 (0.20)	-0.14 (0.50)			-0.03 (0.01)	-2.93 (1.18)
105	-4.44 (2.19)	0.93 (0.34)	5.39 (3.46)	-2.83 (4.05)	0.19 (0.20)	-0.26 (0.49)			-0.03 (0.01)	-2.51 (1.16)
106	-4.37 (2.25)	0.65 (0.39)	4.49 (3.45)	-1.84 (4.04)	0.19 (0.20)	-0.26 (0.50)			-0.03 (0.01)	-2.87 (1.17)
107	-5.31 (2.16)	0.61 (0.34)	6.46 (3.32)	-3.16 (3.92)	0.24 (0.19)	-0.39 (0.49)			-0.03 (0.01)	-3.39 (1.16)
108	-5.68 (2.18)	0.58 (0.34)	6.75 (3.31)	-4.00 (3.95)	0.28 (0.19)	-0.49 (0.49)			-0.03 (0.01)	-3.08 (1.16)
109	-16.05 (3.92)	0.86 (0.31)	7.06 (3.32)	-4.71 (3.82)	0.47 (0.18)	-1.00 (0.46)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
110	-13.48 (3.95)	0.97 (0.33)	5.07 (3.47)	-3.11 (3.99)	0.39 (0.19)	-0.81 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
111	-4.61 (2.22)	0.82 (0.36)	4.68 (3.47)	-1.52 (4.03)	0.19 (0.20)	-0.25 (0.49)			-0.03 (0.01)	-2.94 (1.16)
112	-15.66 (3.88)	0.61 (0.34)	6.71 (3.32)	-4.96 (3.85)	0.46 (0.19)	-0.97 (0.47)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
113	-15.91 (3.93)	0.65 (0.35)	6.43 (3.34)	-4.24 (3.83)	0.44 (0.19)	-0.91 (0.46)	0.12 (0.04)	-0.44 (0.15)	-0.02 (0.01)	
114	-10.02 (3.90)	0.41 (0.36)	6.06 (3.35)	-3.22 (4.01)	0.25 (0.20)	-0.44 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.55 (1.22)
115	-12.11 (3.77)	0.95 (0.36)	4.75 (3.48)	-2.53 (3.95)	0.31 (0.19)	-0.60 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
116	-15.07 (3.90)	0.80 (0.32)	7.07 (3.29)	-5.20 (3.83)	0.47 (0.19)	-1.03 (0.46)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
117	-13.71 (4.00)	1.04 (0.33)	4.73 (3.48)	-2.30 (3.97)	0.37 (0.19)	-0.75 (0.47)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
118	-3.98 (2.21)	0.84 (0.35)	5.31 (3.44)	-2.64 (4.03)	0.17 (0.19)	-0.23 (0.49)			-0.03 (0.01)	-2.74 (1.17)
119	-11.52 (3.87)	0.75 (0.33)	7.19 (3.34)	-4.42 (4.01)	0.32 (0.20)	-0.61 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.03 (0.01)	-2.14 (1.22)
120	-3.41 (2.27)	0.58 (0.40)	4.02 (3.43)	-0.79 (3.99)	0.13 (0.20)	-0.11 (0.50)			-0.03 (0.01)	-3.34 (1.18)
121	-11.13 (3.89)	0.52 (0.36)	6.46 (3.37)	-3.75 (4.03)	0.28 (0.20)	-0.50 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.28 (1.22)
122	-10.51 (3.88)	0.66 (0.33)	6.86 (3.32)	-3.98 (3.99)	0.30 (0.20)	-0.56 (0.50)	0.08 (0.04)	-0.27 (0.14)	-0.02 (0.01)	-2.37 (1.23)
123	-14.90 (3.91)	0.59 (0.35)	6.48 (3.31)	-4.72 (3.83)	0.44 (0.19)	-0.94 (0.47)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
124	-13.67 (3.71)	0.97 (0.31)	8.28 (3.27)	-6.48 (3.80)	0.44 (0.18)	-0.94 (0.46)	0.09 (0.04)	-0.34 (0.14)	-0.03 (0.01)	
125	-3.75 (2.23)	0.77 (0.38)	4.85 (3.46)	-1.91 (4.01)	0.14 (0.20)	-0.13 (0.50)			-0.03 (0.01)	-2.90 (1.16)
126	-4.70 (2.21)	0.41 (0.37)	5.97 (3.33)	-2.76 (3.92)	0.21 (0.20)	-0.30 (0.49)			-0.03 (0.01)	-3.55 (1.16)
127	-4.95 (2.23)	0.79 (0.36)	4.97 (3.46)	-2.30 (4.06)	0.22 (0.20)	-0.34 (0.50)			-0.03 (0.01)	-2.69 (1.16)
128	-4.86 (2.15)	0.74 (0.33)	7.52 (3.28)	-4.41 (3.86)	0.22 (0.19)	-0.34 (0.49)			-0.03 (0.01)	-3.20 (1.15)
129	-14.01 (3.75)	1.02 (0.31)	7.96 (3.28)	-5.70 (3.78)	0.42 (0.18)	-0.90 (0.46)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
130	-13.83 (3.76)	0.80 (0.34)	7.34 (3.30)	-5.24 (3.79)	0.39 (0.19)	-0.81 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
131	-11.78 (3.73)	0.91 (0.35)	5.12 (3.47)	-3.29 (3.98)	0.33 (0.19)	-0.64 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
132	-5.12 (2.21)	0.53 (0.34)	6.58 (3.30)	-3.75 (3.94)	0.25 (0.19)	-0.44 (0.49)			-0.03 (0.01)	-3.26 (1.17)

TABLE 6.5. Extended

MIX_{18km}	RIP_{540m}	$RDdens_{18km}$	$GRASS_{540m}$	AG_{250}	$EDGE_{3km}^{b}$	$iH2Od_{500}$	LL	K	AIC_c	ΔAIC_c	Σw_i
-25.07 (8.00)						0.19 (0.18)	-628.60	11	1,284.40	3.85	0.736
-23.28 (8.07)	1.64 (0.91)	0.26 (0.19)	-0.89 (0.76)	1.35 (0.89)	-0.21 (0.28)		-628.64	11	1,284.48	3.92	0.740
-20.46 (8.02)	1.55 (0.90)		-1.02 (0.76)	0.90 (0.89)	-0.38 (0.28)	0.15 (0.18)	-625.34	14	1,284.48	3.93	0.743
-24.21 (7.98)	1.56 (0.92)	0.28 (0.18)	-0.85 (0.76)	1.25 (0.90)		0.13 (0.18)	-624.23	15	1,284.51	3.95	0.747
-23.94 (8.09)	1.74 (0.91)	0.23 (0.19)	-0.97 (0.76)		-0.18 (0.28)		-625.37	14	1,284.54	3.98	0.750
-21.72 (8.01)	1.89 (0.90)		-0.68 (0.76)	1.06 (0.89)			-626.49	13	1,284.56	4.01	0.754
-22.89 (8.05)	1.65 (0.93)	0.21 (0.18)	-0.79 (0.76)				-628.70	11	1,284.60	4.04	0.757
-23.46 (8.01)	1.98 (0.90)				-0.25 (0.28)	0.17 (0.18)	-628.71	11	1,284.62	4.06	0.760
-22.35 (8.11)	1.72 (0.92)	0.18 (0.18)			-0.29 (0.28)		-627.62	12	1,284.62	4.07	0.764
-23.06 (7.96)	1.90 (0.90)		-0.81 (0.76)	1.10 (0.89)		0.13 (0.18)	-628.73	11	1,284.65	4.09	0.767
-23.31 (8.07)					-0.39 (0.28)	0.22 (0.18)	-626.55	13	1,284.70	4.14	0.770
-23.00 (8.09)				1.12 (0.90)	-0.38 (0.28)		-627.66	12	1,284.71	4.15	0.773
-21.82 (8.08)	1.65 (0.91)	0.21 (0.18)		1.28 (0.89)	-0.31 (0.28)		-627.66	12	1,284.71	4.16	0.776
-26.87 (7.97)		0.36 (0.18)		1.44 (0.91)		0.18 (0.18)	-627.68	12	1,284.74	4.18	0.779
-22.64 (8.00)	1.92 (0.89)			1.25 (0.89)	-0.28 (0.28)	0.15 (0.18)	-627.72	12	1,284.82	4.26	0.782
-21.38 (8.06)	1.79 (0.91)				-0.36 (0.28)	0.16 (0.18)	-626.62	13	1,284.84	4.28	0.785
-20.14 (8.08)	1.77 (0.90)		-0.76 (0.76)	1.12 (0.88)	-0.37 (0.28)		-628.86	11	1,284.92	4.37	0.788
-22.34 (7.98)	1.90 (0.91)			1.08 (0.89)		0.11 (0.18)	-627.80	12	1,284.98	4.43	0.791
-22.55 (8.02)	1.60 (0.92)	0.24 (0.18)	-0.71 (0.76)	1.17 (0.89)			-628.93	11	1,285.07	4.51	0.793
-25.45 (8.06)		0.29 (0.18)					-627.84	12	1,285.07	4.51	0.796
-24.92 (8.03)		0.32 (0.18)		1.32 (0.90)			-631.12	9	1,285.10	4.54	0.799
-27.64 (7.99)		0.33 (0.18)				0.21 (0.18)	-630.04	10	1,285.10	4.55	0.801
-23.94 (8.05)	1.64 (0.91)	0.25 (0.19)		1.37 (0.90)	-0.22 (0.28)	0.15 (0.18)	-628.98	11	1,285.16	4.60	0.804
-23.59 (8.02)	1.67 (0.93)	0.21 (0.18)				0.12 (0.18)	-625.70	14	1,285.21	4.66	0.806
-25.91 (7.98)		0.36 (0.18)	-1.00 (0.76)	1.34 (0.91)		0.18 (0.18)	-629.02	11	1,285.25	4.69	0.809
-26.52 (8.01)		0.33 (0.18)	-1.09 (0.76)			0.20 (0.18)	-626.83	13	1,285.25	4.69	0.811
-21.43 (8.07)			-1.19 (0.76)	0.92 (0.90)	-0.44 (0.28)	0.20 (0.18)	-627.93	12	1,285.25	4.69	0.813
-22.55 (8.03)	1.85 (0.90)		-0.94 (0.76)		-0.27 (0.28)	0.17 (0.18)	-625.72	14	1,285.25	4.70	0.816
-26.09 (8.08)		0.34 (0.18)		1.57 (0.91)	-0.20 (0.28)		-626.84	13	1,285.27	4.71	0.818
-24.68 (8.07)	1.74 (0.92)	0.22 (0.19)			-0.19 (0.28)	0.17 (0.18)	-627.97	12	1,285.33	4.77	0.821
-20.82 (8.04)	1.77 (0.90)			1.14 (0.88)	-0.38 (0.28)	0.14 (0.18)	-626.88	13	1,285.36	4.80	0.823
-24.63 (7.99)				0.97 (0.91)		0.18 (0.18)	-628.03	12	1,285.44	4.89	0.825
-21.47 (8.13)	1.58 (0.93)	0.19 (0.18)	-0.86 (0.76)		-0.32 (0.28)		-628.07	12	1,285.52	4.97	0.827
-23.49 (8.00)			-1.11 (0.76)	0.85 (0.91)		0.17 (0.18)	-628.07	12	1,285.53	4.97	0.829
-22.76 (8.06)				1.04 (0.90)	-0.41 (0.28)	0.21 (0.18)	-626.98	13	1,285.54	4.98	0.831
-24.99 (8.09)		0.34 (0.18)	-1.05 (0.76)	1.47 (0.91)	-0.23 (0.28)		-626.99	13	1,285.58	5.02	0.833
-25.94 (8.02)				1.34 (0.90)			-626.99	13	1,285.58	5.02	0.835
-22.12 (8.03)	1.81 (0.92)		-0.74 (0.76)			0.12 (0.18)	-630.28	10	1,285.58	5.03	0.837
-24.42 (8.08)		0.29 (0.18)	-0.96 (0.76)				-629.19	11	1,285.58	5.03	0.839
-23.17 (7.99)	1.62 (0.93)	0.23 (0.18)		1.20 (0.89)		0.11 (0.18)	-630.30	10	1,285.62	5.06	0.841
-24.67 (8.08)							-628.12	12	1,285.62	5.07	0.843
-26.78 (8.04)							-632.46	8	1,285.64	5.08	0.845
-25.64 (8.05)			-1.10 (0.77)				-631.40	9	1,285.65	5.10	0.847
-21.86 (8.02)	1.80 (0.90)		-0.86 (0.76)	1.17 (0.89)	-0.30 (0.28)	0.15 (0.18)	-630.34	10	1,285.71	5.15	0.849
-23.36 (8.12)		0.28 (0.18)		1.36 (0.90)	-0.34 (0.28)		-625.96	14	1,285.73	5.18	0.851

TABLE 6.5. Continued

Rank	Intercept	$ABIGSAGE_{1km}$	$NDVI_{270}$	$NDVI_{270}^{2}$	$ELEV^{b}$	$ELEV^{2c}$	SOLAR	$SOLAR^{2d}$	TRI_{18km}	$CFRST_{1km}$
133	-3.81 (2.29)	0.57 (0.40)	4.39 (3.43)	-1.65 (4.03)	0.17 (0.20)	-0.21 (0.50)			-0.03 (0.01)	-3.07 (1.18)
134	-3.21 (2.25)	0.66 (0.39)	4.72 (3.44)	-1.65 (3.99)	0.12 (0.20)	-0.08 (0.49)			-0.03 (0.01)	-3.17 (1.17)
135	-5.10 (2.23)	0.40 (0.37)	6.29 (3.33)	-3.59 (3.96)	0.24 (0.20)	-0.40 (0.50)			-0.03 (0.01)	-3.26 (1.16)
136	-13.68 (4.01)	0.83 (0.37)	4.37 (3.49)	-2.08 (3.97)	0.35 (0.19)	-0.69 (0.47)	0.11 (0.04)	-0.40 (0.14)	-0.02 (0.01)	
137	-4.27 (2.18)	0.66 (0.33)	7.19 (3.26)	-3.93 (3.86)	0.19 (0.19)	-0.29 (0.49)			-0.03 (0.01)	-3.43 (1.17)
138	-13.52 (3.72)	0.78 (0.34)	7.70 (3.30)	-6.01 (3.82)	0.41 (0.19)	-0.85 (0.47)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
139	-4.77 (2.20)	0.56 (0.34)	6.29 (3.31)	-2.89 (3.91)	0.22 (0.19)	-0.35 (0.49)			-0.03 (0.01)	-3.56 (1.17)
140	-15.21 (3.97)	0.64 (0.35)	6.14 (3.33)	-3.89 (3.82)	0.42 (0.19)	-0.88 (0.46)	0.12 (0.04)	-0.44 (0.15)	-0.02 (0.01)	
141	-13.46 (3.97)	0.78 (0.37)	4.73 (3.48)	-2.88 (3.99)	0.37 (0.19)	-0.75 (0.48)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
142	-5.15 (2.16)	0.73 (0.33)	7.85 (3.28)	-5.24 (3.91)	0.25 (0.19)	-0.42 (0.49)			-0.03 (0.01)	-2.92 (1.16)
143	-4.15 (2.24)	0.76 (0.36)	4.65 (3.45)	-1.40 (4.01)	0.17 (0.20)	-0.21 (0.49)			-0.03 (0.01)	-3.12 (1.17)
144	-15.41 (3.96)	0.87 (0.32)	6.78 (3.31)	-4.38 (3.82)	0.45 (0.18)	-0.97 (0.46)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
145	-4.54 (2.19)	0.65 (0.33)	7.53 (3.26)	-4.79 (3.90)	0.22 (0.19)	-0.37 (0.49)			-0.03 (0.01)	-3.14 (1.17)
146	-4.24 (2.20)	0.54 (0.36)	7.03 (3.29)	-4.02 (3.87)	0.18 (0.20)	-0.25 (0.49)			-0.03 (0.01)	-3.36 (1.15)
147	-3.55 (2.24)	0.44 (0.37)	6.63 (3.28)	-3.47 (3.86)	0.15 (0.20)	-0.18 (0.49)			-0.03 (0.01)	-3.62 (1.16)
148	-8.37 (3.93)	0.59 (0.39)	2.50 (3.55)	0.94 (4.13)	0.12 (0.20)	-0.07 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.81 (1.24)
149	-4.06 (2.26)	0.34 (0.37)	5.75 (3.32)	-2.45 (3.91)	0.18 (0.20)	-0.24 (0.49)			-0.03 (0.01)	-3.75 (1.17)
150	-15.19 (3.90)	0.77 (0.32)	7.29 (3.29)	-5.42 (3.82)	0.48 (0.18)	-1.03 (0.46)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
151	-5.75 (2.06)	1.24 (0.32)	6.49 (3.39)	-5.19 (3.86)	0.31 (0.19)	-0.58 (0.47)			-0.03 (0.01)	
152	-14.27 (3.75)	0.99 (0.31)	8.20 (3.28)	-5.98 (3.78)	0.43 (0.18)	-0.91 (0.46)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
153	-5.54 (2.18)	0.60 (0.34)	6.72 (3.32)	-3.49 (3.92)	0.26 (0.19)	-0.42 (0.49)			-0.03 (0.01)	-3.30 (1.16)
154	-4.18 (2.26)	0.64 (0.40)	4.42 (3.47)	-1.33 (4.03)	0.17 (0.20)	-0.19 (0.50)			-0.03 (0.01)	-3.10 (1.17)
155	-4.48 (2.25)	0.73 (0.36)	4.95 (3.44)	-2.19 (4.04)	0.20 (0.20)	-0.30 (0.50)			-0.03 (0.01)	-2.87 (1.17)
156	-4.45 (2.27)	0.33 (0.37)	6.08 (3.31)	-3.29 (3.95)	0.21 (0.20)	-0.34 (0.50)			-0.03 (0.01)	-3.46 (1.17)
157	-4.03 (2.24)	0.78 (0.38)	5.16 (3.47)	-2.64 (4.06)	0.17 (0.20)	-0.20 (0.50)			-0.03 (0.01)	-2.66 (1.16)
158	-14.08 (3.76)	0.78 (0.34)	7.58 (3.30)	-5.51 (3.79)	0.40 (0.19)	-0.83 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
159	-5.87 (2.19)	0.58 (0.34)	6.97 (3.31)	-4.25 (3.95)	0.29 (0.19)	-0.51 (0.49)			-0.03 (0.01)	-3.02 (1.16)
160	-13.92 (3.71)	0.95 (0.31)	8.47 (3.27)	-6.68 (3.80)	0.45 (0.18)	-0.95 (0.46)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
161	-15.02 (3.91)	0.58 (0.34)	6.69 (3.31)	-4.94 (3.83)	0.45 (0.19)	-0.95 (0.46)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
162	-3.49 (2.26)	0.66 (0.39)	5.05 (3.44)	-2.42 (4.03)	0.14 (0.20)	-0.16 (0.50)			-0.03 (0.01)	-2.92 (1.17)
163	-13.13 (3.71)	0.93 (0.31)	8.14 (3.26)	-6.32 (3.79)	0.43 (0.18)	-0.93 (0.46)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
164	-9.40 (3.92)	0.71 (0.38)	2.68 (3.57)	0.59 (4.15)	0.14 (0.20)	-0.11 (0.51)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.51 (1.23)
165	-4.52 (2.19)	0.64 (0.33)	7.45 (3.26)	-4.26 (3.85)	0.21 (0.19)	-0.32 (0.49)			-0.03 (0.01)	-3.35 (1.16)
166	-3.86 (2.24)	0.44 (0.37)	6.99 (3.28)	-4.31 (3.91)	0.18 (0.20)	-0.27 (0.50)			-0.03 (0.01)	-3.35 (1.17)
167	-5.13 (2.17)	0.73 (0.33)	7.78 (3.28)	-4.73 (3.87)	0.23 (0.19)	-0.37 (0.49)			-0.03 (0.01)	-3.11 (1.15)
168	-10.94 (4.08)	0.47 (0.40)	3.53 (3.52)	-0.60 (4.15)	0.24 (0.20)	-0.41 (0.51)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.37 (1.23)

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^{2}
[c] Coefficients and standard errors multiplied by 10^{6}
[d] Coefficients and standard errors multiplied by 10^{3}

TABLE 6.5. Extended

MIX$_{18km}$	RIP$_{540m}$	RDdens$_{18km}$	GRASS$_{540m}$	AG$_{250}$	EDGE$_{3km}$[b]	iH2Od$_{500}$	LL	K	AIC$_c$	ΔAIC$_c$	Σw_i
-21.06 (8.10)	1.53 (0.92)	0.21 (0.18)	-0.78 (0.76)	1.21 (0.88)	-0.33 (0.28)		-629.32	11	1,285.84	5.28	0.853
-20.51 (8.09)	1.66 (0.92)		-0.83 (0.76)		-0.39 (0.28)	0.15 (0.18)	-627.13	13	1,285.86	5.30	0.855
-24.02 (8.04)		0.31 (0.18)	-0.88 (0.76)	1.23 (0.90)			-628.25	12	1,285.88	5.33	0.856
-23.77 (8.08)	1.60 (0.92)	0.23 (0.19)	-0.97 (0.76)		-0.21 (0.28)	0.17 (0.18)	-629.36	11	1,285.91	5.35	0.858
-22.99 (8.16)					-0.38 (0.28)		-626.06	14	1,285.92	5.37	0.860
-24.97 (8.03)			-1.01 (0.77)	1.24 (0.90)			-631.55	9	1,285.96	5.41	0.861
-23.98 (8.15)		0.26 (0.18)			-0.32 (0.28)		-629.39	11	1,285.98	5.42	0.863
-25.82 (8.12)		0.32 (0.18)	-1.15 (0.77)		-0.19 (0.28)		-630.49	10	1,286.00	5.44	0.865
-23.16 (8.06)	1.52 (0.92)	0.26 (0.19)	-0.89 (0.76)	1.30 (0.90)	-0.24 (0.28)	0.15 (0.18)	-628.33	12	1,286.04	5.48	0.866
-24.13 (8.06)				1.17 (0.90)			-625.00	15	1,286.05	5.49	0.868
-22.22 (8.09)	1.59 (0.93)	0.18 (0.18)			-0.32 (0.28)	0.15 (0.18)	-631.61	9	1,286.08	5.53	0.870
-27.12 (8.11)		0.32 (0.18)			-0.17 (0.28)		-628.38	12	1,286.14	5.59	0.871
-22.33 (8.14)				1.24 (0.89)	-0.40 (0.28)		-629.49	11	1,286.18	5.62	0.873
-23.65 (8.10)			-0.95 (0.76)				-630.58	10	1,286.18	5.63	0.874
-21.76 (8.18)			-1.03 (0.76)		-0.41 (0.28)		-631.66	9	1,286.19	5.63	0.876
	1.88 (0.92)		-1.29 (0.77)		-0.45 (0.28)		-630.60	10	1,286.22	5.66	0.877
-22.76 (8.17)		0.26 (0.18)	-1.03 (0.76)		-0.35 (0.28)		-628.44	12	1,286.26	5.70	0.879
-25.75 (8.06)		0.33 (0.18)		1.49 (0.91)	-0.24 (0.28)	0.20 (0.18)	-629.54	11	1,286.28	5.72	0.880
-23.36 (8.02)	2.30 (0.89)			1.48 (0.88)			-627.34	13	1,286.28	5.72	0.881
-26.58 (8.01)						0.22 (0.18)	-631.72	9	1,286.29	5.74	0.883
-25.32 (8.04)		0.28 (0.18)				0.17 (0.18)	-630.65	10	1,286.32	5.77	0.884
-22.89 (8.04)	1.55 (0.94)	0.21 (0.18)	-0.77 (0.76)			0.12 (0.18)	-630.65	10	1,286.32	5.77	0.886
-21.72 (8.06)	1.54 (0.92)	0.20 (0.18)		1.23 (0.89)	-0.34 (0.28)	0.13 (0.18)	-628.49	12	1,286.37	5.81	0.887
-22.28 (8.14)		0.28 (0.18)	-0.95 (0.76)	1.27 (0.89)	-0.36 (0.28)		-627.41	13	1,286.40	5.85	0.888
-21.74 (8.01)	1.81 (0.91)		-0.67 (0.76)	1.02 (0.89)		0.10 (0.18)	-628.52	12	1,286.42	5.87	0.890
-25.48 (8.02)			-1.07 (0.77)			0.21 (0.18)	-628.53	12	1,286.45	5.90	0.891
-24.83 (8.01)		0.31 (0.18)		1.26 (0.90)		0.15 (0.18)	-629.65	11	1,286.50	5.95	0.892
-25.81 (8.00)				1.25 (0.91)		0.20 (0.18)	-629.68	11	1,286.55	5.99	0.894
-24.67 (8.07)		0.33 (0.18)	-1.04 (0.76)	1.39 (0.91)	-0.26 (0.28)	0.20 (0.18)	-629.68	11	1,286.56	6.01	0.895
-20.06 (8.06)	1.65 (0.91)		-0.76 (0.76)	1.07 (0.88)	-0.40 (0.28)	0.14 (0.18)	-626.39	14	1,286.58	6.03	0.896
-24.68 (8.10)				1.43 (0.90)	-0.30 (0.28)		-627.51	13	1,286.61	6.05	0.897
	2.05 (0.92)		-1.20 (0.77)				-629.72	11	1,286.64	6.09	0.899
-22.71 (8.13)					-0.42 (0.28)	0.22 (0.18)	-629.72	11	1,286.64	6.09	0.900
-21.25 (8.15)			-0.96 (0.76)	1.15 (0.89)	-0.43 (0.28)		-630.82	10	1,286.67	6.11	0.901
-24.56 (8.06)						0.19 (0.18)	-629.76	11	1,286.72	6.16	0.902
-21.81 (8.05)	1.22 (0.92)	0.28 (0.18)	-1.06 (0.76)	1.01 (0.90)	-0.32 (0.28)	0.14 (0.18)	-631.93	9	1,286.72	6.16	0.903

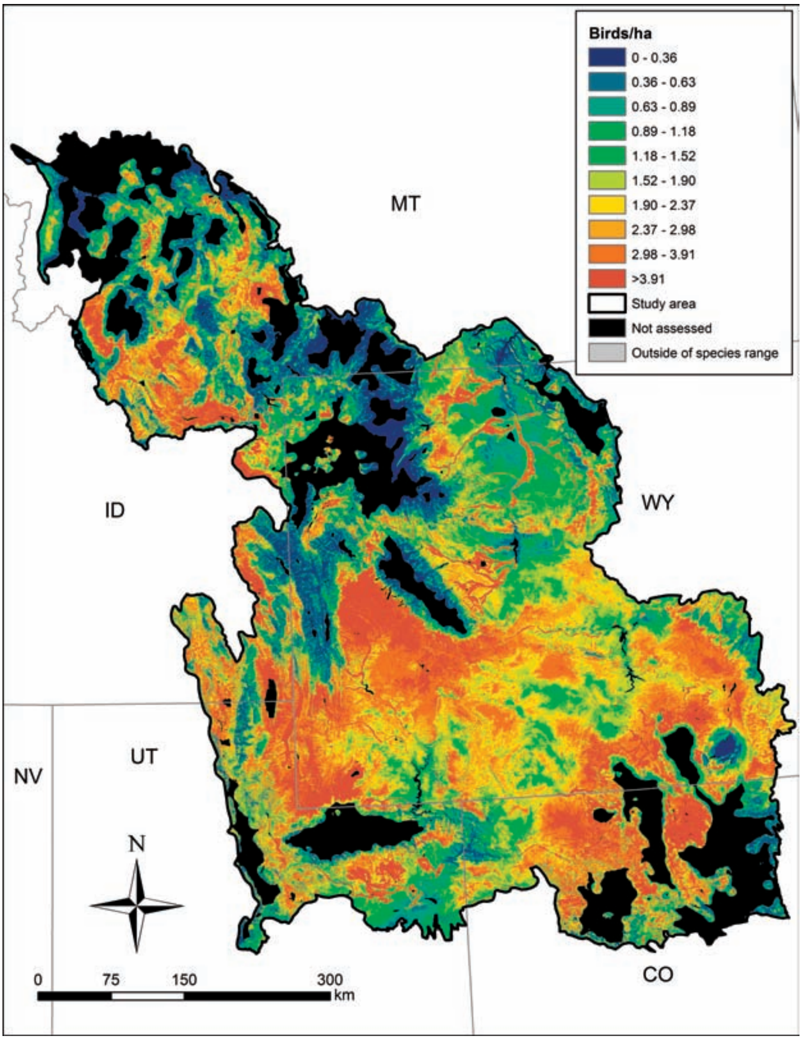

FIG. 6.2. Predicted density estimates (birds/ha) for Brewer's sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one Brewer's sparrow, the lowest density that could support a viable territory is 0.42 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

0.33), and the global density was estimated at 0.10 birds/ha (95% CI = 0.07–0.12). Plot level density estimates could not be developed for many sites because of single detections at many survey blocks.

Lark sparrow

A hazard rate model with a simple polynomial adjustment and 25-m groupings combined with a truncation distance of 175 m provided the best fit to the distance data for lark sparrow ($\chi^2_4 = 4.96$, $p = 0.29$). We used 132 detections at 67 of the 318 survey blocks for this model. The top AIC-selected detection model included the base model with covariates for shrub index and survey start time. The top AIC-selected lark sparrow model had reasonable fit ($\chi^2_2 = 5.97$, $p = 0.05$) and outcompeted all other covariate distance models; ΔAIC values

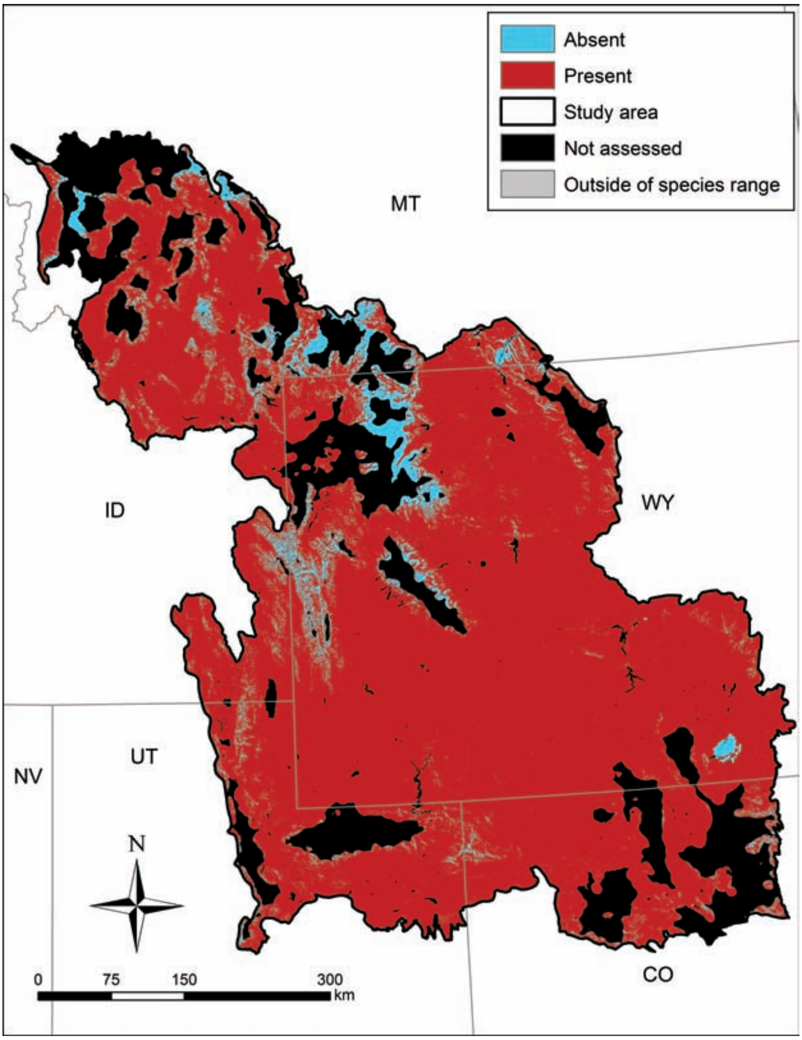

FIG. 6.3. Distribution of Brewer's sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.42 birds/ha), the largest territory sizes required to support one Brewer's sparrow. Semi-transparent grey shaded areas are outside the range of Brewer's sparrow and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

ranged from 1.02 to 8.46. Detectability was 0.27 (95% CI = 0.23–0.32) with an overall density estimate of 0.16 (95% CI = 0.12–0.20) birds/ha. Where present, mean lark sparrow density was 0.76 (range: 0.20–2.95) birds/ha.

Sage sparrow

A hazard rate model with a simple polynomial adjustment, and 20-m grouping and aggregation of detections <40 m, combined with a truncation distance of 220 m provided the best fit to the distance data for sage sparrow. We used 299 detections at 114 of the 318 survey blocks for this model. The sage sparrow model with no covariates had reasonable fit ($\chi^2_5 = 10.47$, p = 0.06), and based on AIC, outcompeted all other distance models fit with covariates; ΔAIC values ranged from 11.75 to 21.73. Detect-

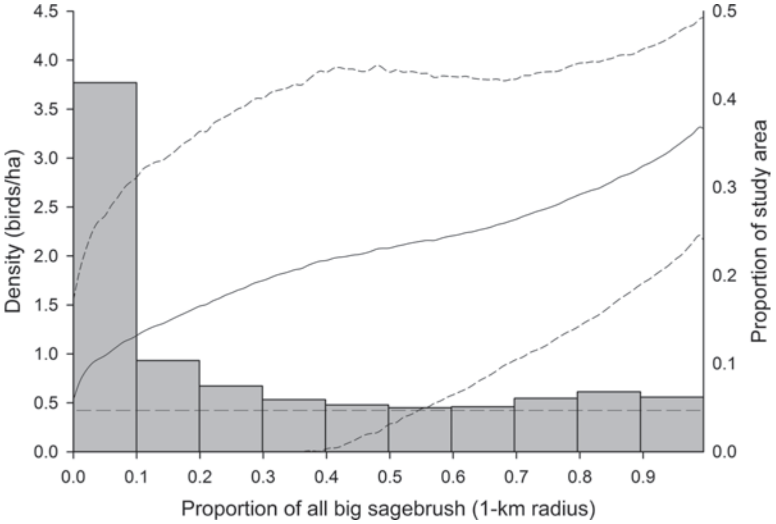

FIG. 6.4. Brewer's sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata* spp.) within a 1-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 1-km radius. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.42 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10 percent segment of all big sagebrush within 1 km.

ability was 0.27 (95% CI = 0.22–0.33) with an overall density estimate of 0.12 birds/ha (95% CI = 0.10–0.14) birds. Where present, mean sage sparrow density was 0.32 (range: 0.12–0.99) birds/ha.

Sage thrasher

A hazard rate model with a simple polynomial adjustment and 50-m grouping combined with a truncation distance of 450 m provided the best fit to the distance data for sage thrasher ($\chi^2_6 = 6.18$, $p = 0.40$). We used 420 detections at 199 of the 318 survey blocks for this model. The top AIC-selected detection model included the base model with a covariate for shrub index. All other models had ΔAIC values ranging from 1.33–72.5. The top AIC-selected sage thrasher model with one covariate had reasonable fit ($\chi^2_5 = 10.89$, $p = 0.05$); ΔAIC values ranged from 1.97 to 9.13. Detectability for sage thrasher was the lowest for all species modeled at 0.09 (95% CI = 0.08–0.10) with an overall density estimate of 0.23 (95% CI = 0.21–0.25) birds/ha. Where present, mean sage thrasher density was 0.36 (range: 0.17–1.03) birds /ha.

Vesper sparrow

A hazard rate model with a simple polynomial adjustment, 25-m grouping and aggregation of detections <50 m, combined with a truncation distance of 240 m provided the best fit to the distance data for vesper sparrow ($\chi^2_5 = 7.53$, $p = 0.18$). This resulted in 509 detections being used at 167 of the 318 survey blocks. The top AIC-selected detection model included covariates for shrub index, observer group, detection type, and Julian date of survey. All other models had ΔAIC values ranging from 4.56 to 35.74. A goodness of fit test could not be generated for the top vesper sparrow model due to limited degrees of freedom. Detection probability was 0.16 (95% CI = 0.15–0.18) with an overall density estimate of 0.54 (95% CI = 0.46–0.62) birds/ha. Where present, mean vesper sparrow density was 1.04 (range: 0.16–3.04) birds/ha.

TABLE 6.6. Results of AIC_c-based model selection for green-tailed towhee occurrence models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$MTNSAGE_{5km} + NDVI_{5km}$	-126.27	3	258.70	0.00	0.09
2	$MTNSAGE_{3km} + NDVI_{5km}$	-126.46	3	259.08	0.38	0.07
3	$ABIGSAGE_{5km} + NDVI_{5km}$	-126.72	3	259.58	0.88	0.06
4	$MTNSAGE_{5km} + NDVI_{3km}$	-126.98	3	260.12	1.42	0.04
5	$MTNSAGE_{270} + NDVI_{5km}$	-127.06	3	260.28	1.58	0.04
6	$MTNSAGE_{3km} + NDVI_{3km}$	-127.11	3	260.37	1.66	0.04
7	$ABIGSAGE_{3km} + NDVI_{5km}$	-127.11	3	260.37	1.67	0.04
8	$ALLSAGE_{5km} + NDVI_{5km}$	-127.12	3	260.39	1.69	0.04
9	$MTNSAGE_{540} + NDVI_{5km}$	-127.17	3	260.50	1.80	0.04

[a] Variable definitions provided in Table 4.2

Model Selection, Spatial Application, Dose Response, and Evaluation

Brewer's sparrow

Two variables were excluded from the *a priori* candidate set of variables for Brewer's sparrow abundance models, conifer forest (0.27-km radius) and mixed shrubland (0.27 km), because these habitats were present on only 20 or fewer survey blocks. Also, we did not consider temperature variables for this species, but did consider solar radiation. Several remaining variables were dropped, including many of the sagebrush contagion, patch, and edge variables, because they were correlated with other sagebrush variables. We considered NDVI as a non-linearity at all scales but non-linearities were not evident for any sagebrush variable. Interactions between sagebrush and NDVI variables were not considered.

Initial exploration of the count data without covariates suggested that a zero-inflated negative binomial may be most appropriate. However, inclusion of sagebrush and NDVI covariates with the offset term using a negative binomial model (without zero-inflation) had a better fit to the data ($z = 0.94$, $p = 0.17$) and was used to fit the sagebrush/NDVI base models. The top AIC_c-selected sagebrush/NDVI model consisted of all big sagebrush (*A. tridentata*) within 1 km ($ABIGSAGE_{1km}$) and NDVI as a quadratic within 0.27 km ($NDVI_{270} + NDVI_{270}^2$), which had low support ($w_i = 0.07$; Table 6.2). Use locations averaged 9.3% more big sagebrush habitat than absence locations (Appendix 6.1). Using this sagebrush/NDVI base model to evaluate individual multi-scale covariates (Table 6.3), the top vegetation submodel consisted of conifer forest within 1 km ($CFRST_{1km}$), grassland within 0.54 km ($GRASS_{540m}$), mixed shrubland within 18 km (MIX_{18km}), riparian within 0.54 km (RIP_{540}), and all sagebrush edge density within 3 km ($EDGE_{3km}$; Table 6.4). The top AIC_c-selected abiotic model consisted of Compound Topographic Index (CTI), elevation as a quadratic ($ELEV + ELEV^2$), 0.5-km distance decay from intermittent water ($iH2Od_{500}$), solar radiation as a quadratic ($SOLAR + SOLAR^2$), and topographic ruggedness within 18 km (TRI_{18km}; Table 6.4). Decay distance (0.25 km) to agricultural land (AG_{250}) and density of all roads within 18 km ($RDdens_{18km}$) were

TABLE 6.7. Evaluation statistics from AIC$_c$-based univariate model selection for green-tailed towhee occurrence models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes (AIC$_c$), change in AIC$_c$ value from the top model [ΔAIC$_c$], and Akaike weight [w_i]). We ran models with mountain sagebrush (5-km radius) and NDVI (5-km radius) variables as a base model for variables tested. We used AIC$_c$ to sort models for each variable in ascending order to identify the extent at which green-tailed towhees respond to individual variables.

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	$CFRST_{540}$	-125.61	4	259.36	0.00	0.41
	$CFRST_{1km}$	-125.80	4	259.73	0.38	0.34
	$CFRST_{270}$	-126.15	4	260.43	1.07	0.24
	$GRASS_{5km}$	-124.88	4	257.88	0.00	0.25
	$GRASS_{3km}$	-125.07	4	258.27	0.39	0.20
	$GRASS_{1km}$	-125.20	4	258.53	0.65	0.18
	$GRASS_{270}$	-125.41	4	258.94	1.06	0.15
	$GRASS_{540}$	-125.42	4	258.98	1.10	0.14
	$GRASS_{18km}$	-126.10	4	260.32	2.44	0.07
	MIX_{270}	-125.21	4	258.54	0.00	0.31
	MIX_{3km}	-125.66	4	259.44	0.90	0.20
	MIX_{540}	-125.99	4	260.11	1.57	0.14
	MIX_{5km}	-126.00	4	260.13	1.59	0.14
	MIX_{1km}	-126.22	4	260.56	2.01	0.11
	MIX_{18km}	-126.26	4	260.64	2.10	0.11
	RIP_{3km}	-125.78	4	259.69	0.00	0.24
	RIP_{5km}	-126.19	4	260.51	0.83	0.16
	RIP_{18km}	-126.21	4	260.54	0.85	0.16
	RIP_{270}	-126.26	4	260.64	0.95	0.15
	RIP_{540}	-126.26	4	260.65	0.96	0.15
	RIP_{1km}	-126.27	4	260.67	0.98	0.15
	$SALT_{18km}$	-125.73	4	259.58	0.00	0.23
	$SALT_{270}$	-125.87	4	259.87	0.29	0.20
	$SALT_{540m}$	-126.13	4	260.38	0.80	0.15
	$SALT_{5km}$	-126.16	4	260.44	0.86	0.15
	$SALT_{1km}$	-126.16	4	260.45	0.87	0.15
	$SALT_{3km}$	-126.26	4	260.65	1.07	0.13
	$PATCH_{1km}$	-124.71	4	257.55	0.00	0.31
	$EDGE_{5km}$	-125.32	4	258.78	1.23	0.17
	$CONTAG_{3km}$	-125.92	4	259.96	2.41	0.09
	$EDGE_{3km}$	-125.95	4	260.04	2.49	0.09
	$EDGE_{1km}$	-126.13	4	260.38	2.83	0.07
	$PATCH_{3km}$	-126.17	4	260.46	2.91	0.07

TABLE 6.7. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	PATCH$_{5km}$	-126.22	4	260.57	3.03	0.07
	CONTAG$_{1km}$	-126.27	4	260.67	3.12	0.06
	CONTAG$_{5km}$	-126.27	4	260.67	3.12	0.06
Abiotic	CTI	-126.14	4	260.41	0.00	1.00
	ELEV	-126.27	4	260.67	0.00	1.00
	iH2Od$_{1km}$[b]	-125.52	4	259.16	0.00	0.48
	iH2Od$_{500}$[b]	-126.01	4	260.14	0.98	0.29
	iH2Od$_{250}$[b]	-126.25	4	260.63	1.47	0.23
	pH2Od$_{1km}$[b]	-126.10	4	260.33	0.00	0.35
	pH2Od$_{250}$[b]	-126.12	4	260.37	0.04	0.34
	pH2Od$_{250}$[b]	-126.22	4	260.56	0.23	0.31
	SOLAR	-125.67	4	259.47	0.00	1.00
	TRI$_{270}$	-123.36	4	254.86	0.00	0.45
	TRI	-124.31	4	256.76	1.90	0.17
	TRI$_{540}$	-124.36	4	256.84	1.98	0.17
	TRI$_{1km}$	-124.96	4	258.05	3.20	0.09
	TRI$_{5km}$	-125.47	4	259.06	4.20	0.05
	TRI$_{3km}$	-125.67	4	259.47	4.61	0.04
	TRI$_{18km}$	-126.21	4	260.55	5.69	0.03
Disturbance	AG$_{250}$[b]	-125.72	4	259.56	0.00	0.44
	AG$_{500}$[b]	-126.12	4	260.37	0.81	0.30
	AG$_{1km}$[b]	-126.25	4	260.63	1.07	0.26
	MjRD$_{1km}$[b]	-124.82	4	257.76	0.00	0.38
	MjRD$_{500}$[b]	-124.91	4	257.96	0.20	0.34
	MjRD$_{250}$[b]	-125.13	4	258.39	0.63	0.28
	PIPE$_{250}$[b]	-125.49	4	259.11	0.00	0.37
	PIPE$_{500}$[b]	-125.63	4	259.38	0.27	0.33
	PIPE$_{1km}$[b]	-125.71	4	259.54	0.43	0.30
	POWER$_{1km}$[b]	-126.08	4	260.29	0.00	0.36
	POWER$_{500}$[b]	-126.16	4	260.44	0.15	0.34
	POWER$_{250}$[b]	-126.27	4	260.68	0.38	0.30
	RDdens$_{540}$	-125.56	4	259.25	0.00	0.17
	2RD$_{250}$[b]	-125.80	4	259.72	0.47	0.14
	2RD$_{500}$[b]	-125.91	4	259.95	0.70	0.12
	RDdens$_{270}$	-126.03	4	260.19	0.94	0.11
	2RD$_{1km}$[b]	-126.06	4	260.25	1.00	0.11

TABLE 6.7. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{18km}$	-126.19	4	260.51	1.26	0.09
	$RDdens_{5km}$	-126.23	4	260.59	1.34	0.09
	$RDdens_{1km}$	-126.27	4	260.67	1.42	0.09
	$RDdens_{3km}$	-126.27	4	260.67	1.42	0.09
	$WELL_{1km}$[b]	-125.41	4	258.94	0.00	0.51
	$WELL_{500}$[b]	-126.02	4	260.17	1.23	0.28
	$WELL_{250}$[b]	-126.27	4	260.66	1.72	0.22

[a] Variable definitions provided in Table 4.2

[b] Distance decay function ($e^{(\text{Euclidian distance from feature/-distance parameter})}$)

included in the top disturbance submodel (Table 6.4).

The top AIC_c-selected Brewer's sparrow abundance model combined vegetation, abiotic, and disturbance factors (Table 6.5). Brewer's sparrow abundance was positively associated with proportion of big sagebrush, more productive habitats (positive and increasing quadratic function), moderate elevations, proportion of riparian land cover, and road densities (at large scales; Table 6.5). Lower abundance was associated with high solar radiation, more rugged terrain, and proportion of both conifer forest and mixed shrubland (Table 6.5). However, the weight of evidence for the top model was low (w_i = 0.03), with 168 candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.5). Other models indicated Brewer's sparrow abundance increased with proportion of agricultural land and with proximity to intermittent water sources but decreased with proportion of grassland and sagebrush edge density (Table 6.5). The final model-averaged abundance model was:

$$\text{Density} = \exp(-9.42 + 0.63 * ABIGSAGE_{1km} + 3.77 * NDVI_{270} - 1.30 * NDVI_{270}^2 + 0.0023 * ELEV - 0.41 * ELEV^2 + 0.073 * SOLAR - 0.00026 * SOLAR^2 - 0.02 * TRI_{18km} - 1.59 * CFRST_{1km} - 20.04 * MIX_{18km} + 1.05 * RIP_{540} + 0.15 * RDdens_{18km} - 0.41 * GRASS_{540} + 0.39 * AG_{250} - 0.08 * EDGE_{3km} + 0.03 * iH2Od_{500} + 1.07) \tag{6.1}$$

The mean offset for the survey blocks is represented by the final constant in the model (1.07).

The final model-averaged Brewer's sparrow abundance model predicted mean densities that were significantly and positively correlated with independent count data from 96 BBS routes (r_s = 0.54, $p < 0.001$). When applied spatially, the low elevation areas dominated by sagebrush habitats in the southwestern, southcentral, and northwestern portions of the WBEA area were predicted to support high densities of Brewer's sparrow (Fig. 6.2). Based on the lowest density that could support a Brewer's sparrow territory (0.42 birds/ha; Fig. 6.2), 87.7% of the area (302,891 km^2) of the Wyoming Basins was predicted to contain enough resources to support breeding Brewer's sparrows (Fig. 6.3). Brewer's sparrow densities increased linearly from 0.5 to 3.0 birds/ha as proportion of all big sagebrush in a 1-km radius increased from 0.0

TABLE 6.8. Results of AIC$_c$-based submodel selection for green-tailed towhee occurrence models in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC$_c$), change in AIC$_c$ value from the top model (ΔAIC$_c$), and Akaike weight (w_i). Only models with ΔAIC$_c$ ≤ 2 are shown.

Category	Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	1	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + MIX$_{270m}$ + PATCH$_{1km}$	-123.61	5	257.41	0.00	0.04
	2	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + PATCH$_{1km}$	-124.71	4	257.55	0.14	0.04
	3	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$ + MIX$_{270m}$	-123.79	5	257.78	0.37	0.04
	4	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$	-124.88	4	257.88	0.48	0.04
	5	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + MIX$_{270m}$ + RIP$_{3km}$ + PATCH$_{1km}$	-122.96	6	258.19	0.78	0.03
	6	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + RIP$_{3km}$ + PATCH$_{1km}$	-124.04	5	258.27	0.86	0.03
	7	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$ + MIX$_{270m}$ + PATCH$_{1km}$	-123.14	6	258.54	1.14	0.03
	8	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + MIX$_{270m}$	-125.21	4	258.54	1.14	0.03
	9	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$ + SALT$_{18km}$	-124.20	5	258.58	1.18	0.02
	10	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$ + MIX$_{270m}$ + SALT$_{18km}$	-123.16	6	258.59	1.18	0.02
	11	MTNSAGE$_{5km}$ + NDVI$_{5km}$	-126.27	3	258.62	1.22	0.02
	12	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$ + GRASS$_{5km}$ + MIX$_{270m}$	-123.18	6	258.63	1.23	0.02
	13	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$ + PATCH$_{1km}$	-124.23	5	258.65	1.24	0.02
	14	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$ + GRASS$_{5km}$	-124.23	5	258.66	1.25	0.02
	15	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + MIX$_{270m}$ + PATCH$_{1km}$ + SALT$_{18km}$	-123.31	6	258.89	1.49	0.02
	16	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + PATCH$_{1km}$ + SALT$_{18km}$	-124.39	5	258.96	1.56	0.02
	17	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$ + MIX$_{270m}$ + PATCH$_{1km}$	-123.38	6	259.02	1.61	0.02
	18	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$ + MIX$_{270m}$ + RIP$_{3km}$	-123.40	6	259.06	1.66	0.02
	19	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$ + PATCH$_{1km}$	-124.45	5	259.09	1.68	0.02
	20	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + GRASS$_{5km}$ + RIP$_{3km}$	-124.47	5	259.12	1.72	0.02
	21	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$ + GRASS$_{5km}$ + SALT$_{18km}$	-123.43	6	259.14	1.73	0.02
	22	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$ + GRASS$_{5km}$ + MIX$_{270m}$ + SALT$_{18km}$	-122.44	7	259.25	1.84	0.02
	23	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$ + MIX$_{270m}$	-124.58	5	259.34	1.94	0.02
	24	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + CFRST$_{540m}$	-125.61	4	259.36	1.95	0.02
Abiotic	1	MTNSAGE$_{5km}$ + NDVI$_{5km}$ + SOLAR + TRI$_{270}$	-121.90	5	254.00	0.00	0.09

TABLE 6.8. Continued

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
	2	$MTNSAGE_{5km} + NDVI_{5km} + pH2Od_{1km} + SOLAR + TRI_{270}$	-120.98	6	254.24	0.24	0.08
	3	$MTNSAGE_{5km} + NDVI_{5km} + iH2Od_{1km} + SOLAR + TRI_{270}$	-121.02	6	254.31	0.31	0.08
	4	$MTNSAGE_{5km} + NDVI_{5km} + TRI_{270}$	-123.36	4	254.86	0.86	0.06
	5	$MTNSAGE_{5km} + NDVI_{5km} + iH2Od_{1km} + TRI_{270}$	-122.41	5	255.01	1.01	0.06
	6	$MTNSAGE_{5km} + NDVI_{5km} + iH2Od_{1km} + pH2Od_{1km} + SOLAR + TRI_{270}$	-120.52	7	255.40	1.40	0.05
	7	$MTNSAGE_{5km} + NDVI_{5km} + CTI + SOLAR + TRI_{270}$	-121.69	6	255.66	1.66	0.04
	8	$MTNSAGE_{5km} + NDVI_{5km} + pH2Od_{1km} + TRI_{270}$	-122.81	5	255.81	1.82	0.04
	9	$MTNSAGE_{5km} + NDVI_{5km} + CTI + pH2Od_{1km} + SOLAR + TRI_{270}$	-120.75	7	255.86	1.86	0.04
Disturbance	1	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km}$	-124.82	4	257.76	0.00	0.06
	2	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + WELL_{1km}$	-123.80	5	257.79	0.03	0.06
	3	$MTNSAGE_{5km} + NDVI_{5km}$	-126.27	3	258.62	0.86	0.04
	4	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + RDdens_{540}$	-124.23	5	258.65	0.89	0.04
	5	$MTNSAGE_{5km} + NDVI_{5km} + WELL_{1km}$	-125.41	4	258.94	1.18	0.03
	6	$MTNSAGE_{5km} + NDVI_{5km} + PIPE_{250}$	-125.49	4	259.11	1.35	0.03
	7	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + PIPE_{250}$	-124.50	5	259.19	1.43	0.03
	8	$MTNSAGE_{5km} + NDVI_{5km} + AG_{250} + MjRD_{1km}$	-124.51	5	259.21	1.45	0.03
	9	$MTNSAGE_{5km} + NDVI_{5km} + RDdens_{540}$	-125.56	4	259.25	1.49	0.03
	10	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + RDdens_{540} + WELL_{1km}$	-123.51	6	259.28	1.52	0.03
	11	$MTNSAGE_{5km} + NDVI_{5km} + AG_{250} + MjRD_{1km} + WELL_{1km}$	-123.53	6	259.33	1.57	0.03
	12	$MTNSAGE_{5km} + NDVI_{5km} + AG_{250}$	-125.72	4	259.56	1.80	0.02
	13	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + PIPE_{250} + WELL_{1km}$	-123.66	6	259.58	1.83	0.02

[a] Variable definitions provided in Table 4.2

to 1.0 and densities exceeded the occurrence threshold across the entire range of values (Fig. 6.4).

Green-tailed towhee

Seven variables were excluded from the *a priori* candidate set of variables for green-tailed towhee models because they were represented in fewer than 20 survey blocks. These included conifer forest (0.27 km), mixed shrubland (0.27 km, 0.54 km, 1 km), riparian (0.27 km), and salt-desert shrubland (0.27 km, 0.54 km). We did not consider temperature variables for this species but did consider solar radiation and mountain big sagebrush. Slope and several of the conifer forest variables were correlated with other variables and were dropped. Non-linearities were not evident for NDVI or sagebrush variables, and we did not consider interactions between sagebrush and NDVI variables.

Initial exploration of the count data with covariates revealed major issues of non-convergence with count-base models. This was due to the limited number of survey blocks where site-specific density estimates for the offset term could be derived because of small sample sizes (only 59 presences) and single detections at many survey blocks. Therefore, we only modeled probability of occurrence for green-tailed towhee. The top AIC_c-selected sagebrush/NDVI logistic regression model consisted of mountain sagebrush within 5 km ($MTNSAGE_{1km}$) and NDVI within 5 km ($NDVI_{5km}$; Table 6.6). Use locations averaged 15.4% more mountain sagebrush habitat than absence locations (Appendix 6.2). Using this base model to evaluate individual multi-scale covariates (Table 6.7), the top vegetation submodel consisted of mixed shrubland within 0.27 km (MIX_{270}) and mean patch size of sagebrush within 1km ($PATCH_{1km}$); Table 6.8). The top AIC_c-selected abiotic model consisted of 1-km decay distance from permanent water ($pH2Od_{250}$), solar radiation, and topographic ruggedness within

TABLE 6.9. Results of AIC_c-based model selection for the combined green-tailed towhee occurrence models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters (K), Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) just ≥ 0.9.

Rank	Intercept	$MTNSAGE_{5km}$	$NDVI_{5km}$	SOLAR	TRI_{270}	$PATCH_{1km}$[b]	$MjRD_{1km}$	MIX_{270m}	LL	K	AIC_c	ΔAIC_c	Σw_i
1	-3.64 (1.50)	0.86 (0.81)	7.14 (1.67)	-0.02 (0.01)	0.03 (0.01)	0.53 (0.21)			-118.26	6	248.79	0.00	0.173
2	-3.57 (1.51)	0.75 (0.81)	7.01 (1.68)	-0.02 (0.01)	0.03 (0.01)	0.53 (0.21)		-27.34 (28.01)	-117.28	7	248.93	0.14	0.334
3	-3.81 (1.51)	0.86 (0.81)	7.32 (1.68)	-0.01 (0.01)	0.03 (0.01)	0.52 (0.21)	-0.97 (0.86)		-117.57	7	249.51	0.73	0.455
4	-5.64 (0.92)	0.91 (0.80)	6.34 (1.62)		0.03 (0.01)	0.52 (0.21)		-29.28 (28.54)	-118.69	6	249.65	0.86	0.567
5	-5.78 (0.92)	1.04 (0.79)	6.47 (1.61)		0.03 (0.01)	0.53 (0.21)			-119.76	5	249.71	0.93	0.676
6	-5.7 (0.92)	1.03 (0.8)	6.77 (1.63)		0.03 (0.01)	0.51 (0.21)	-1.19 (0.87)		-118.74	6	249.75	0.96	0.783
7	-5.56 (0.92)	0.91 (0.8)	6.62 (1.64)		0.03 (0.01)	0.50 (0.21)	-1.15 (0.87)	-27.59 (28.02)	-117.72	7	249.80	1.01	0.887
8	-1.96 (1.27)	1.72 (0.73)	5.24 (1.44)	-0.02 (0.01)	0.02 (0.01)				-121.90	5	254.00	5.21	0.900
9	-1.88 (1.28)	1.59 (0.74)	5.10 (1.45)	-0.02 (0.01)	0.03 (0.01)			-28.89 (27.79)	-120.87	6	254.00	5.22	0.912

[a] Variable definitions provided in Table 4.2

[b] Coefficients and standard errors multiplied by 10^2

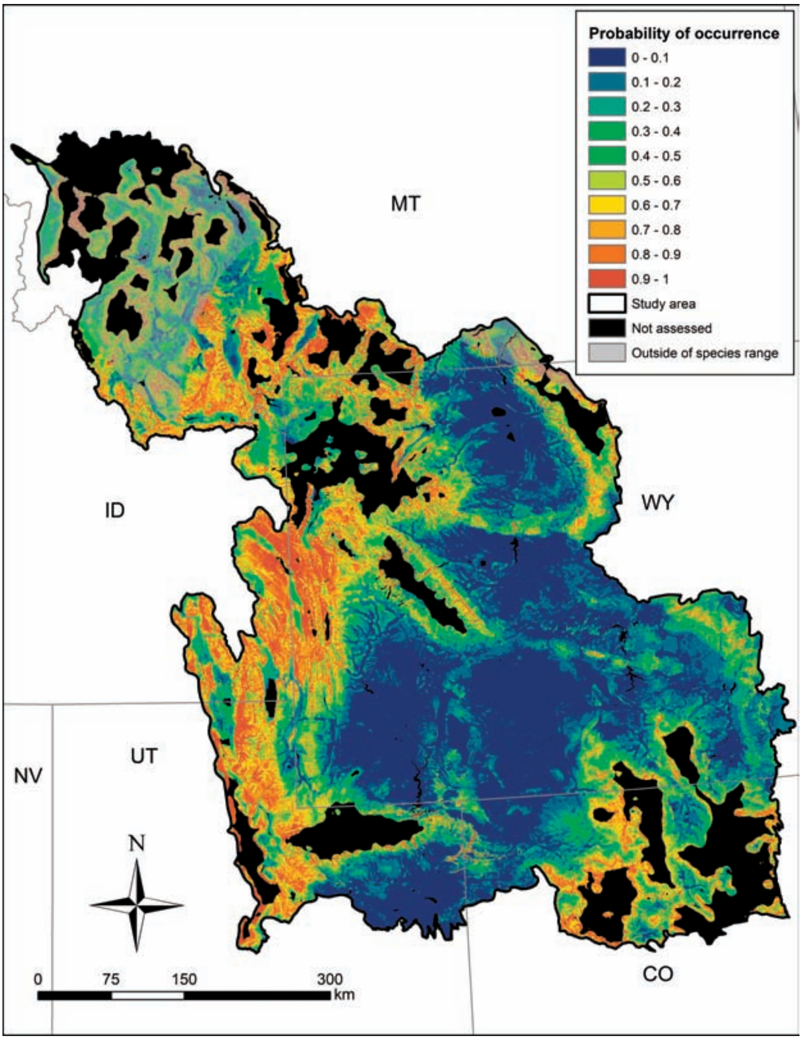

FIG. 6.5. Predicted occurrence (probability) for green-tailed towhee in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the range of the green-tailed towhee and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the optimal classification, the lowest probability where the occurrence of green-tailed towhee is predicted is 0.17. We infer that spatial predictions above this threshold predict occupied patches.

0.27 km (TRI_{270}; Table 6.8). Decay distance (1 km) from interstate/federal and state highways ($MjRD_{1km}$) was the only variable in the top disturbance submodel (Table 6.8).

The top AIC_c-selected occurrence model for green-tailed towhees combined vegetation, abiotic, and disturbance factors (Table 6.9). Green-tailed towhees selected more productive areas with a greater proportion of mountain sagebrush with larger patches of sagebrush and more rugged terrain, but avoided areas with increased solar radiation (Table 6.9). The weight of evidence for the top model was low (w_i = 0.17), with 7 other candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.9). Other models indicated green-tailed towhees showed weak (large coefficient SEs) avoidance of mixed

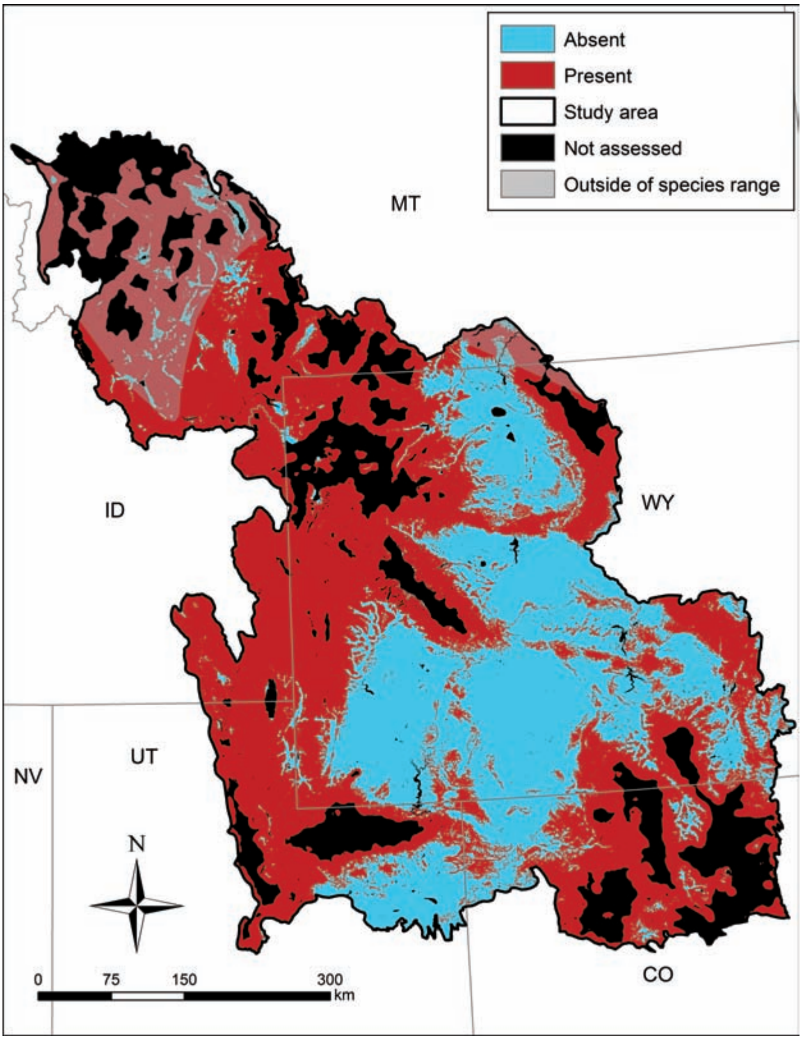

FIG. 6.6. Distribution of green-tailed towhee in the Wyoming Basins Ecoregional Assessment area based on an optimal probability cutoff threshold of 0.17. Semi-transparent grey shaded areas are outside the range of green-tailed towhee and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

shrubland and areas close to interstate highways (Table 6.9). The final model-averaged occurrence model was:

$$\text{Prob} = 1 / (1 + (\exp(-(-4.56 + 0.92 * \text{MTNSAGE}_{5km} + 6.80 * \text{NDVI}_{5km} - 0.01 * \text{SOLAR} + 0.03 * \text{TRI}_{270} + 0.01 * \text{PATCH}_{1km} - 0.40 * \text{MjRD}_{1km} - 12.00 * \text{MIX}_{270})))) \quad (6.2)$$

When applied spatially, the final model-averaged occurrence model for green-tailed towhees predicted the greatest occurrence at higher elevations along the western portion of the WBEA area and in more mountainous shrub habitats containing mountain sagebrush (Fig. 6.5). The final composite green-tailed towhee model had good accuracy (ROC AUC = 0.82 ± 0.03) when predicting green-tailed

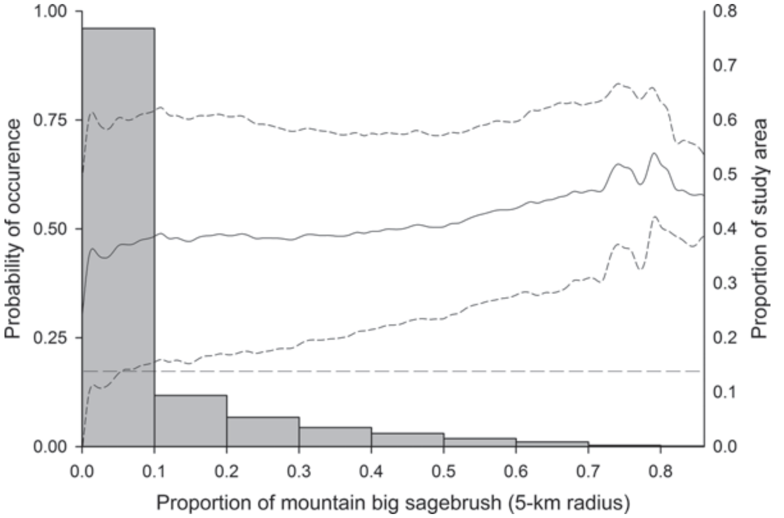

FIG. 6.7. Green-tailed towhee predicted occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of mountain sagebrush (*Artemisia tridentata* ssp. *vaseyana*.) within a 5-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of mountain sagebrush within a 5-km radius moving window. Range of predicted densities relate to the observed range of mountain sagebrush at study site locations. The dashed horizontal line represents the probability above which green-tailed towhee is predicted to occur (0.17). Histogram values represent the proportion of the total study area in each 10% segment of mountain sagebrush within 5 km.

towhee presence. This was comparable to the accuracy of the top AIC$_c$-selected model (ROC AUC = 0.82 ± 0.03). Based on the optimal probability threshold classification cut-point (0.17; Fig. 6.5), this model had an overall classification accuracy of 73.9%. Using this cutoff threshold, 67.5% of the WBEA area (230,078 km^2) was predicted to support green-tailed towhee occurrence (Fig. 6.6). Probability of occurrence increased linearly (although weak) from ~0.45 to ~0.60 as the proportion of mountain big sagebrush habitat increased within a 5-km radius from 0 to 0.8, and green-tailed towhees were likely to occur across the entire range of mountain big sagebrush habitat values (Fig. 6.7). The final green-tailed towhee model predicted probabilities of occurrence that were significantly and positively correlated (although weakly) with independent count data from 96 BBS routes ($r_s = 0.21$, $p = 0.04$).

Lark sparrow

Five variables were excluded from the *a priori* candidate set of variables for lark sparrow abundance models because they

TABLE 6.10. Results of AIC$_c$-based model selection for lark sparrow zero-inflated negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC$_c$), change in AIC$_c$ value from the top model (ΔAIC$_c$), and Akaike weight (w_i). Only models with ΔAIC$_c$ ≤ 2 are shown.

Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
1	ABIGSAGE$_{18km}$ + NDVI$_{18km}$	-235.68	7	486.07	0.00	0.59

[a] Variable definitions provided in Table 4.2

TABLE 6.11. Evaluation statistics from AIC_c-based univariate model selection for lark sparrow zero-inflated negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran models with mountain sagebrush (5-km radius) and NDVI (5-km radius) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which lark sparrows respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-233.55	9	486.27	0.00	1.00
	$GRASS_{5km}$	-233.91	9	487.00	0.00	0.29
	$GRASS_{3km}$	-234.24	9	487.66	0.66	0.21
	$GRASS_{270}$	-234.66	9	488.49	1.49	0.14
	$GRASS_{540}$	-234.66	9	488.49	1.50	0.13
	$GRASS_{1km}$	-234.71	9	488.59	1.60	0.13
	$GRASS_{18km}$	-234.87	9	488.90	1.91	0.11
	MIX_{1km}	-232.13	9	483.43	0.00	1.00
	MIX_{18km}	-240.04	9	499.24	15.82	0.00
	MIX_{5km}	-242.41	9	504.00	20.57	0.00
	MIX_{3km}	-244.41	9	507.99	24.56	0.00
	RIP_{18km}	-226.33	9	471.83	0.00	0.73
	RIP_{5km}	-227.35	9	473.87	2.04	0.26
	RIP_{3km}	-231.91	9	482.99	11.16	0.00
	RIP_{1km}	-234.57	9	488.30	16.48	0.00
	RIP_{540}	-235.62	9	490.41	18.59	0.00
	RIP_{270}	-235.63	9	490.44	18.61	0.00
	$SALT_{1km}$	-247.87	9	514.91	0.00	0.67
	$SALT_{540}$	-248.60	9	516.36	1.45	0.33
	$CONTAG_{5km}$	-661.62	4	1,335.51	0.00	0.35
	$PATCH_{3km}$	-661.88	4	1,336.04	0.53	0.27
	$PATCH_{5km}$	-662.21	4	1,336.69	1.18	0.19
	$EDGE_{5km}$	-662.88	4	1,338.03	2.53	0.10
	$CONTAG_{3km}$	-662.99	4	1,338.26	2.75	0.09
Abiotic	CTI	-234.53	9	488.22	0.00	0.88
	CTI[2b]	-234.26	11	492.24	4.01	0.12
	ELEV	-232.48	9	484.13	0.00	1.00
	ELEV[2b]	-240.20	11	504.14	20.01	0.00
	$iH2Od_{250}$[c]	-235.13	9	489.42	0.00	0.41
	$iH2Od_{1km}$[c]	-235.43	9	490.03	0.61	0.30
	$iH2Od_{500}$[c]	-235.44	9	490.05	0.62	0.30
	$pH2Od_{1km}$[c]	-234.09	9	487.35	0.00	0.53
	$pH2Od_{250}$[c]	-234.66	9	488.48	1.13	0.30

TABLE 6.11. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	pH2Od$_{250}$[c]	-235.25	9	489.67	2.32	0.17
	SOLAR	-235.21	9	489.60	0.00	0.91
	SOLAR^{2}[b]	-235.22	11	494.16	4.56	0.09
	TRI$_{3\text{km}}^{2}$[b]	-231.03	11	485.79	0.00	0.49
	TRI$_{5\text{km}}$	-234.74	9	488.65	2.86	0.12
	TRI$_{5\text{km}}^{2}$[b]	-232.71	11	489.15	3.36	0.09
	TRI$_{3\text{km}}$	-235.01	9	489.19	3.40	0.09
	TRI$_{1\text{km}}$	-235.38	9	489.92	4.14	0.06
	TRI	-235.56	9	490.29	4.51	0.05
	TRI$_{540}$	-235.61	9	490.40	4.61	0.05
	TRI$_{270}$	-235.67	9	490.52	4.73	0.05
	TRI$_{1\text{km}}^{2}$[b]	-242.57	11	508.86	23.07	0.00
	TRI^{2}[b]	-244.93	11	513.59	27.80	0.00
	TRI$_{270}^{2}$[b]	-244.95	11	513.63	27.84	0.00
Disturbance	AG$_{1\text{km}}$[c]	-232.70	9	484.56	0.00	1.00
	AG$_{500}$[c]	-247.58	9	514.32	29.76	0.00
	AG$_{250}$[c]	-248.19	9	515.54	30.98	0.00
	MjRD$_{250}$[c]	-246.49	9	512.16	0.00	0.46
	MjRD$_{500}$[c]	-246.97	9	513.10	0.94	0.29
	MjRD$_{1\text{km}}$[c]	-247.09	9	513.36	1.20	0.25
	PIPE$_{1\text{km}}$[c]	-235.58	9	490.33	0.00	0.34
	PIPE$_{500}$[c]	-235.59	9	490.35	0.03	0.34
	PIPE$_{250}$[c]	-235.66	9	490.50	0.17	0.32
	POWER$_{1\text{km}}$[c]	-234.28	9	487.73	0.00	0.52
	POWER$_{500}$[c]	-234.94	9	489.05	1.32	0.27
	POWER$_{250}$[c]	-235.14	9	489.45	1.72	0.22
	RDdens$_{540}$	-234.01	9	487.20	0.00	0.22
	RDdens$_{270}$	-234.02	9	487.20	0.00	0.22
	2RD$_{500}$[c]	-234.75	9	488.67	1.47	0.11
	2RD$_{250}$[c]	-234.78	9	488.72	1.52	0.10
	2RD$_{1\text{km}}$[c]	-234.92	9	489.00	1.80	0.09
	RDdens$_{18\text{km}}$	-235.08	9	489.33	2.14	0.08
	RDdens$_{5\text{km}}$	-235.32	9	489.82	2.62	0.06
	RDdens$_{3\text{km}}$	-235.33	9	489.83	2.63	0.06
	RDdens$_{1\text{km}}$	-235.41	9	489.98	2.79	0.06
	WELL$_{1\text{km}}$[c]	-233.94	9	487.04	0.00	0.64

TABLE 6.11. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	WELL$_{500}$[c]	-234.99	9	489.14	2.10	0.22
	WELL$_{250}$[c]	-235.50	9	490.16	3.12	0.13

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function (e$^{(\text{Euclidian distance from feature/-distance parameter})}$)

were represented in 20 or fewer survey blocks. These variables included conifer forest (0.27 km, 0.54 km), mixed shrubland (0.27 km, 0.54 km), and salt-desert shrubland (0.27 km). We did not consider temperature variables but did assess solar radiation. Several remaining variables were dropped due to correlation, such as slope, some conifer forest variables, and some salt-desert shrubland variables. We considered non-linear responses of lark sparrow to NDVI, but not for sagebrush because non-linearities were not evident. Interactions between sagebrush and NDVI variables were not apparent and thus not considered.

Initial exploration of the count data without covariates suggested that a zero-inflated negative binomial may be the most appropriate model. This was confirmed by comparing fit with sagebrush and NDVI covariates between a zero inflated to a standard negative binomial model (without zero-inflation; z = 3.17, p < 0.001). The zero-inflated model was used to fit the sagebrush/NDVI base models. The top AIC$_c$-selected sagebrush/NDVI model consisted of all big sagebrush within 18 km (ABIGSAGE$_{18km}$) and NDVI within 18 km (NDVI$_{18km}$; Table 6.10). Use locations averaged 2.8% more all big sagebrush habitat than absence locations (Appendix 6.3). Using this base model to evaluate and select individual covariates (Table 6.11), the top vegetation submodel consisted of conifer forest within 1 km (CFRST$_{1km}$), mixed shrubland within 1 km (MIX$_{1km}$), and riparian within 18 km (RIP$_{18km}$; Table 6.12). The top AIC$_c$-selected abiotic model consisted of only elevation as a quadratic (ELEV+ ELEV^2; Table 6.12). Decay distance (1 km) to agricultural land (AG$_{1km}$) and 1-km decay distance to oil and gas wells (WELL$_{1km}$) were included in the top disturbance submodel (Table 6.12).

The top AIC$_c$-selected lark sparrow occurrence portion of the zero-inflated abundance model was a combination of vegetation and disturbance factors (Table 6.13). Lark sparrow occurrence was negatively associated with proportion of all big sagebrush, conifer forest, proportion of riparian land cover, and proportion of agricultural land, but positively associated with productive habitats, proportion of mixed shrubland, and proportion of agricultural land (Table 6.13a). Despite avoidance of sagebrush in the occurrence model, abundance was positively associated with proportion of big sagebrush, conifer forest, proportion of mixed shrubland, and proportion of riparian land cover (Table 6.13b). However, relationships were weak for most variables except sagebrush. Weight of evidence for the top model was moderate (w_i = 0.25), with 12 candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.13). Other models indicated positive but weak relationships between proximity to wells (decay) and elevation (note coefficient instability across models) with lark sparrow occurrence (Table 6.13a). Abundance, however, declined with proximity to energy wells and higher elevation sites (both

TABLE 6.12. Results of AIC_c-based submodel selection for lark sparrow zero-inflated negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{18km} + NDVI_{18km} + CFRST_{1km} + MIX_{1km} + RIP_{18km}$	-218.94	13	465.09	0.00	0.39
	2	$ABIGSAGE_{18km} + NDVI_{18km} + MIX_{1km} + RIP_{18km}$	-221.45	11	465.75	0.67	0.28
Abiotic	1	$ABIGSAGE_{18km} + NDVI_{18km} + ELEV$	-232.48	9	483.54	0	0.17
	2	$ABIGSAGE_{18km} + NDVI_{18km} + CTI + ELEV + pH2Od_{1km} + TRI_{3km} + TRI_{3km}^2$	-223.81	17	483.66	0.11	0.16
	3	$ABIGSAGE_{18km} + NDVI_{18km} + pH2Od_{1km} + TRI_{3km} + TRI_{3km}^2$	-228.39	13	483.98	0.43	0.14
	4	$ABIGSAGE_{18km} + NDVI_{18km} + TRI_{3km} + TRI_{3km}^2$	-231.03	11	484.93	1.38	0.09
	5	$ABIGSAGE_{18km} + NDVI_{18km} + CTI + pH2Od_{1km} + TRI_{3km} + TRI_{3km}^2$	-226.95	15	485.48	1.94	0.07
Disturbance	1	$ABIGSAGE_{18km} + NDVI_{18km} + AG_{1km} + WELL_{1km}$	-226.22	11	0.00	0.00	0.55
	2	$ABIGSAGE_{18km} + NDVI_{18km} + AG_{1km} + RDdens_{540} + WELL_{1km}$	-224.95	13	1.46	1.80	0.22

[a] Variable definitions provided in Table 4.2

weak effects; Table 6.13b). The final model averaged abundance model was:

$$\text{Density} = 1 / (1 + (\exp(-(-90.22 - 42.87 * ABIGSAGE_{18km} + 495.94 * NDVI_{18km} - 255.25 * CFRST_{1km} + 270.14 * MIX_{1km} - 400.67 * RIP_{18km} - 15.92 * AG_{1km} + 5.38 * WELL_{1km} - 0.00068 * ELEV)))) * \exp(-2.50 + 3.14 * ABIGSAGE_{18km} - 2.34 * NDVI_{18km} + 3.06 * CFRST_{1km} + 1.42 * MIX_{1km} + 2.98 * RIP_{18km} + 0.15 * AG_{1km} - 0.43 * WELL_{1km} - 0.00014 * ELEV + 0.96) \tag{7.3}$$

The mean offset for the survey blocks is represented by the final constant in the model (0.96).

The final model-averaged lark sparrow abundance model had weak correlation with independent count data from 96 BBS routes ($r_s = 0.08$, $p = 0.45$). When applied spatially, moderate elevation sagebrush habitats across the WBEA area had the highest predicted densities of lark sparrow (Fig. 6.8). Based on the lowest density that could support a lark sparrow territory (0.17 birds/ha; Fig. 6.8), 60.5% of the Wyoming Basins (209,010 km^2) was predicted to support breeding lark sparrows (Fig. 6.9). Lark sparrow showed gradual but linear increases in density, with birds/ha increasing from 0.25 to 0.75 as proportion of all big sagebrush habitat across a 18-km radius area increased from about 0 to 0.8 (Fig. 6.10). Although lark sparrow occurrence was likely across the entire range of all big sagebrush habitat values, a threshold occurred when the proportion of all big sagebrush habitat exceeded 50% of a large landscape (18 km), where abundance of lark sparrow increased (Fig. 6.10).

Sage sparrow

Five variables were excluded from the *a priori* candidate set of variables for sage sparrow abundance models because they occurred on fewer than 20 survey blocks.

These variables included conifer forest (0.27 km, 0.54 km, 1 km), mixed shrubland (0.27 km), and riparian (0.27 km). We did not consider temperature variables for this species but did consider solar radiation. Again, several additional variables were removed from consideration due to correlations with other variables. We considered NDVI as a non-linearity at all scales but non-linearities were not evident for any sagebrush variable. Interactions between sagebrush and NDVI variables were also evaluated as competing models.

Initial exploration of the count data without covariates suggested that a zero-inflated Poisson model was most appropriate. The top AIC_c-selected sagebrush/NDVI model consisted of all sagebrush within 18 km ($ALLGSAGE_{18km}$) and NDVI as a quadratic within 18 km ($NDVI_{18km} + NDVI_{18km}^2$), which had low support ($w_i = 0.15$; Table 6.14). When fit with these base covariates, a Vuong test confirmed that the zero-inflated Poisson model had better fit over the Poisson model ($z = 4.7$, $p < 0.001$). Use locations averaged 6.1% more all sagebrush habitat than absence locations (Appendix 6.4). Using the base model to evaluate and select individual covariates (Table 6.15), the top vegetation submodel consisted of grassland within 3 km ($GRASS_{3km}$), mixed shrubland within 5 km (MIX_{5km}), riparian within 1 km (RIP_{1km}), sagebrush contagion within 3 km ($CONTAG_{3km}$), and salt-desert shrubland within 1 km ($SALT_{1km}$; Table 6.16). The top AIC_c-selected abiotic model had only the addition of topographic ruggedness within 5 km (TRI_{5km}; Table 6.16). Road density within 18 km ($RDdens_{18km}$), and 0.25-km decay distance to oil and gas wells ($WELL_{250}$) were included in the top disturbance submodel (Table 6.16).

The top AIC_c-selected sage sparrow occurrence portion of the zero-inflated abundance model combined vegetation, abiotic, and disturbance factors (Table 6.17). Despite presence locations containing a greater proportion (18 km) of all sagebrush ($\bar{x} = 0.68 \pm 0.01$) compared to absence locations ($\bar{x} = 0.63 \pm 0.01$; Appendix 6.4), the occurrence portion of the sage sparrow model appeared negatively associated with proportion of all sagebrush habitat. Occurrence was also correlated with greater proportion of riparian land cover (weak effect) and salt-desert shrubland, increased contagion of sagebrush, proximity to oil and gas wells (weak effect), and areas with greater overall road density (Table 6.17). However, sage sparrows avoided areas with rugged terrain or higher proportions of mixed shrubland (Table 6.17). Sage sparrow abundance was associated with lower proportions of all sagebrush, lower vegetation productivity, as well as lower proportions of mixed shrubland, riparian, and salt-desert shrubland habitats, higher sagebrush contagion, more rugged terrain, lower road densities, and areas closer to oil and gas wells (Table 6.17). However, most effects, except for sagebrush, NDVI, and wells, were weak (large SEs; Table 6.17). Weight of evidence for the top model was moderate ($w_i = 0.30$), with 10 candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.17). These 10 models contained a subset of the variables in the top model, with the only additional covariate in some models being negative for occurrence and abundance of grasslands, although the effect was very weak (see SEs; Table 6.17). The final model averaged abundance model was

$$\begin{aligned}
&Density = 1 / (1 + (exp(-(15.90 - 9.46 * \\
&ALLSAGE_{18km} - 54.46 * NDVI_{18km} + \\
&48.79 * NDVI_{18km}^{2} - 86.06 * MIX_{5km} + \\
&1.22 * RIP_{1km} + 0.055 * CONTAG_{3km} + \\
&9.18 * SALT_{1km} - 0.08 * TRI_{5km} + 1.52 * \\
&RDdens_{18km} + 4.68 * WELL_{250} - 1.49 * \\
&GRASS_{3km})))) * exp(1.29 - 2.32 * \\
&ALLSAGE_{18km} + 2.51 * \\
&NDVI_{18km} - 11.45 * NDVI_{18km}^{2} - 19.58 * \\
&MIX_{5km} - 3.63 * RIP_{1km} - 0.0008 * \\
&CONTAG_{3km} - 0.97 * SALT_{1km} - 0.01 * \\
&TRI_{5km} - 0.31 * RDdens_{18km} + 1.70 * \\
&WELL_{250} - 0.27 * GRASS_{3km} + 2.09)
\end{aligned} \tag{7.4}$$

TABLE 6.13. Results of AIC$_c$-based model selection for the combined lark sparrow zero-inflated negative binomial abundance models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence (occurrence), whereas section (B) includes the count (abundance) portion of the model.

Rank	Intercept	ABIGSAGE$_{18km}$	NDVI$_{18km}$	CFRST$_{1km}$	MIX$_{1km}$	RIP$_{18km}$
(A) Occurrence						
1	-105.93 (56.11)	-45.77 (26.19)	563.68 (296.09)	-402.10 (217.34)	335.91 (226.86)	-462.49 (260.39)
2	-110.67 (63.34)	-45.40 (25.44)	581.35 (323.99)	-395.47 (222.94)	376.71 (273.49)	-489.19 (289.98)
3	-101.64 (55.81)	-42.39 (21.58)	534.21 (279.98)		366.67 (242.66)	-446.10 (250.70)
4	-97.75 (63.85)	-44.78 (31.34)	520.97 (333.91)	-363.35 (243.22)	356.56 (279.81)	-403.41 (294.23)
5	-52.90 (26.02)	-36.84 (15.08)	316.34 (135.42)	-235.80 (99.86)		-262.74 (127.10)
6	-101.20 (55.60)	-45.18 (24.65)	542.95 (291.51)		303.60 (182.34)	-443.13 (258.29)
7	-15.19 (12.71)	-41.97 (17.89)	305.60 (127.42)			-149.94 (66.22)
8	-52.68 (26.05)	-34.18 (13.69)	318.42 (140.24)	-232.57 (102.52)		-261.60 (129.41)
9	-49.78 (18.97)	-32.43 (13.34)	295.24 (100.63)	-210.77 (73.35)		-217.52 (88.78)
10	-48.86 (20.35)	-33.22 (14.24)	296.92 (104.19)	-212.99 (75.61)		-222.02 (92.61)
11	-88.40 (53.02)	-41.20 (21.77)	468.85 (247.29)		360.44 (251.82)	-353.16 (211.33)
12	-110.95 (74.20)	-46.29 (29.18)	582.61 (374.59)	-395.72 (249.90)	401.19 (372.20)	-482.52 (325.96)
13	-103.32 (60.96)	-44.24 (23.05)	542.89 (299.39)		403.43 (304.02)	-443.10 (262.11)
(B) Abundance						
1	-2.52 (1.24)	2.99 (1.23)	-2.94 (2.14)	4.08 (2.54)	1.75 (6.02)	3.47 (5.08)
2	-2.59 (1.27)	2.95 (1.23)	-2.58 (2.04)	3.81 (2.57)	1.97 (6.17)	2.45 (5.14)
3	-2.72 (1.26)	2.72 (1.16)	-1.59 (1.86)		2.25 (6.27)	1.71 (5.14)
4	-2.40 (1.27)	3.07 (1.24)	-3.38 (2.21)	3.99 (2.54)	1.38 (5.99)	3.55 (5.07)
5	-2.28 (1.25)	4.47 (1.39)	-0.45 (2.47)	5.58 (2.62)		3.49 (5.04)
6	-2.71 (1.25)	2.74 (1.16)	-1.66 (1.95)		2.28 (6.21)	2.11 (5.10)
7	-2.18 (1.23)	3.82 (1.26)	-1.29 (2.43)			4.23 (4.87)
8	-2.58 (1.23)	3.17 (1.24)	-3.02 (2.16)	4.23 (2.55)		3.37 (5.04)
9	-2.33 (1.23)	3.22 (1.22)	-3.78 (2.19)	4.12 (2.53)		3.43 (5.04)
10	-2.05 (1.24)	4.30 (1.36)	-1.40 (2.48)	5.27 (2.60)		3.27 (4.98)
11	-2.51 (1.28)	2.83 (1.17)	-2.38 (2.11)		1.68 (6.10)	2.56 (5.28)
12	-2.51 (1.27)	2.90 (1.24)	-2.59 (2.03)	3.62 (2.56)	1.63 (6.18)	2.58 (5.15)
13	-2.63 (1.27)	2.71 (1.16)	-1.68 (1.86)		1.81 (6.26)	1.91 (5.14)

[a] Variable definitions provided in Table 4.2

[b] Coefficients and standard errors multiplied by 10^3

TABLE 6.13. Extended

AG_{1km}	$WELL_{1km}$	$ELEV^b$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
-21.18 (12.63)			-216.15	15	463.89	0.00	0.25
			-218.94	13	465.09	1.19	0.14
			-221.45	11	465.75	1.86	0.10
-25.66 (15.50)	8.70 (7.05)		-215.17	17	466.38	2.49	0.07
-13.52 (6.49)		1.40 (3.78)	-217.40	15	466.38	2.49	0.07
-19.97 (11.89)			-219.86	13	466.91	3.02	0.06
-65.38 (29.54)	73.79 (30.97)	-15.73 (8.34)	-217.87	15	467.33	3.44	0.05
-13.64 (6.72)			-220.11	13	467.43	3.53	0.04
-17.60 (7.04)	6.66 (5.33)		-218.41	15	468.41	4.52	0.03
-17.42 (7.23)	6.50 (5.53)	-0.26 (3.87)	-216.21	17	468.46	4.57	0.03
-25.57 (15.74)	11.40 (10.54)		-218.49	15	468.56	4.67	0.02
	4.99 (14.05)		-218.49	15	468.58	4.68	0.02
	6.42 (9.83)		-220.76	13	468.72	4.83	0.02
0.04 (0.77)			-216.15	15	463.89	0.00	0.25
			-218.94	13	465.09	1.19	0.14
			-221.45	11	465.75	1.86	0.10
0.42 (0.82)	-1.16 (1.01)		-215.17	17	466.38	2.49	0.07
-0.11 (0.77)		-1.03 (0.45)	-217.40	15	466.38	2.49	0.07
-0.03 (0.75)			-219.86	13	466.91	3.02	0.06
1.42 (0.87)	-3.18 (1.00)	-0.72 (0.44)	-217.87	15	467.33	3.44	0.05
0.08 (0.77)			-220.11	13	467.43	3.53	0.04
0.61 (0.86)	-1.46 (1.14)		-218.41	15	468.41	4.52	0.03
0.35 (0.85)	-1.21 (1.11)	-0.91 (0.44)	-216.21	17	468.46	4.57	0.03
0.50 (0.91)	-1.49 (1.20)		-218.49	15	468.56	4.67	0.02
	-1.01 (0.96)		-218.49	15	468.58	4.68	0.02
	-1.14 (0.94)		-220.76	13	468.72	4.83	0.02

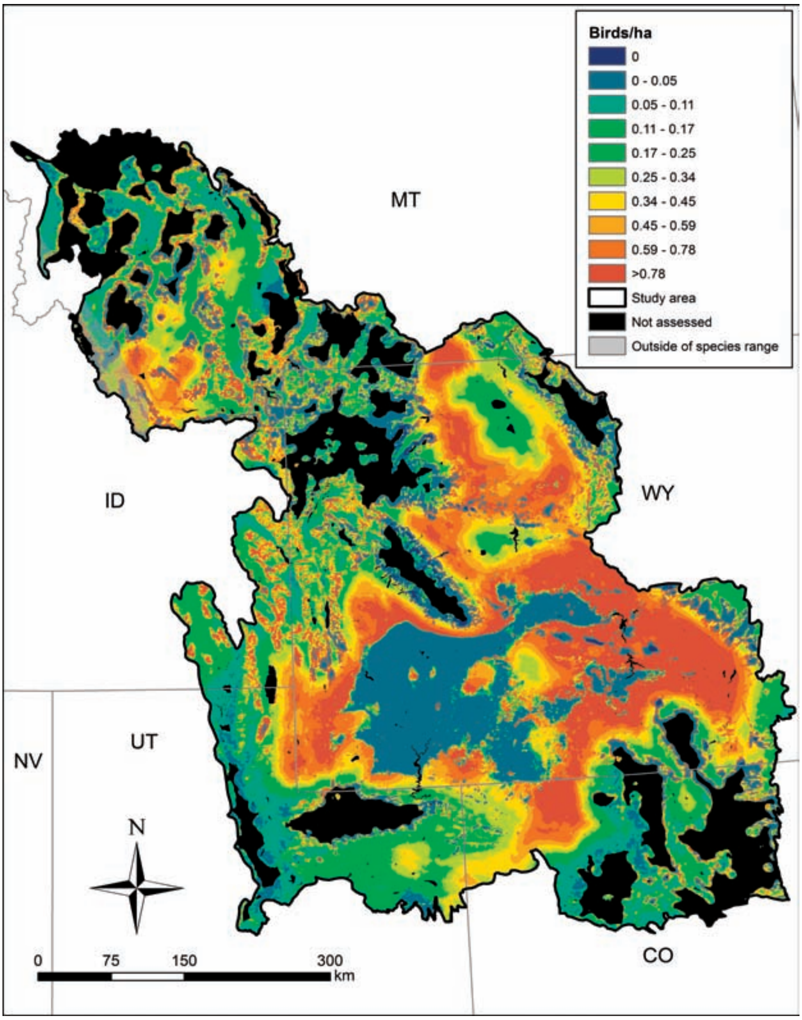

FIG. 6.8. Predicted density estimates (birds/ha) for lark sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one lark sparrow, the lowest density that could support a viable territory is 0.17 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

The mean offset for the survey blocks is represented by the final constant in the model (2.09).

The final model-averaged abundance model for sage sparrow accurately predicted independent count data from 96 BBS routes ($r_s = 0.57$, $p < 0.001$). When applied spatially across the WBEA area within the range of the species, sage sparrow densities were predicted to be highest in lower elevation shrublands, with low densities in more productive high-elevation sites (Fig. 6.11). A negative relationship between abundance and road density was seen in some areas, with road areas having lower predicted bird density than the surrounding landscape matrix (Fig. 6.11). Based on the lowest density that could support a sage sparrow territory (0.14 birds/ha; Fig. 6.11), 49.0% of the Wyoming Basins (169,300 km^2) was predicted to support breeding sage sparrows (Fig. 6.12). Despite the apparent avoidance of sagebrush based on model covariates (negative oc-

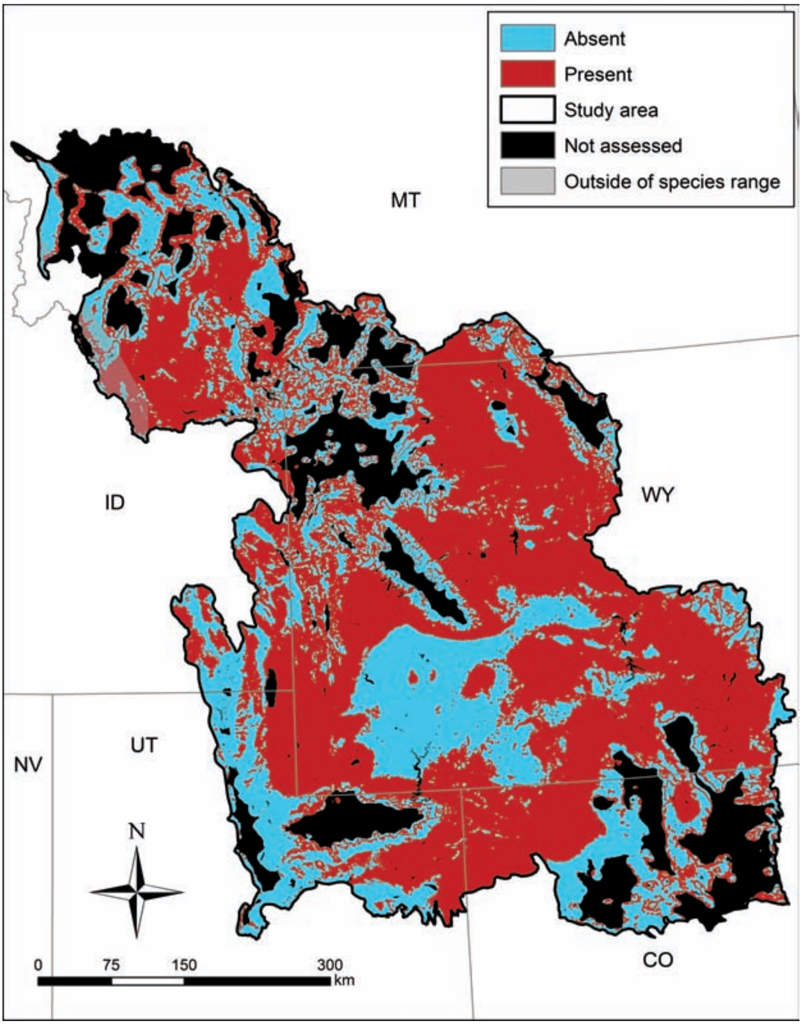

FIG. 6.9. Distribution of lark sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.17 birds/ha), the largest territory sizes required to support one lark sparrow. Semi-transparent grey shaded areas are outside the range of lark sparrow and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

currence and abundance relationship with $\mathrm{ALLSAGE}_{18\mathrm{km}}$; Table 6.17), predicted sage sparrow densities assessed across the WBEA area were low (<0.5 birds/ha) when sagebrush land cover (all species) fell below approximately 20% of a large 18-km radius, but densities only increased slightly (up to 0.75 birds/ha) when sagebrush land cover increased (Fig. 6.13). Sage sparrows exceeded the threshold density for occurrence across the range of all sagebrush values (Fig. 6.13).

Sage thrasher

Two variables were excluded from the *a priori* candidate set of variables for sage thrasher abundance models because they were represented at fewer than 20 survey blocks for either presences or absences. These included conifer forest (0.27 km) and mixed shrubland (0.27 km). We did not consider temperature variables for this species, but did consider solar radiation. Several additional variables were removed

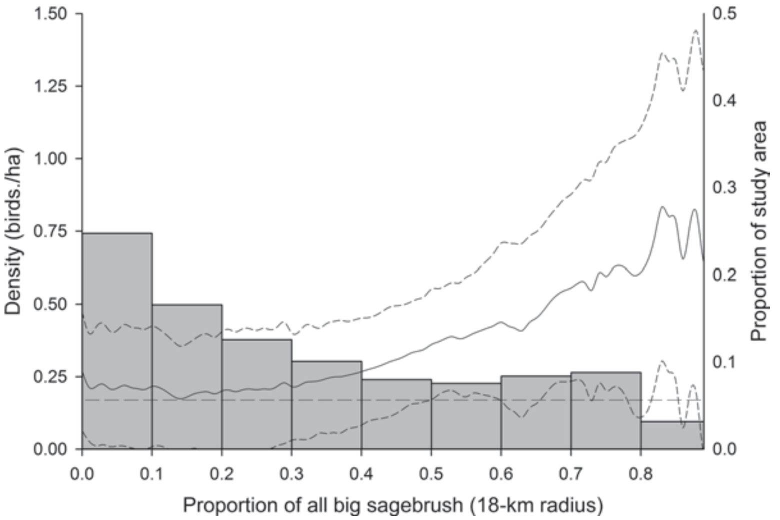

FIG. 6.10. Lark sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata*) within an 18-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 1-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.17 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 18 km.

from consideration due to correlations with other variables. We considered non-linear responses in sage thrasher to NDVI but not for any sagebrush variable. Interactions between sagebrush and NDVI variables were not evident and thus not evaluated as competing models.

Initial exploration of count data without covariates suggested that a zero-inflated Poisson model was most appropriate. The top AIC_c-selected sagebrush/NDVI model consisted of all big sagebrush within 0.27 km ($ABIGSAGE_{270}$) and NDVI as a quadratic within 18 km ($NDVI_{18km} + NDVI_{18km}{}^2$), which had low support ($w_i = 0.09$; Table 6.18). When fit with these base covariates, a Vuong test confirmed that the zero-inflated Poisson model had better fit than the Poisson model without zero-inflation ($z = 2.81$, $p < 0.01$). Use locations averaged 15.8% more big sagebrush habitat than absence locations (Appendix 6.5). Using the base model to evaluate and select individual

TABLE 6.14. Results of AIC_c-based model selection for sage sparrow zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}{}^2$	-335.92	8	688.30	0.00	0.15
2	$ABIGSAGE_{18km} + NDVI_{18km} + NDVI_{18km}{}^2$	-336.74	8	689.95	1.65	0.06

[a] Variable definitions provided in Table 4.2

TABLE 6.15. Evaluation statistics from AIC_c-based univariate model selection for sage sparrow zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran models with all sagebrush (18-km radius) and NDVI (18-km radius; quadratic) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which sage sparrows respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-334.92	10	690.56	0.00	0.50
	$CFRST_{540m}$	-335.57	10	691.86	1.30	0.26
	$CFRST_{270m}$	-335.71	10	692.13	1.57	0.23
	$GRASS_{3km}$	-326.55	10	673.81	0.00	0.55
	$GRASS_{5km}$	-326.76	10	674.23	0.42	0.44
	$GRASS_{1km}$	-330.88	10	682.47	8.66	0.01
	$GRASS_{540m}$	-332.49	10	685.69	11.89	0.00
	$GRASS_{18km}$	-333.86	10	688.43	14.62	0.00
	$GRASS_{270m}$	-333.96	10	688.64	14.84	0.00
	MIX_{5km}	-327.32	10	675.36	0.00	0.34
	MIX_{3km}	-327.39	10	675.50	0.14	0.32
	MIX_{18km}	-327.49	10	675.70	0.34	0.29
	MIX_{270m}	-329.71	10	680.15	4.79	0.03
	MIX_{540m}	-331.10	10	682.92	7.56	0.01
	MIX_{1km}	-331.18	10	683.08	7.72	0.01
	RIP_{1km}	-332.07	10	684.86	0.00	0.43
	RIP_{540m}	-332.17	10	685.07	0.21	0.39
	RIP_{5km}	-333.69	10	688.10	3.24	0.08
	RIP_{3km}	-334.16	10	689.04	4.18	0.05
	RIP_{270}	-334.54	10	689.80	4.94	0.04
	RIP_{18km}	-335.73	10	692.19	7.33	0.01
	$SALT_{1km}$	-332.34	10	685.40	0.00	0.56
	$SALT_{270}$	-333.21	10	687.14	1.73	0.24
	$SALT_{540m}$	-333.38	10	687.48	2.08	0.20
	$CONTAG_{3km}$	-327.14	10	675.00	0.00	0.91
	$EDGE_{3km}$	-329.72	10	680.16	5.16	0.07
	$EDGE_{5km}$	-332.13	10	684.97	9.97	0.01
	$CONTAG_{5km}$	-332.56	10	685.84	10.84	0.00
	$PATCH_{1km}$	-332.59	10	685.90	10.90	0.00
	$CONTAG_{1km}$	-333.25	10	687.21	12.21	0.00
	$EDGE_{1km}$	-333.99	10	688.70	13.69	0.00
	$PATCH_{3km}$	-334.69	10	690.09	15.09	0.00

TABLE 6.15. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Abiotic	CTI	-335.39	10	691.49	0.00	0.53
	CTI^{2b}	-333.36	12	691.75	0.26	0.47
	ELEV	-335.54	10	691.79	0.00	0.81
	$ELEV^{2b}$	-334.84	12	694.69	2.90	0.19
	$iH2Od_{1km}^{c}$	-334.09	10	688.89	0.00	0.46
	$iH2Od_{500}^{c}$	-334.38	10	689.47	0.57	0.35
	$iH2Od_{250}^{c}$	-334.95	10	690.62	1.72	0.19
	$pH2Od_{1km}^{c}$	-334.43	10	689.58	0.00	0.43
	$pH2Od_{250}^{c}$	-334.79	10	690.30	0.72	0.30
	$pH2Od_{250}^{c}$	-334.88	10	690.47	0.89	0.27
	SLOPE	-335.50	10	691.72	0.00	0.84
	$SLOPE^{2b}$	-335.04	12	695.11	3.39	0.16
	TRI_{5km}	-327.31	10	675.34	0.00	0.63
	TRI_{5km}^{2b}	-325.93	12	676.88	1.54	0.29
	TRI_{3km}	-329.54	10	679.80	4.46	0.07
	TRI_{3km}^{2b}	-329.16	12	683.34	8.00	0.01
	TRI_{1km}	-332.88	10	686.47	11.13	0.00
	TRI_{1km}^{2b}	-331.69	12	688.41	13.07	0.00
	TRI_{540}	-334.20	10	689.12	13.78	0.00
	TRI_{270}	-334.51	10	689.75	14.41	0.00
	TRI_{540}^{2b}	-332.83	12	690.69	15.35	0.00
	TRI_{270}^{2b}	-332.99	12	691.00	15.66	0.00
	TRI	-335.35	10	691.41	16.07	0.00
	TRI^{2b}	-335.05	12	695.13	19.79	0.00
Disturbance	AG_{500}^{c}	-335.74	10	692.19	0.00	0.36
	AG_{250}^{c}	-335.81	10	692.33	0.13	0.33
	AG_{1km}^{c}	-335.88	10	692.48	0.28	0.31
	$MjRD_{1km}^{c}$	-335.77	10	692.25	0.00	0.34
	$MjRD_{250}^{c}$	-335.77	10	692.26	0.02	0.33
	$MjRD_{500}^{c}$	-335.78	10	692.27	0.02	0.33
	$PIPE_{250}^{c}$	-334.95	10	690.62	0.00	0.45
	$PIPE_{500}^{c}$	-335.38	10	691.47	0.85	0.30
	$PIPE_{1km}^{c}$	-335.54	10	691.80	1.18	0.25
	$POWER_{250}^{c}$	-335.65	10	692.02	0.00	0.37
	$POWER_{500}^{c}$	-335.76	10	692.23	0.22	0.33
	$POWER_{1km}^{c}$	-335.87	10	692.45	0.43	0.30

TABLE 6.15. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{18km}$	-329.33	10	679.38	0.00	0.77
	$RDdens_{5km}$	-330.92	10	682.56	3.18	0.16
	$RDdens_{3km}$	-331.80	10	684.32	4.93	0.07
	$RDdens_{1km}$	-334.98	10	690.68	11.30	0.00
	$RDdens_{270}$	-335.59	10	691.89	12.50	0.00
	$2RD_{250}{}^{c}$	-335.71	10	692.14	12.76	0.00
	$RDdens_{540}$	-335.72	10	692.15	12.77	0.00
	$2RD_{500}{}^{c}$	-335.89	10	692.49	13.11	0.00
	$2RD_{1km}{}^{c}$	-335.91	10	692.55	13.16	0.00
	$WELL_{250}{}^{c}$	-331.34	10	683.39	0.00	0.55
	$WELL_{500}{}^{c}$	-332.04	10	684.80	1.41	0.27
	$WELL_{1km}{}^{c}$	-332.47	10	685.66	2.28	0.18

[a] Variable definitions provided in Table 4.2
[b] Quadratic function (variable + variable^2)
[c] Distance decay function ($e^{(\text{Euclidian distance from feature/-distance parameter})}$)

covariates (Table 6.19), the top vegetation submodel consisted of conifer forest within 1 km ($CFRST_{1km}$), mixed shrubland within 18 km (MIX_{18km}), riparian within 1 km (RIP_{1km}), and all sagebrush edge density within 5 km ($EDGE_{5km}$; Table 6.20). The top AIC_c-selected abiotic model included the addition of elevation (ELEV), 0.25-km decay distance to intermittent water ($iH2Od_{250}$), and topographic ruggedness within 1 km (TRI_{1km}; Table 6.20). Decay distance to secondary roads ($2RD_{1km}$) was the only variable included in the top disturbance submodel, which had low support ($w_i = 0.13$; Table 6.20).

The top AIC_c-selected zero-inflated abundance model for sage thrashers combined vegetation and abiotic factors (Table 6.20). Sage thrasher occurrence was positively associated with proportion of all sagebrush habitat (Table 6.21). Presence was greatest at high elevation sites (containing higher vegetation productivity), in proximity to intermittent water, and was weakly associated with proportion of conifer forest and mean sagebrush edge density (Table 6.21). Sage thrashers avoided areas with more rugged terrain, as well as grassland and mixed shrubland habitats, although only the latter had a strong effect (Table 6.21). Sage thrasher abundance was associated with greater proportions of all big sagebrush and vegetation productivity at higher elevations but decreased as the proportion of conifer forest increased and terrain became more rugged (Table 6.21). Effects of proximity to intermittent water, grassland, mixed shrubland, and edge habitat were generally negatively correlated with abundance, but all had a weak influence on the final model (see SEs and unstable coefficients across models; Table 6.21). Weight of evidence for the top model was low ($w_i = 0.15$), with 24 total candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.21). These 24 models each contained a subset of the variables in the top model, with some having the addition of riparian land cover or decay distance to secondary roads, although

TABLE 6.16. Results of AIC_c-based submodel selection for sage sparrow zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \le 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + GRASS_{3km} + MIX_{5km} + RIP_{1km} + CONTAG_{3km} + SALT_{1km}$	-303.27	18	644.82	0.00	0.42
	2	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + GRASS_{3km} + MIX_{5km} + RIP_{1km} + CONTAG_{3km}$	-306.29	16	646.39	1.57	0.19
Abiotic	1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km}$	-327.31	10	675.34	0.00	0.20
	2	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + iH2Od_{1km}$	-325.30	12	675.62	0.28	0.18
	3	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + CTI$	-326.01	12	677.04	1.70	0.09
	4	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + CTI + iH2Od_{1km}$	-323.91	14	677.21	1.87	0.08
	5	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + SLOPE$	-326.11	12	677.25	1.91	0.08
Disturbance	1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + RDdens_{18km} + WELL_{250}$	-325.13	12	675.27	0.00	0.34
	2	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + PIPE_{250} + RDdens_{18km} + WELL_{250}$	-323.70	14	676.78	1.51	0.16

[a] Variable definitions provided in Table 4.2

contribution of each to the model was weak (see large SEs; Table 6.21a,b). The final model averaged abundance model was:

$$\text{Density} = 1 / (1 + (\exp(-(-0.79 + 5.11 * ABIGSAGE_{270} - 60.52 * NDVI_{18km} + 51.08 * NDVI_{18km}^2 + 0.00653 * ELEV + 2.54 * iH2Od_{250} - 0.04 * TRI_{1km} + 50.35 * CFRST_{1km} - 6.51 * GRASS_{270} - 159.79 * MIX_{18km} + 0.02 * EDGE_{5km} + 4.15 * RIP_{1km} - 0.22 * 2RD_{1km})))) * \exp(-2.33 + 0.27 * ABIGSAGE_{270} - 0.85 * NDVI_{18km} + 2.06 * NDVI_{18km}^2 + 0.61 * ELEV + 0.00034 * iH2Od_{250} - 0.02 * TRI_{1km} + -5.93 * CFRST_{1km} - 1.22 * GRASS_{270} - 5.92 * MIX_{18km} + 0.0002 * EDGE_{5km} + 0.14 * RIP_{1km} + 0.03 * 2RD_{1km} + 1.77) \quad (7.5)$$

The mean offset for the survey blocks is represented by the final constant in the model (1.77).

The final model-averaged abundance model for sage thrasher accurately predicted independent count data from 96 BBS routes ($r_s = 0.65$, $p < 0.01$). When applied spatially across the WBEA area within the range of the species, sage thrasher densities were predicted to be highest in sagebrush habitats with high productivity but not higher elevation conifer forests or more productive high elevation sites (Fig. 6.14). Avoidance of grassland areas within the WBEA area was also apparent (Fig. 6.14). Based on the lowest density that could support a sage thrasher territory (0.59 birds/ha; Fig. 6.14), only 31.6% of the Wyoming Basins (109,054 km^2) was predicted to support breeding sage thrashers (Fig. 6.15). Predicted sage thrasher densities assessed across WBEA area increased from 0.1 to 1.5 birds/ha as the proportion of all big sagebrush (0.27 km) increased from 0 to 1.0 (Fig. 6.16). Based on the density threshold, landscapes containing >50% all big sagebrush land cover were likely to support sage thrashers (Fig. 6.16).

Vesper sparrow

Only one variable, mixed shrubland (0.27 km), was excluded from the *a priori* candidate set of variables for vesper sparrow abundance models because they were represented on fewer than 20 survey blocks for presences or absences. We did not consider temperature variables or solar radiation for this species. Several additional variables were removed from consideration due to correlations with other variables. We considered NDVI as a non-linearity at all scales, but non-linearities were not evident for any sagebrush variable. Interactions between sagebrush and NDVI variables were also evaluated as competing models.

Initial exploration of the count data without covariates suggested that a zero-inflated negative binomial was most appropriate. The top AIC_c-selected sagebrush/NDVI model consisted of big sagebrush (*A. t.* ssp. *wyomingensis*, *A. t.* spp. *tridentata*) within 18 km ($BIGSAGE_{18km}$) and NDVI within 3 km ($NDVI_{3km}$) with a sagebrush/NDVI interaction ($BIGSAGE_{18km}$ * $NDVI_{3km}$), which had moderate support (w_i = 0.27; Table 6.22). When fit with these base covariates, a Vuong test confirmed that the zero-inflated negative binomial model had better fit over the negative binomial model without zero-inflation ($z = 4.67$, $p < 0.001$). Use locations averaged 5.9% less big sagebrush habitat than absence locations (Appendix 6.6). Using the base model for vesper sparrow (Table 6.23), the top vegetation submodel consisted of conifer forest within 0.54 km ($CFRST_{540}$), mixed shrubland within 3 km (MIX_{3km}), riparian within 18 km (RIP_{18km}), and salt-desert shrubland within 0.27 km ($SALT_{270}$; Table 6.24). The top AIC_c-selected abiotic included the addition of elevation as a quadratic ($ELEV + ELEV^2$) and topographic ruggedness as a quadratic within 0.27 km ($TRI_{270} + TRI_{270}^2$; Table 6.24). Decay distance (1 km) to pipeline ($PIPE_{1km}$) and density of all roads within 3 km ($RDdens_{3km}$) were the only two variables included in the top disturbance submodel (Table 6.24).

The top AIC_c-selected vesper sparrow zero-inflated abundance model was a combination of vegetation and disturbance factors (Table 6.25). Vesper sparrow occurrence was positively associated with proportion of all sagebrush habitat and vegetation productivity (Table 6.25). However, the large negative interaction term suggested that productive sagebrush sites, specifically, were avoided (Table 6.25). The top model also suggested selection for mixed shrubland and avoidance of conifer forest and proximity to pipelines (Table 6.25). Riparian, salt-desert shrubland and density of all roads were weak contributors to the top model (see coefficient SEs and instability of estimates; Table 6.25). Vesper sparrow abundance decreased with proportion of big sagebrush land cover, but increased with vegetation productivity (Table 6.25). The positive interaction term between these variables suggested that abundance increased with increasing proportions of productive big sagebrush habitat, which is opposite of the occurrence portion of the model (Table 6.25). Vesper sparrow abundance decreased with salt-desert shrubland (Table 6.25). As with the occurrence portion, several variables were weak contributors, including conifer forest, mixed shrubland, riparian, proximity to piplines, and density of roads (large coefficient SEs; Table 6.25). Weight of evidence for the top model was low (w_i = 0.20), with 20 total candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.25). These 20 models each contained a subset of the variables in the top model, with some having the addition of the two abiotic variables, topographic ruggedness and elevation (Table 6.25). Both these variables showed generally positive but decreasing quadratic relationships, suggesting occurrence and abundance were highest with moderate terrain ruggedness and mid-elevations, but the contribution of each variable to the model was weak (large SEs and

TABLE 6.17. Results of AIC_c-based model selection for the combined sage sparrow zero-inflated Poisson abundance models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [$\sum w_i$]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence (occurrence), whereas Section (B) includes the count (abundance) portion of the model.

Rank	Intercept	$ALLSAGE_{18km}$	$NDVI_{18km}$	$NDVI_{18km}^2$	MIX_{5km}	RIP_{1km}	$CONTAG_{3km}$[b]
(A) Occurrence							
1	16.26 (3.68)	-9.94 (2.90)	-59.85 (21.64)	55.62 (29.96)	-105.65 (37.64)	1.44 (7.28)	5.49 (1.71)
2	16.19 (3.50)	-9.92 (2.76)	-59.47 (20.40)	54.19 (27.35)	-100.81 (35.37)		5.61 (1.58)
3	14.46 (3.53)	-8.20 (2.58)	-41.47 (19.54)	35.22 (26.07)	-53.02 (78.88)	4.64 (7.42)	5.77 (1.66)
4	16.82 (3.82)	-9.90 (2.90)	-59.37 (21.99)	53.70 (29.87)	-100.44 (36.42)	0.35 (7.10)	4.89 (1.73)
5	13.71 (3.15)	-8.10 (2.51)	-38.46 (16.99)	30.55 (22.36)	-59.14 (65.15)		5.94 (1.51)
6	16.38 (3.88)	-8.74 (2.71)	-46.83 (20.10)	38.96 (26.15)	-35.38 (72.36)	2.41 (7.17)	5.21 (1.64)
7	16.94 (3.72)	-10.03 (2.76)	-59.54 (21.23)	52.98 (28.22)	-96.43 (34.35)		5.10 (1.61)
8	15.85 (3.71)	-8.79 (2.57)	-44.90 (18.74)	35.71 (23.78)	-39.51 (69.51)		5.52 (1.56)
9	16.07 (3.53)	-9.81 (2.81)	-60.79 (20.38)	55.76 (27.66)	-90.24 (39.69)	-0.58 (6.42)	5.50 (1.64)
10	16.09 (3.41)	-9.91 (2.69)	-60.27 (19.74)	54.26 (26.25)	-86.03 (37.27)		5.63 (1.55)
(B) Abundance							
1	0.89 (1.36)	-2.26 (0.76)	4.93 (9.40)	-14.71 (13.92)	-12.31 (24.33)	-5.73 (3.04)	0.07 (0.41)
2	1.07 (1.33)	-2.39 (0.76)	5.04 (9.33)	-14.27 (13.72)	-9.39 (24.82)		0.07 (0.41)
3	1.54 (1.22)	-2.32 (0.84)	-0.60 (8.30)	-7.87 (12.87)	-38.27 (38.07)	-6.33 (3.00)	-0.32 (0.35)
4	1.36 (1.54)	-2.27 (0.76)	2.41 (10.17)	-11.51 (14.67)	-10.15 (25.93)	-5.60 (3.01)	0.02 (0.41)
5	2.01 (1.17)	-2.38 (0.86)	-2.84 (7.98)	-4.33 (12.30)	-32.44 (35.45)		-0.42 (0.34)
6	1.91 (1.36)	-2.42 (0.80)	-1.86 (8.48)	-6.30 (12.78)	-43.38 (28.84)	-6.09 (2.95)	-0.37 (0.33)
7	1.45 (1.53)	-2.39 (0.76)	2.95 (10.21)	-11.63 (14.67)	-6.82 (26.49)		0.04 (0.41)
8	2.32 (1.33)	-2.54 (0.81)	-3.63 (8.41)	-3.46 (12.57)	-39.20 (30.31)		-0.45 (0.33)
9	1.06 (1.37)	-1.87 (0.77)	1.61 (9.39)	-10.09 (13.89)	-29.13 (22.87)	-4.91 (2.75)	-0.32 (0.39)
10	1.24 (1.35)	-1.99 (0.77)	1.57 (9.44)	-9.53 (13.91)	-25.35 (22.86)		-0.31 (0.39)

[a] Variable definitions provided in Table 4.2

[b] Coefficient and standard error multiplied by 10^2

coefficient instabilities across models; Table 6.25). The final model-averaged abundance model was

$$
\begin{aligned}
&\text{Density} = 1 / (1 + (\text{Exp}(-(-123.81 + 142.3 * \text{BIGSAGE}_{18k} + 369.72 * \text{NDVI}_{3km} - 478.87 * \text{BIGSAGE}_{18k} * \\
&\text{NDVI}_{3km} - 141.52 * \text{CFRST}_{540} + 60.87 * \text{MIX}_{3km} - 19.94 * \text{RIP}_{18km} + 2.39 * \text{SALT}_{270} - 2.95 * \text{PIPE}_{1km} + 0.18 * \\
&\text{RDdens}_{3km} - 0.11 * \text{TRI}_{270} + 0.0020 * \text{TRI}_{270}^{2} + 0.02 * \text{ELEV} - 0.000006 * \text{ELEV}^{2}))) * \text{Exp}(-2.46 - 2.08 * \\
&\text{BIGSAGE}_{18k} + 0.49 * \text{NDVI}_{3km} + 6.32 * \text{BIGSAGE}_{18k} * \text{NDVI}_{3km} - 1.09 * \text{CFRST}_{540} + 8.53 * \text{MIX}_{3km} + 7.23 * \\
&\text{RIP}_{18km} - 3.85 * \text{SALT}_{270} - 0.10 * \text{PIPE}_{1km} + 0.12 * \text{RDdens}_{3km} - 0.000078 * \text{TRI}_{270} - 0.000079 * \text{TRI}_{270}^{2} + 0.0015 * \\
&\text{ELEV} - 0.00000037 * \text{ELEV}^{2} + 1.05)
\end{aligned}
\tag{7.6}
$$

TABLE 6.17. Extended

$SALT_{1km}$	$TRI_{5km}{}^{b}$	$RDdens_{18km}$	$WELL_{250}$	$GRASS_{3km}$	LL	K	AIC_c	ΔAIC_c	Σw_i
9.46 (3.61)	-8.78 (2.92)	2.27 (0.99)	3.39 (3.54)		-291.61	22	630.65	0.00	0.30
9.52 (3.56)	-7.98 (2.65)	2.14 (0.95)	3.87 (3.55)		-294.40	20	631.62	0.98	0.19
9.49 (3.58)	-9.59 (2.80)		7.70 (4.77)		-294.94	20	632.71	2.06	0.11
8.80 (3.80)	-7.72 (3.00)	2.04 (1.00)	3.45 (3.50)	-4.99 (5.51)	-290.71	24	633.52	2.88	0.07
9.05 (3.42)	-8.22 (2.66)		7.49 (4.28)		-297.66	18	633.61	2.97	0.07
8.09 (3.73)	-8.04 (2.85)		7.56 (4.03)	-8.29 (5.71)	-293.19	22	633.80	3.15	0.06
8.93 (3.72)	-7.06 (2.72)	1.90 (0.98)	3.91 (3.51)	-4.92 (5.20)	-293.59	22	634.61	3.96	0.04
7.91 (3.58)	-7.09 (2.63)		7.56 (4.00)	-7.67 (5.49)	-296.07	20	634.98	4.33	0.03
8.52 (3.33)	-7.64 (2.68)	2.38 (0.90)			-296.79	20	636.41	5.76	0.02
8.57 (3.27)	-7.08 (2.52)	2.22 (0.89)			-299.40	18	637.08	6.43	0.01
-0.93 (0.56)	-0.48 (1.09)	-0.43 (0.31)	1.96 (0.64)		-291.61	22	630.65	0.00	0.30
-0.88 (0.55)	-1.28 (1.03)	-0.52 (0.31)	1.85 (0.63)		-294.40	20	631.62	0.98	0.19
-1.03 (0.55)	-0.27 (1.16)		1.52 (0.61)		-294.94	20	632.71	2.06	0.11
-1.05 (0.57)	-0.46 (1.11)	-0.40 (0.31)	1.87 (0.64)	-1.32 (1.83)	-290.71	24	633.52	2.88	0.07
-1.01 (0.54)	-1.36 (1.17)		1.34 (0.58)		-297.66	18	633.61	2.97	0.07
-1.10 (0.56)	-0.20 (1.11)		1.43 (0.58)	-1.15 (1.79)	-293.19	22	633.80	3.15	0.06
-0.97 (0.57)	-1.27 (1.03	-0.50 (0.31)	1.78 (0.63)	-1.08 (1.86)	-293.59	22	634.61	3.96	0.04
-1.07 (0.56)	-1.17 (1.07)		1.27 (0.57)	-0.98 (1.83)	-296.07	20	634.98	4.33	0.03
-1.02 (0.56)	-0.65 (1.11)	-0.14 (0.29)			-296.79	20	636.41	5.76	0.02
-0.96 (0.55)	-1.37 (1.06)	-0.22 (0.30)			-299.40	18	637.08	6.43	0.01

The mean offset for the survey blocks is represented by the final constant in the model (1.05).

The final model-averaged abundance model for vesper sparrows accurately predicted independent count data from 96 BBS routes ($r_s = 0.52$, $p < 0.01$). When applied spatially across the WBEA within the range of the species, vesper sparrow densities were predicted to be highest in sagebrush habitats with higher productivity and lowest in more xeric shrubland communities (Fig. 6.17). Avoidance of higher elevation sites associated with conifer forests was also evident (Fig. 6.17). Based on the lowest density that could support a vesper sparrow territory (0.12 birds/ha; Fig. 6.17), 74.8% of the Wyoming Basins (292,896 km^2) was predicted to contain enough resources to support breeding

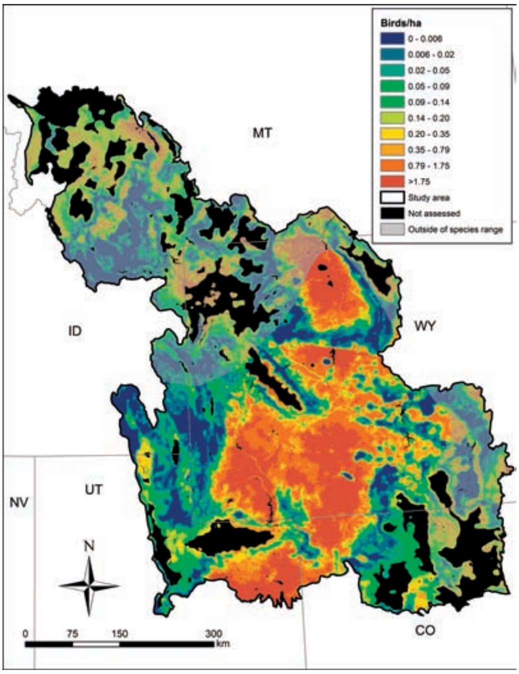

FIG. 6.11. Predicted density estimates (birds/ha) for sage sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one sage sparrow, the lowest density that could support a viable territory is 0.14 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

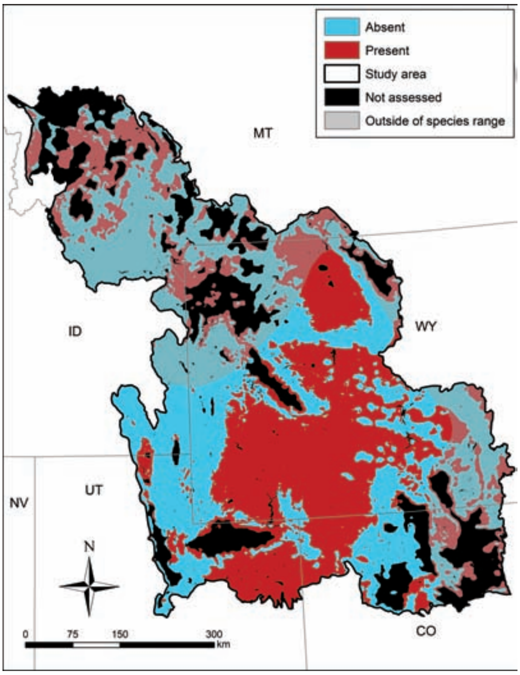

FIG. 6.12. Distribution of sage sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.14 birds/ha), the largest territory size required to support one sage sparrow. Semi-transparent grey shaded areas are outside the range of sage sparrow and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

vesper sparrows (Fig. 6.18). Predicted vesper sparrow densities assessed across the WBEA area increased from 1 birds/ha to between 1.5-3 birds/ha when the proportion of big sagebrush (18 km) was between 0.1 and 0.75, and decreased back to 1 bird/ha as proportion of sagebrush increased to 1.0 with densities exceeding the occurrence threshold across the entire range of big sagebrush values (Fig. 6.19). However, based on the landscape summarized as a whole (Fig. 6.19), vesper sparrow density was not strongly correlated with sagebrush habitat across the WBEA area. Most areas were predicted to have enough habitat to support at least 1 birds/ha (Fig. 6.17, Fig. 6.18, Fig. 6.19).

DISCUSSION

Increasing our knowledge of how sagebrush-associated species respond to the distribution of environmental factors is important to improve our efforts at conservation and management of these species. We found strong relationships between habitat and abiotic factors and occurrence and abundance of selected bird species. Brewer's sparrows, green-tailed towhees, lark sparrows, sage sparrows, and sage thrashers all had positive relationships with sagebrush of some variety, reinforcing the importance of key sagebrush or shrubland vegetation structure components to these birds. The scale at which each of these species responded to

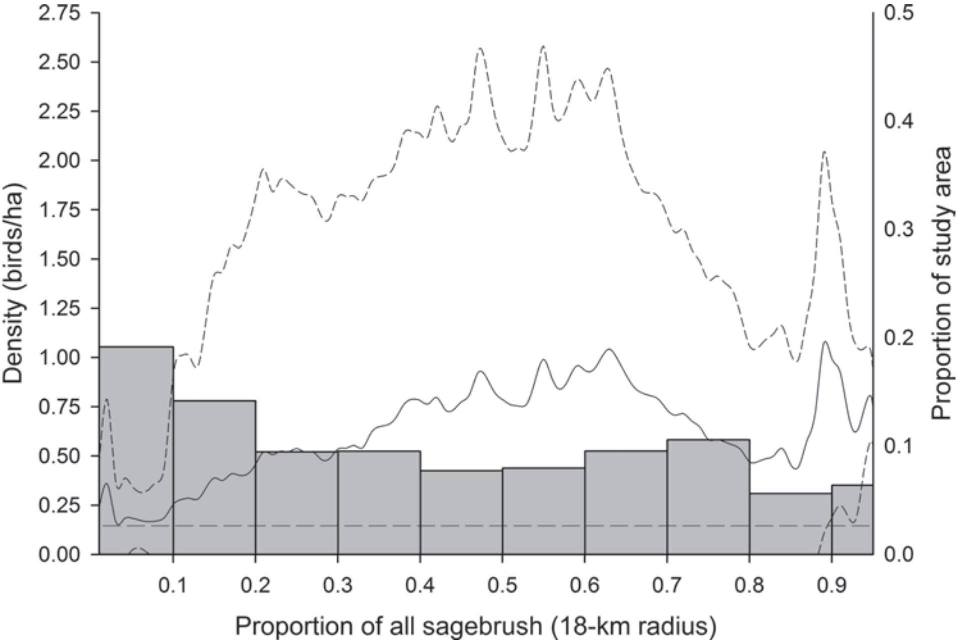

FIG. 6.13. Sage sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all sagebrush (*Artemisia* spp.) within an 18-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all sagebrush within a 1-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.14 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of all sagebrush within 1 km.

TABLE 6.18. Results of AIC_c-based model selection for sage thrasher zero-inflated Poisson abundance models in relation to multi-scale sagebrush and NDVI in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with ΔAIC_c ≤ 2 are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2$	-457.15	8	930.77	0.00	0.09
2	$ABIGSAGE_{540} + NDVI_{18km} + NDVI_{18km}^2$	-457.40	8	931.26	0.49	0.07
3	$ABIGSAGE_{270} + NDVI_{18km}$	-459.51	6	931.30	0.53	0.07
4	$ABIGSAGE_{270} + NDVI_{5km}$	-459.58	6	931.43	0.67	0.07
5	$ALLSAGE_{540} + NDVI_{18km} + NDVI_{18km}^2$	-457.52	8	931.51	0.74	0.06
6	$ABIGSAGE_{540} + NDVI_{18km}$	-460.06	6	932.40	1.63	0.04
7	$ABIGSAGE_{270} + NDVI_{3km}$	-460.10	6	932.47	1.70	0.04
8	$ABIGSAGE_{540} + NDVI_{5km}$	-460.12	6	932.51	1.74	0.04
9	$ABIGSAGE_{270} + NDVI_{1km}$	-460.20	6	932.66	1.90	0.04

[a] Variable definitions provided in Table 4.2

TABLE 6.19. Evaluation statistics from AIC_c-based univariate model selection for sage thrasher zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We models with all big sagebrush (0.27-km radius) and NDVI (18-km radius; quadratic) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which sage thrashers respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-442.90	10	906.51	0.00	0.56
	$CFRST_{3km}$	-443.19	10	907.09	0.58	0.42
	$CFRST_{540}$	-446.18	10	913.09	6.57	0.02
	$CFRST_{18km}$	-452.69	10	926.09	19.58	0.00
	$CFRST_{270}$	-456.40	10	933.52	27.01	0.00
	$GRASS_{270}$	-442.86	10	906.43	0.00	1.00
	$GRASS_{540}$	-449.46	10	919.63	13.20	0.00
	$GRASS_{1km}$	-450.75	10	922.22	15.79	0.00
	$GRASS_{3km}$	-450.76	10	922.24	15.81	0.00
	$GRASS_{5km}$	-451.15	10	923.01	16.58	0.00
	$GRASS_{18km}$	-451.50	10	923.72	17.29	0.00
	MIX_{18km}	-446.13	10	912.97	0.00	0.95
	MIX_{5km}	-449.23	10	919.17	6.20	0.04
	MIX_{1km}	-450.96	10	922.64	9.67	0.01
	MIX_{3km}	-451.94	10	924.59	11.62	0.00
	MIX_{540}	-453.66	10	928.04	15.07	0.00
	MIX_{270}	-455.13	10	930.98	18.01	0.00
	RIP_{1km}	-434.96	10	890.63	0.00	1.00
	RIP_{540}	-453.64	10	928.00	37.37	0.00
	RIP_{270}	-454.37	10	929.46	38.82	0.00
	RIP_{3km}	-454.54	10	929.81	39.17	0.00
	RIP_{18km}	-455.57	10	931.87	41.23	0.00
	RIP_{5km}	-455.96	10	932.64	42.01	0.00
	$SALT_{270}$	-456.51	10	933.74	0.00	0.31
	$SALT_{540}$	-456.75	10	934.21	0.46	0.24
	$SALT_{3km}$	-456.78	10	934.28	0.53	0.24
	$SALT_{1km}$	-456.88	10	934.47	0.72	0.21
	$EDGE_{5km}$	-445.76	10	912.23	0.00	0.73
	$CONTAG_{5km}$	-446.84	10	914.39	2.16	0.25
	$CONTAG_{3km}$	-449.16	10	919.03	6.80	0.02
	$EDGE_{3km}$	-451.05	10	922.81	10.59	0.00
	$EDGE_{1km}$	-454.10	10	928.92	16.69	0.00
	$CONTAG_{1km}$	-455.49	10	931.70	19.47	0.00

TABLE 6.19. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	PATCH$_{1km}$	-456.21	10	933.13	20.91	0.00
	PATCH$_{5km}$	-456.39	10	933.50	21.28	0.00
	PATCH$_{3km}$	-457.13	10	934.97	22.75	0.00
Abiotic	CTI	-456.50	10	933.71	0.00	0.86
	CTI^2[b]	-456.19	12	937.40	3.70	0.14
	ELEV	-428.41	10	877.54	0.00	0.58
	ELEV^2[b]	-426.58	12	878.18	0.64	0.42
	iH2Od$_{250}$[c]	-454.82	10	930.35	0.00	0.47
	iH2Od$_{500}$[c]	-455.23	10	931.18	0.83	0.31
	iH2Od$_{1km}$[c]	-455.61	10	931.94	1.59	0.21
	pH2Od$_{1km}$[c]	-454.97	10	930.66	0.00	0.49
	pH2Od$_{250}$[c]	-455.36	10	931.43	0.76	0.33
	pH2Od$_{250}$[c]	-456.00	10	932.71	2.05	0.18
	SOLAR	-450.25	10	921.22	0.00	0.50
	SOLAR^2[b]	-448.11	12	921.23	0.01	0.50
	TRI$_{1km}$	-439.00	10	898.72	0.00	0.41
	TRI$_{5km}$	-439.46	10	899.63	0.91	0.26
	TRI$_{540}$	-439.52	10	899.75	1.04	0.24
	TRI$_{3km}$	-440.69	10	902.11	3.39	0.08
	TRI$_{270}$	-442.62	10	905.96	7.25	0.01
	TRI	-446.60	10	913.91	15.19	0.00
	TRI$_{18km}$	-448.16	10	917.04	18.32	0.00
Disturbance	AG$_{250}$[c]	-455.29	10	931.30	0.00	0.66
	AG$_{500}$[c]	-456.41	10	933.53	2.23	0.22
	AG$_{1km}$[c]	-456.94	10	934.59	3.29	0.13
	MjRD$_{1km}$[c]	-456.61	10	933.93	0.00	0.38
	MjRD$_{500}$[c]	-456.79	10	934.30	0.37	0.31
	MjRD$_{250}$[c]	-456.82	10	934.35	0.42	0.31
	PIPE$_{250}$[c]	-456.32	10	933.35	0.00	0.51
	PIPE$_{500}$[c]	-456.96	10	934.63	1.28	0.27
	PIPE$_{1km}$[c]	-457.13	10	934.98	1.63	0.22
	POWER$_{1km}$	-456.31	10	933.34	0.00	0.43
	POWER$_{250}$	-456.54	10	933.80	0.46	0.34
	POWER$_{500}$	-456.93	10	934.57	1.23	0.23
	2RD$_{1km}$[c]	-454.95	10	930.61	0.00	0.21
	2RD$_{500}$[c]	-454.99	10	930.70	0.09	0.20

TABLE 6.19. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	RDdens$_{18km}$	-455.12	10	930.96	0.35	0.18
	2RD$_{250}$[c]	-455.25	10	931.22	0.61	0.15
	RDdens$_{270}$	-455.58	10	931.88	1.27	0.11
	RDdens$_{540}$	-456.38	10	933.48	2.87	0.05
	RDdens$_{3km}$	-456.65	10	934.01	3.40	0.04
	RDdens$_{1km}$	-456.67	10	934.06	3.45	0.04
	RDdens$_{5km}$	-456.98	10	934.67	4.06	0.03
	WELL$_{250}$[c]	-456.40	10	933.52	0.00	0.35
	WELL$_{500}$[c]	-456.41	10	933.54	0.02	0.35
	WELL$_{1km}$[c]	-456.53	10	933.79	0.27	0.31

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function ($e^{(\text{Euclidian distance from feature/-distance parameter})}$)

sagebrush and the other environmental factors varied widely. These scales were well beyond the typical home range of each species. Although we developed spatially explicit models by selecting a single scale for each GIS derived variable, it is important to understand that these species are influenced simultaneously by habitat factors at multiple spatial scales, including local vegetation cover (Knick et al. 2008, Erickson 2011, Hanser and Knick 2011). The strong relationships with the quantity and configuration of sagebrush, as well as other habitat variables, reiterates the importance of minimizing reductions in these habitats, either natural or human caused, if species are to be maintained (Braun et al. 1976, Knopf 1996, Wiens and Rotenberry 1985, Knick and Rotenberry 1995, Knick et al. 2003). Two species, Brewer's sparrows and sage thrashers, were common at sampled sites, suggesting that even if declines in these species have occurred (Sauer et al. 2003) or continue to occur, these species are likely to persist across at least some locations within the Wyoming Basins, based on the current distribution of sagebrush habitat. However, our models predict only Brewer's sparrows are likely to occur at suitable densities across the majority of the Wyoming Basins (87.7% above density threshold), whereas sage thrashers are predicted to occur in only 31.6% of the area, the lowest of any species modeled, despite being a sagebrush-obligate species. The sage thrasher and other species with lower detection rates (sage sparrow, lark sparrow, and green-tailed towhee) could be more sensitive to future losses of habitat, which might also suggest slower recovery for these species following disturbance. The minimum density estimates we obtained for individual species from DISTANCE (Thomas et al. 2006) were comparable to density thresholds derived from the largest known territory sizes for each species (Poole 2005), suggesting the count response data modeled with offsets and thresholds applied to binary maps capture biologically plausible density estimates. Indeed, most models accurately predicted independent BBS count data, despite differences in data collection and the broad areas assessed along BBS routes. Below, we discuss the key factors

TABLE 6.20. Results of AIC_c-based submodel selection for sage thrasher zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta\text{AIC}_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{CFRST}_{1\text{km}} + \text{GRASS}_{270\text{m}} + \text{MIX}_{18\text{km}} + \text{RIP}_{1\text{km}} + \text{EDGE}_{5\text{km}}$	-411.18	18	860.65	0.00	0.25
	2	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{CFRST}_{1\text{km}} + \text{GRASS}_{270\text{m}} + \text{MIX}_{18\text{km}} + \text{RIP}_{1\text{km}}$	-413.49	16	860.78	0.13	0.23
	3	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{CFRST}_{1\text{km}} + \text{MIX}_{18\text{km}} + \text{RIP}_{1\text{km}} + \text{EDGE}_{5\text{km}} + \text{SALT}_{270}$	-411.82	18	861.93	1.29	0.13
	4	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{CFRST}_{1\text{km}} + \text{MIX}_{18\text{km}} + \text{RIP}_{1\text{km}} + \text{EDGE}_{5\text{km}}$	-414.25	16	862.31	1.67	0.11
	5	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{CFRST}_{1\text{km}} + \text{GRASS}_{270\text{m}} + \text{MIX}_{18\text{km}} + \text{RIP}_{1\text{km}} + \text{EDGE}_{5\text{km}} + \text{SALT}_{270}$	-409.88	20	862.59	1.94	0.09
Abiotic	1	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{ELEV} + \text{iH2Od}_{250} + \text{TRI}_{1\text{km}}$	-413.73	14	856.85	0.00	0.54
	2	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{ELEV} + \text{iH2Od}_{250} + \text{SOLAR} + \text{TRI}_{1\text{km}}$	-411.99	16	857.79	0.94	0.34
Disturbance	1	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{2RD}_{1\text{km}}$	-454.95	10	930.61	0.00	0.13
	2	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{AG}_{250}$	-455.29	10	931.30	0.69	0.09
	3	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{POWER}_{1\text{km}} + \text{2RD}_{1\text{km}}$	-453.66	12	932.34	1.73	0.05
	4	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{AG}_{250} + \text{WELL}_{250}$	-453.71	12	932.44	1.83	0.05
	5	$\text{ABIGSAGE}_{270} + \text{NDVI}_{18\text{km}} + \text{NDVI}_{18\text{km}}^{2} + \text{AG}_{250} + \text{2RD}_{1\text{km}}$	-453.72	12	932.45	1.84	0.05

[a] Variable definitions provided in Table 4.2

TABLE 6.21. Results of AIC$_c$-based model selection for the combined sage thrasher zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates[a] (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and cumulative Akaike weight [$\sum w_i$]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence, whereas section (B) includes the count portion of the model.

Rank	Intercept	ABIGSAGE$_{270}$	NDVI$_{18km}$	NDVI$_{18km}^2$	ELEV[b]	iH2Od$_{250}$	TRI$_{1km}$	CFRST$_{1km}$
(A) Occurrence								
1	-8.83 (7.90)	7.55 (2.84)	-56.56 (29.29)	41.18 (30.68)	8.38 (1.93)	4.37 (1.81)	-0.06 (0.04)	68.76 (37.25)
2	0.74 (5.65)	4.72 (2.51)	-62.23 (30.95)	50.39 (32.15)	6.41 (1.51)	3.76 (2.25)	-0.03 (0.04)	49.87 (30.49)
3	1.27 (4.97)	1.91 (2.44)	-43.78 (21.32)	33.53 (24.24)	5.48 (1.18)		-0.04 (0.03)	39.34 (35.76)
4	0.27 (4.07)	3.71 (1.87)	-47.28 (17.76)	37.17 (19.18)	5.39 (1.10)		-0.04 (0.03)	36.60 (20.71)
5	-0.91 (4.59)	5.75 (2.23)	-58.84 (25.39)	45.11 (25.27)	6.57 (1.50)	3.77 (1.98)	-0.03 (0.03)	56.12 (27.85)
6	-0.34 (5.00)	5.20 (2.81)	-58.92 (28.66)	46.78 (27.85)	6.31 (1.67)	3.28 (2.91)	-0.03 (0.03)	49.79 (29.08)
7	-7.69 (7.82)	7.81 (2.88)	-57.31 (29.96)	41.30 (31.82)	8.47 (2.03)	4.64 (1.74)	-0.07 (0.04)	71.95 (42.88)
8	-1.28 (3.61)	4.83 (1.71)	-44.83 (16.72)	33.48 (17.85)	5.43 (1.09)		-0.04 (0.02)	42.88 (20.07)
9	1.58 (5.04)	4.13 (2.24)	-56.64 (26.27)	44.87 (27.94)	6.15 (1.31)	3.65 (1.81)	-0.03 (0.03)	49.86 (33.54)
10	-10.82 (8.99)	8.01 (3.04)	-49.10 (29.74)	33.32 (31.33)	8.26 (2.01)	4.06 (2.01)	-0.07 (0.04)	68.72 (35.79)
11	-1.58 (4.39)	6.30 (2.55)	-58.34 (25.65)	44.58 (24.42)	6.51 (1.67)	3.44 (2.48)	-0.04 (0.03)	56.16 (26.69)
12	-2.10 (11.16)	2.48 (3.86)	-38.92 (25.76)	28.47 (28.63)	6.00 (1.53)		-0.05 (0.03)	41.82 (35.69)
13	-0.86 (3.84)	3.85 (1.62)	-41.41 (17.72)	30.49 (19.32)	5.35 (1.03)		-0.04 (0.03)	40.97 (23.42)
14	2.24 (5.14)	1.70 (2.31)	-44.32 (21.27)	34.12 (24.26)	5.37 (1.14)		-0.04 (0.03)	39.07 (38.02)
15	-7.13 (6.94)	7.11 (2.40)	-50.60 (24.90)	35.37 (25.56)	7.49 (1.69)	3.82 (1.61)	-0.05 (0.03)	63.04 (27.74)
16	-0.35 (4.38)	5.31 (1.86)	-53.67 (23.22)	40.50 (23.89)	6.26 (1.31)	3.64 (1.65)	-0.04 (0.03)	53.69 (28.00)
17	16.05 (14.00)	3.34 (2.98)	-91.16 (44.49)	75.80 (41.44)	5.39 (1.27)		-0.02 (0.03)	46.28 (25.60)
18	1.63 (4.27)	3.81 (1.91)	-48.15 (17.61)	38.21 (18.98)	5.14 (1.08)		-0.05 (0.03)	34.52 (20.99)
19	1.14 (4.54)	5.07 (2.08)	-55.79 (21.91)	44.32 (22.62)	5.96 (1.29)	3.34 (1.89)	-0.04 (0.03)	45.98 (25.97)
20	40.67 (18.25)	7.85 (2.17)	-291.08 (112.67)	386.89 (161.48)	3.78 (1.14)		-0.02 (0.03)	
21	-9.60 (9.04)	8.62 (3.05)	-49.46 (29.95)	33.47 (31.81)	8.37 (2.21)	4.47 (1.93)	-0.08 (0.05)	67.77 (39.16)
22	-0.41 (4.03)	6.07 (1.82)	-53.34 (20.25)	40.57 (20.75)	6.09 (1.27)	3.37 (1.71)	-0.05 (0.03)	51.01 (23.06)
23	50.69 (31.06)	6.47 (2.61)	-380.09 (189.36)	536.67 (287.32)	4.80 (2.10)	2.71 (4.13)	0.01 (0.04)	-58.82 (38.34)
24	10.22 (10.65)	1.89 (3.06)	-62.60 (32.42)	47.23 (32.68)	5.34 (1.25)		-0.03 (0.03)	57.23 (50.72)
(B) Abundance								
1	-2.52 (1.06)	0.20 (0.35)	-1.21 (3.76)	2.33 (4.31)	0.79 (0.39)	0.01 (0.18)	-0.02 (0.01)	-5.75 (2.01)
2	-2.20 (0.90)	0.18 (0.34)	-0.68 (3.54)	1.85 (4.12)	0.60 (0.40)	-0.01 (0.18)	-0.02 (0.01)	-5.84 (2.00)
3	-1.97 (0.85)	0.34 (0.36)	-0.75 (3.48)	2.13 (4.03)	0.41 (0.38)		-0.01 (0.01)	-6.10 (2.06)
4	-1.94 (0.85)	0.24 (0.37)	-1.27 (3.60)	2.69 (4.18)	0.48 (0.39)		-0.01 (0.01)	-6.28 (2.06)
5	-2.50 (0.82)	0.31 (0.33)	-0.23 (3.46)	1.37 (3.98)	0.63 (0.39)	-0.01 (0.18)	-0.02 (0.01)	-6.21 (1.99)
6	-2.13 (0.88)	0.18 (0.36)	-1.27 (3.68)	2.54 (4.24)	0.61 (0.40)	0.00 (0.19)	-0.02 (0.01)	-6.00 (2.02)
7	-2.52 (1.05)	0.20 (0.35)	-1.92 (3.72)	3.25 (4.29)	0.79 (0.37)	0.00 (0.18)	-0.02 (0.01)	-6.08 (2.05)
8	-2.16 (0.80)	0.36 (0.37)	-0.89 (3.57)	2.27 (4.11)	0.48 (0.38)		-0.02 (0.01)	-6.54 (2.07)

TABLE 6.21. Extended

GRASS$_{270m}$	MIX$_{18km}$	EDGE$_{5km}$^{c}	RIP$_{1km}$	2RD$_{1km}$	LL	K	AIC$_{c}$	ΔAIC$_{c}$	Σw$_{i}$
-12.83 (6.95)	-204.14 (57.63)	8.42 (4.32)			-393.38	22	834.18	0.00	0.147
-6.20 (5.14)	-164.68 (49.75)				-395.70	20	834.24	0.05	0.289
-7.47 (5.71)	-129.78 (33.55)				-398.30	18	834.90	0.71	0.392
-5.62 (4.45)	-122.51 (34.12)		12.79 (8.57)		-396.42	20	835.67	1.49	0.462
	-170.62 (50.51)				-398.75	18	835.79	1.61	0.527
-5.05 (4.81)	-151.50 (49.97)		9.18 (9.32)		-394.73	22	836.88	2.70	0.565
-14.52 (7.20)	-216.84 (60.34)	8.87 (4.32)		-1.63 (1.54)	-392.42	24	836.93	2.75	0.602
	-122.75 (33.62)		12.12 (7.09)		-399.50	18	837.29	3.11	0.633
-7.23 (5.07)	-169.28 (46.28)			-1.34 (1.37)	-394.95	22	837.34	3.16	0.663
-11.35 (7.18)	-191.11 (57.49)	8.53 (4.89)	8.50 (10.97)		-392.66	24	837.41	3.22	0.693
	-158.32 (50.94)		8.85 (7.45)		-397.31	20	837.45	3.27	0.721
-8.32 (6.08)	-130.40 (35.81)	2.18 (6.79)			-397.39	20	837.61	3.43	0.748
	-128.94 (32.34)				-401.91	16	837.64	3.45	0.774
-8.35 (5.86)	-132.25 (33.87)			-0.56 (1.27)	-397.79	20	838.42	4.23	0.791
	-188.30 (52.92)	4.71 (3.72)			-397.92	20	838.67	4.48	0.807
	-172.16 (46.24)			-1.11 (1.22)	-398.10	20	839.02	4.84	0.820
	-110.40 (48.71)	-11.13 (7.47)	16.71 (8.71)		-398.12	20	839.08	4.89	0.833
-6.08 (4.52)	-127.08 (34.51)		14.45 (9.67)	-0.97 (1.32)	-395.85	22	839.14	4.95	0.845
-5.76 (4.69)	-160.89 (45.26)		12.54 (10.10)	-1.90 (1.40)	-393.55	24	839.20	5.02	0.857
	-138.20 (45.75)		32.09 (13.02)		-402.71	16	839.22	5.04	0.869
-12.86 (7.31)	-205.12 (59.35)	9.02 (5.00)	12.10 (12.79)	-2.31 (1.69)	-391.33	26	839.48	5.30	0.879
	-164.77 (44.57)		12.16 (8.09)	-1.89 (1.31)	-396.06	22	839.56	5.38	0.889
-5.62 (5.46)			48.58 (30.20)		-398.38	20	839.59	5.40	0.899
	-123.80 (43.57)	-8.10 (6.52)			-400.95	18	840.19	6.01	0.906
-1.64 (1.28)	-2.65 (8.85)	-0.02 (0.51)			-393.38	22	834.18	0.00	0.147
-1.82 (1.30)	-7.13 (10.67)				-395.70	20	834.24	0.05	0.289
-1.53 (1.31)	-7.51 (10.27)				-398.30	18	834.90	0.71	0.392
-1.49 (1.32)	-7.00 (10.37)		0.38 (1.04)		-396.42	20	835.67	1.49	0.462
	-7.37 (10.52)				-398.75	18	835.79	1.61	0.527
-1.75 (1.33)	-7.32 (11.84)		0.42 (1.03)		-394.73	22	836.88	2.70	0.565
-1.42 (1.28)	-2.22 (8.67)	-0.09 (0.50)		0.23 (0.21)	-392.42	24	836.93	2.75	0.602
	-6.70 (10.38)		0.56 (1.03)		-399.50	18	837.29	3.11	0.633

TABLE 6.21. Continued

Rank	Intercept	$ABIGSAGE_{270}$	$NDVI_{18km}$	$NDVI_{18km}^2$	$ELEV^b$	$iH2Od_{250}$	TRI_{1km}	$CFRST_{1km}$
9	-2.33 (0.87)	0.22 (0.34)	-1.05 (3.48)	2.39 (4.06)	0.59 (0.38)	-0.01 (0.18)	-0.02 (0.01)	-6.09 (2.04)
10	-2.46 (1.06)	0.22 (0.37)	-1.95 (3.95)	3.15 (4.50)	0.82 (0.40)	0.02 (0.18)	-0.02 (0.01)	-5.82 (2.03)
11	-2.42 (0.82)	0.33 (0.34)	-0.95 (3.61)	2.21 (4.14)	0.64 (0.39)	0.00 (0.18)	-0.02 (0.01)	-6.31 (2.02)
12	-2.58 (1.18)	0.46 (0.52)	0.54 (4.20)	0.69 (4.71)	0.46 (0.43)		-0.02 (0.01)	-5.64 (2.13)
13	-2.21 (0.80)	0.38 (0.36)	-0.02 (3.43)	1.32 (3.95)	0.43 (0.38)		-0.02 (0.01)	-6.38 (2.04)
14	-2.13 (0.86)	0.35 (0.35)	-1.17 (3.48)	2.69 (4.04)	0.43 (0.38)		-0.01 (0.01)	-6.32 (2.10)
15	-2.70 (1.05)	0.33 (0.36)	-0.33 (3.75)	1.44 (4.28)	0.73 (0.39)	0.00 (0.18)	-0.02 (0.01)	-6.08 (2.02)
16	-2.58 (0.81)	0.31 (0.33)	-0.53 (3.42)	1.82 (3.96)	0.62 (0.38)	-0.02 (0.18)	-0.02 (0.01)	-6.41 (2.02)
17	-3.23 (1.02)	0.89 (0.44)	0.42 (3.82)	0.83 (4.36)	0.48 (0.37)		-0.02 (0.01)	-5.67 (2.16)
18	-2.13 (0.86)	0.23 (0.37)	-1.62 (3.61)	3.15 (4.19)	0.52 (0.39)		-0.01 (0.01)	-6.52 (2.08)
19	-2.29 (0.86)	0.18 (0.36)	-1.47 (3.56)	2.88 (4.13)	0.62 (0.38)	-0.01 (0.18)	-0.02 (0.01)	-6.29 (2.05)
20	-3.38 (0.77)	0.65 (0.31)	2.47 (3.43)	-3.55 (3.91)	0.78 (0.38)		-0.02 (0.01)	
21	-2.45 (1.05)	0.19 (0.37)	-2.57 (3.89)	3.96 (4.45)	0.81 (0.38)	0.01 (0.18)	-0.02 (0.01)	-6.19 (2.06)
22	-2.53 (0.80)	0.28 (0.34)	-1.09 (3.52)	2.48 (4.06)	0.64 (0.37)	-0.01 (0.18)	-0.02 (0.01)	-6.59 (2.04)
23	-3.10 (0.87)	0.18 (0.34)	-0.18 (4.04)	0.09 (4.56)	1.00 (0.51)	0.04 (0.19)	-0.02 (0.01)	-3.41 (1.99)
24	-3.24 (1.01)	0.85 (0.41)	1.26 (3.81)	-0.12 (4.30)	0.44 (0.38)		-0.02 (0.01)	-5.60 (2.11)

[a] Variable definitions provided in Table 4.2

[b] Coefficient and standard error multiplied by 10^3

[c] Coefficient and standard error multiplied by 10^2

influencing abundance or occurrence of each bird species assessed across the WBEA area.

Brewer's Sparrow

Brewer's sparrow, the most common species modeled, was predicted to occur at moderate densities throughout much of the Wyoming Basins sagebrush habitat, especially in southwestern Wyoming. Brewer's sparrow density was positively associated with all big sagebrush at a moderate scale. An association with sagebrush was expected, with previous research demonstrating that Brewer's sparrows are often the most abundant bird species in sagebrush habitats (Wiens and Rotenberry 1981). Abundance of sagebrush at the landscape, territory, and nesting patch scale has been linked to Brewer's sparrow habitat selection and fitness (Chalfoun and Martin 2007), with large-scale habitat fragmentation thought to be responsible for declines observed in Breeding Bird Survey data (Rotenberry 1998). Brewer's sparrows in the Wyoming Basins illustrated this sensitivity to increased fragmentation with reduced densities in areas of increased sagebrush edge density. Expansion of energy development in the region and the subsequent fragmentation (Ch. 3) could result in reductions in Brewer's sparrow abundance; reductions have been shown at more local scales in Wyoming (Gilbert and Chalfoun 2011). Other factors predicting abundance of Brewer's sparrows in the Wyoming Basins included an association with moderate site productivity at higher (mid-range) elevations with less rugged terrain, describing the sagebrush plateaus of southwest Wyoming as well as riparian areas. Brewer's sparrows occur in ripar-

TABLE 6.21. Extended

$GRASS_{270m}$	MIX_{18km}	$EDGE_{5km}^{c}$	RIP_{1km}	$2RD_{1km}$	LL	K	AIC_c	ΔAIC_c	Σw_i
-1.55 (1.32)	-5.10 (9.73)			0.21 (0.22)	-394.95	22	837.34	3.16	0.663
-1.58 (1.30)	-2.59 (9.05)	-0.05 (0.52)	0.45 (1.02)		-392.66	24	837.41	3.22	0.693
	-7.36 (11.55)		0.65 (1.02)		-397.31	20	837.45	3.27	0.721
-1.72 (1.37)	-6.68 (12.43)	0.44 (0.89)			-397.39	20	837.61	3.43	0.748
	-6.73 (9.97)				-401.91	16	837.64	3.45	0.774
-1.37 (1.32)	-6.81 (10.07)			0.22 (0.22)	-397.79	20	838.42	4.23	0.791
	-3.20 (9.19)	-0.01 (0.53)			-397.92	20	838.67	4.48	0.807
	-5.30 (9.75)			0.20 (0.22)	-398.10	20	839.02	4.84	0.820
	-18.51 (9.43)	0.92 (0.48)	0.97 (1.04)		-398.12	20	839.08	4.89	0.833
-1.31 (1.32)	-6.16 (10.07)		0.20 (1.05)	0.21 (0.22)	-395.85	22	839.14	4.95	0.845
-1.48 (1.32)	-4.86 (9.90)		0.22 (1.04)	0.22 (0.22)	-393.55	24	839.20	5.02	0.857
	-4.18 (9.15)		0.63 (1.00)		-402.71	16	839.22	5.04	0.869
-1.34 (1.29)	-2.44 (8.94)	-0.13 (0.51)	0.29 (1.03)	0.22 (0.21)	-391.33	26	839.48	5.30	0.879
	-4.52 (9.76)		0.41 (1.03)	0.22 (0.22)	-396.06	22	839.56	5.38	0.889
-1.67 (1.35)			0.26 (1.01)		-398.38	20	839.59	5.40	0.899
	-18.23 (10.41)	0.90 (0.48)			-400.95	18	840.19	6.01	0.906

ian habitat in the Great Basin (Dobkin and Rich 1998) and have highest densities within 500 m of riparian habitat in Arizona (Szaro and Jakle 1985). Brewer's sparrow densities in the WBEA area decreased with increases in conifer forest at local scales and mixed shrubland at landscape scales. When selecting foraging patches, Brewer's sparrows preferentially use patches dominated by sagebrush over yellow (*Chrysothamnus viscidiflorous*) and gray (*Ericameria nauseosus*) rabbitbrush (Rotenberry and Wiens 1998); both rabbitbrush species are primary components of the mixed shrubland land cover type in the Wyoming Basins. Brewer's sparrows are shrubland-associated birds, so the decrease in abundance we found in relation to conifer forest was expected.

No significant impact was observed between local anthropogenic factors and the abundance of Brewer's sparrow in the WBEA area. Likewise, Rotenberry and Knick (1995) found no measurable effect of 2-track roads on the presence of Brewer's sparrow in southwest Idaho. However, Ingelfinger and Anderson (2004) demonstrated a reduction in Brewer's sparrow abundance of up to 50% along low traffic volume roads (within 100 m and up to 697 cars/day) associated with natural gas developments in Wyoming. The 100-m zone tested by Ingelfinger and Anderson (2004) was not always significant for all energy roads, suggesting that impacts are highly variable. Similarly, Brewer's sparrow abundance, on average, decreased at three local oil fields assessed in southwestern Wyoming, although the response varied across sites, with no declines at one older oil field (Gilbert and Chalfoun 2011). The large spatial extent

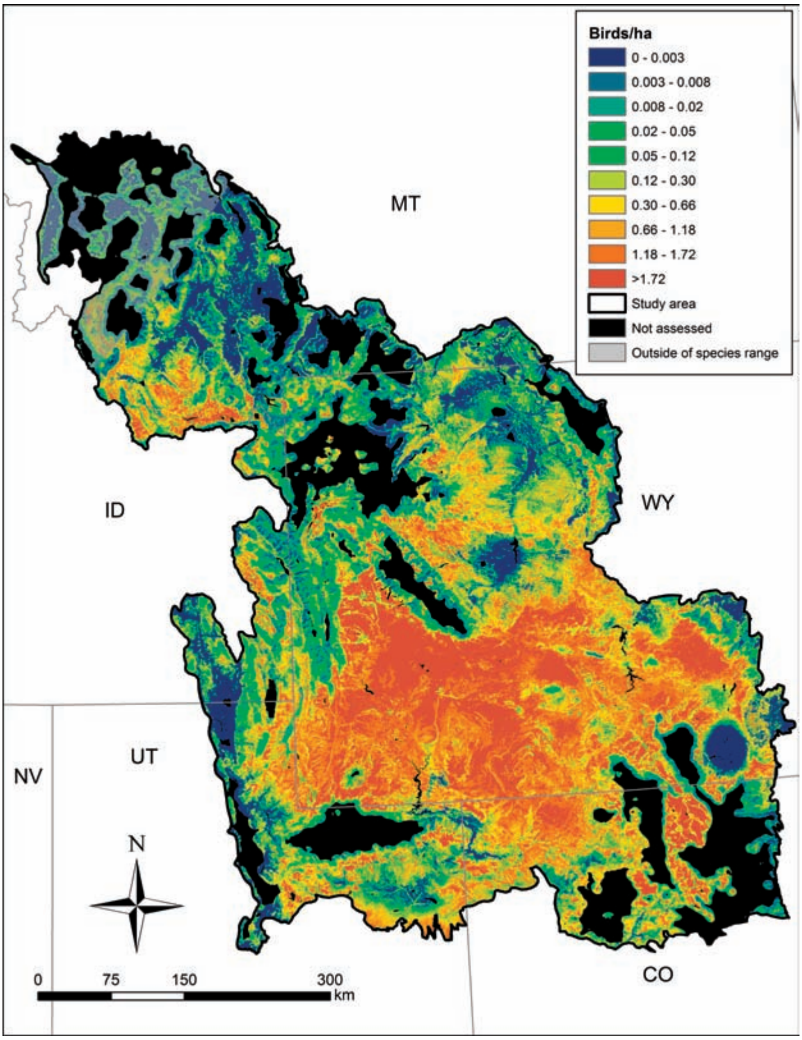

FIG. 6.14. Predicted density estimates (birds/ha) for sage thrasher in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the range of the sage thrasher and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one sage thrasher, the lowest density that could support a viable territory is 0.59 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

of our analyses across the WBEA area may have limited our ability to capture these more localized effects but provides insights to patterns across the region.

Green-tailed towhee

Green-tailed towhees are common throughout their range and, in general, populations have remained relatively stable since 1961 (Hejl 1994, Knopf 1994, Dobbs et al. 1998). However, biological and habitat relationships are less well understood because of the species' secretive nature (Dobbs et al. 1998). Accordingly, we had low detection rates (18.6% of plots) and low probability of detection (25%) for green-tailed towhees. Nevertheless, our model had good accuracy and reasonable classification success in predicting occurrence of green-tailed towhees.

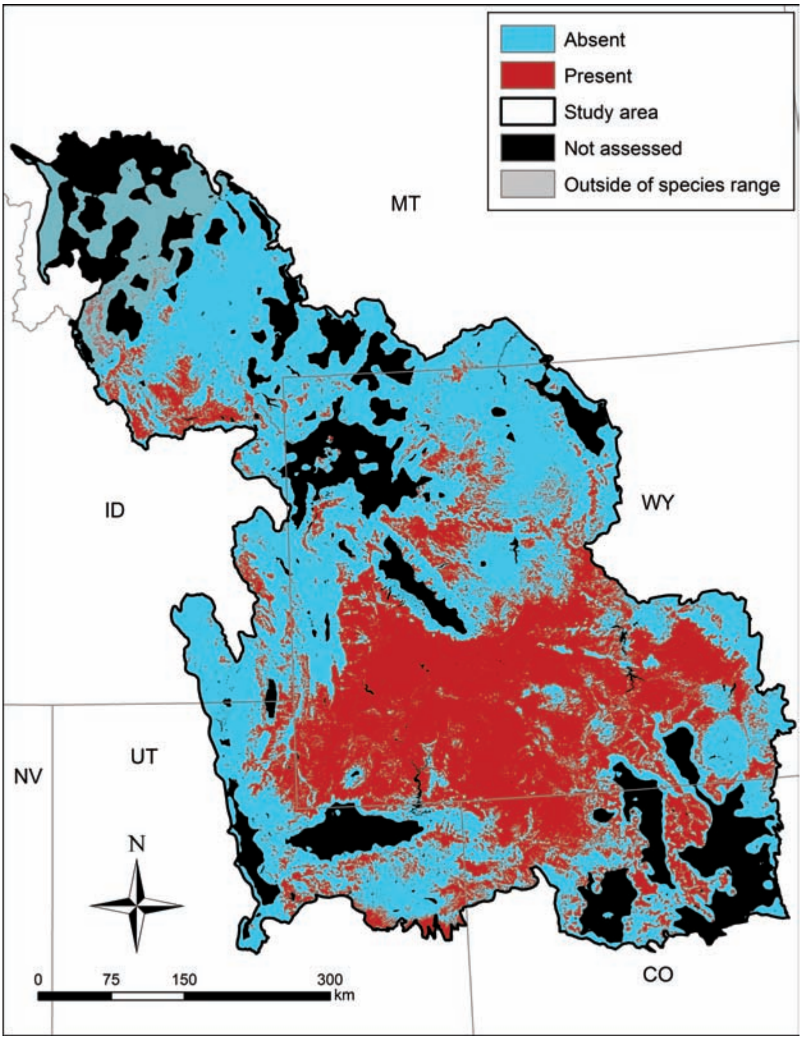

FIG 6.15. Distribution of sage thrasher in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.59 birds/ha), the largest territory size required to support one sage thrasher. Semi-transparent grey shaded areas are outside the range of sage thrasher and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

Green-tailed towhees prefer a diverse mix of shrub species and are often associated with shrub steppe habitats and communities dominated by sagebrush or interspersed with pinyon (*Pinus* spp.)-juniper (Wiens and Rotenberry 1981, Sedgwick 1987, Knopf et al., 1990, Dobbs et al. 1998) as well as with heterogeneous habitats with no single dominant shrub (Berry and Bock 1998). Mapped occurrence of green-tailed towhees in the WBEA area was greatest along edges of sagebrush habitats, supporting other research indicating that ecotones between sagebrush and other shrubs or trees are ideal habitat for this species (Knopf et al. 1990). Although we found no relationship with forested habitats, occurrence was associated with a greater proportion of mountain big sagebrush at a moderate (5 km) extent. Species-diverse

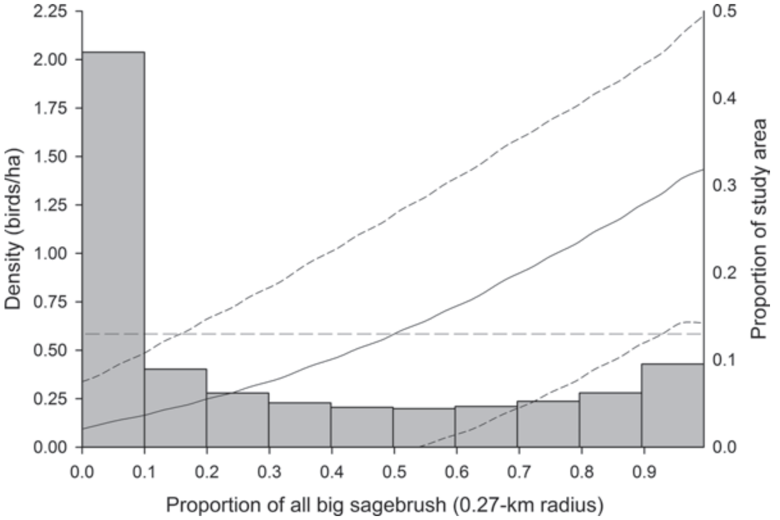

FIG. 6.16. Sage thrasher predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata*) within a 0.27-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 0.27-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.59 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 0.27 km.

shrub habitats were important green-tailed towhee habitat in Colorado at local patch scales but not at landscape scales (Berry and Bock 1998). Landscape fragmentation might not be an issue for birds, such as green-tailed towhees, which evolved in foothills shrub communities that are naturally fragmented (Berry and Bock 1998). We found higher occurrence in habitats with more rugged topography but larger mean patch size of sagebrush, suggesting heterogeneity of habitats may be important to green-tailed towhees, even within large patches of sagebrush habitat. Within shrub steppe habitats, vigor and heterogeneity of shrubs within a patch is important for nesting habitat (Knopf et al. 1990, Berry and Bock 1998). Similarly, occurrence of green-tailed towhees in the WBEA area was positively correlated within maximum NDVI values. These more productive habitats likely support a greater diversity of

TABLE 6.22. Results of AIC_c-based model selection for vesper sparrow zero-inflated negative binomial abundance models in relation to multi-scale sagebrush and NDVI in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta\text{AIC}_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$\text{BIGSAGE}_{18km} + \text{NDVI}_{3km} + (\text{BIGSAGE}_{18km} * \text{NDVI}_{3km})$	-503.24	9	1,025.06	0.00	0.27
2	$\text{BIGSAGE}_{18km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}2$	-503.98	9	1,026.55	1.48	0.13

[a] Variable definitions provided in Table 4.2

TABLE 6.23. Evaluation statistics from AIC$_c$-based univariate model selection for vesper sparrow zero-inflated inflated negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and Akaike weight [w_i]). We ran models with big sagebrush (18-km radius), NDVI (3-km radius), and the big sagebrush NDVI interaction term variables as a base model for variables tested. We used AIC$_c$ to sort models for each variable in ascending order to identify the extent at which vesper sparrow respond to individual variables.

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	CFRST$_{540m}$	-494.65	11	1,012.17	0.00	0.86
	CFRST$_{1km}$	-496.52	11	1,015.90	3.73	0.13
	CFRST$_{270m}$	-500.30	11	1,023.47	11.30	0.00
	GRASS$_{1km}$	-502.07	11	1,026.99	0.00	0.22
	GRASS$_{3km}$	-502.19	11	1,027.24	0.25	0.20
	GRASS$_{540m}$	-502.23	11	1,027.32	0.33	0.19
	GRASS$_{5km}$	-502.35	11	1,027.57	0.57	0.17
	GRASS$_{270m}$	-502.52	11	1,027.90	0.90	0.14
	GRASS$_{18km}$	-503.06	11	1,028.98	1.99	0.08
	MIX$_{3km}$	-498.00	11	1,018.85	0.00	0.42
	MIX$_{5km}$	-498.53	11	1,019.93	1.08	0.25
	MIX$_{18km}$	-498.70	11	1,020.27	1.41	0.21
	MIX$_{540m}$	-499.76	11	1,022.38	3.53	0.07
	MIX$_{1km}$	-500.46	11	1,023.79	4.94	0.04
	MIX$_{270m}$	-501.54	11	1,025.94	7.09	0.01
	RIP$_{18km}$	-495.93	11	1,014.73	0.00	0.52
	RIP$_{5km}$	-496.96	11	1,016.78	2.06	0.18
	RIP$_{540m}$	-497.25	11	1,017.35	2.63	0.14
	RIP$_{1km}$	-497.27	11	1,017.40	2.67	0.14
	RIP$_{3km}$	-499.45	11	1,021.76	7.03	0.02
	RIP$_{270m}$	-499.89	11	1,022.65	7.93	0.01
	SALT$_{270}$	-496.83	11	1,016.52	0.00	0.72
	SALT$_{1km}$	-498.00	11	1,018.86	2.34	0.22
	SALT$_{540m}$	-499.38	11	1,021.63	5.11	0.06
	PATCH$_{1km}$	-500.17	11	1,023.20	0.00	0.35
	CONTAG$_{3km}$	-500.43	11	1,023.72	0.52	0.27
	EDGE$_{3km}$	-500.91	11	1,024.67	1.47	0.17
	PATCH$_{3km}$	-501.68	11	1,026.22	3.02	0.08
	CONTAG$_{5km}$	-502.38	11	1,027.63	4.42	0.04
	EDGE$_{5km}$	-502.60	11	1,028.07	4.87	0.03
	CONTAG$_{1km}$	-502.67	11	1,028.21	5.01	0.03
	EDGE$_{1km}$	-502.98	11	1,028.82	5.62	0.02
	PATCH$_{5km}$	-503.17	11	1,029.21	6.00	0.02
	PATCH$_{1km}$	-500.17	11	1,023.20	0.00	0.35

TABLE 6.23. Continued

Category	Variable^{a}	LL	K	AIC$_{c}$	ΔAIC$_{c}$	w_{i}
Abiotic	CTI^{2b}	-496.81	13	1,020.83	0.00	0.75
	CTI	-500.08	11	1,023.02	2.20	0.25
	ELEV^{2b}	-495.44	13	1,018.08	0.00	1.00
	ELEV	-503.22	11	1,029.31	11.23	0.00
	iH2Od$_{1km}^{c}$	-502.90	11	1,028.66	0.00	0.35
	iH2Od$_{250}^{c}$	-502.94	11	1,028.74	0.08	0.33
	iH2Od$_{500}^{c}$	-502.97	11	1,028.80	0.14	0.32
	pH2Od$_{1km}^{c}$	-502.19	11	1,027.23	0.00	0.41
	pH2Od$_{250}^{c}$	-502.42	11	1,027.71	0.48	0.32
	pH2Od$_{250}^{c}$	-502.61	11	1,028.08	0.85	0.27
	TRI$_{270}^{2b}$	-492.70	13	1,012.60	0.00	0.38
	TRI$_{270}$	-495.77	11	1,014.40	1.80	0.16
	TRI$_{5km}^{2b}$	-493.90	13	1,015.00	2.40	0.12
	TRI$_{3km}^{2b}$	-494.29	13	1,015.77	3.17	0.08
	TRI$_{540}^{2b}$	-494.43	13	1,016.06	3.46	0.07
	TRI^{2b}	-494.77	13	1,016.73	4.13	0.05
	TRI$_{540}$	-496.96	11	1,016.78	4.17	0.05
	TRI$_{1km}^{2b}$	-494.85	13	1,016.91	4.30	0.04
	TRI$_{1km}$	-497.53	11	1,017.92	5.32	0.03
	TRI	-497.54	11	1,017.93	5.33	0.03
	TRI$_{3km}$	-500.40	11	1,023.66	11.06	0.00
	TRI$_{5km}$	-501.03	11	1,024.93	12.33	0.00
Disturbance	AG$_{250}^{c}$	-501.54	11	1,025.95	0.00	0.52
	AG$_{500}^{c}$	-502.26	11	1,027.39	1.44	0.25
	AG$_{1km}^{c}$	-502.34	11	1,027.55	1.60	0.23
	MjRD$_{1km}^{c}$	-500.30	11	1,023.47	0.00	0.68
	MjRD$_{500}^{c}$	-501.56	11	1,025.98	2.51	0.19
	MjRD$_{250}^{c}$	-502.04	11	1,026.95	3.48	0.12
	PIPE$_{1km}^{c}$	-496.41	11	1,015.69	0.00	0.97
	PIPE$_{500}^{c}$	-500.28	11	1,023.42	7.72	0.02
	PIPE$_{250}^{c}$	-501.29	11	1,025.45	9.76	0.01
	POWER$_{1km}^{c}$	-501.62	11	1,026.11	0.00	0.66
	POWER$_{500}^{c}$	-502.97	11	1,028.79	2.69	0.17
	POWER$_{250}^{c}$	-502.99	11	1,028.84	2.73	0.17
	RDdens$_{3km}$	-499.07	11	1,021.01	0.00	0.41
	RDdens$_{5km}$	-499.93	11	1,022.72	1.71	0.17
	RDdens$_{270}$	-499.98	11	1,022.81	1.80	0.17

TABLE 6.23. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$2RD_{250}{}^c$	-500.72	11	1,024.29	3.28	0.08
	$RDdens_{540}$	-500.98	11	1,024.82	3.80	0.06
	$2RD_{500}{}^c$	-501.21	11	1,025.29	4.27	0.05
	$RDdens_{1km}$	-501.68	11	1,026.22	5.21	0.03
	$2RD_{1km}{}^c$	-501.70	11	1,026.27	5.26	0.03
	$RDdens_{18km}$	-502.95	11	1,028.77	7.76	0.01
	$WELL_{1km}{}^c$	-503.16	11	1,029.18	0.00	0.35
	$WELL_{250}{}^c$	-503.21	11	1,029.29	0.10	0.33
	$WELL_{500}{}^c$	-503.23	11	1,029.31	0.13	0.32

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function ($e^{(\text{Euclidian distance from feature/-distance parameter})}$)

shrub species and structural variation within mountain shrub communities, which are important for breeding and nesting habitat for green-tailed towhees (Braun et al. 1976, Knopf et al. 1990, Dobbs et al. 1998).

Braun et al. (1976) suggested that long-term loss and destruction of sagebrush habitat negatively impacts green-tailed towhees. Other than reviews of the potential effects of fragmentation and loss of shrub steppe habitats (Braun et al. 1976, Knopf et al. 1990), no recorded research has specifically addressed the impacts of anthropogenic disturbances on green-tailed towhee populations. Green-tailed towhees were one of the few species for which we found an avoidance of human features, although the effect was not very strong. Green-tailed towhees avoided habitat in proximity to major (interstate and state/federal highways) roads, suggesting that cumulative anthropogenic developments may have negative consequences for populations, although these types of disturbance are less common in higher elevation mountain sagebrush communities. Further research directly assessing the consequences of human developments on green-tailed towhee populations is needed, especially given increasing rates of development for human habitation and recreational use at the sagebrush-conifer ecotone, where this species commonly occurs, and the increasing rates and extents of energy developments throughout sagebrush ecosystems.

Lark sparrow

Lark sparrows in western North America have remained relatively stable on BBS routes since surveys began in 1966 (Martin and Parrish 2000, Sauer et al. 2003). Although few habitat studies have been conducted for this species, birds tend to be found at ecotone boundaries in more open grassland or shrub steppe habitats adjacent to forest (pinyon-juniper) edges, although agricultural fields and roadside edges may also be selected (Knopf 1996, Martin and Parrish 2000). Our model predicted lark sparrows to occur in the grass dominated regions in the eastern and southern portions of the WBEA area, even though grassland did not enter into the model as a predictor. However, this may simply be an artifact of our sampling design targeting sagebrush habitats. Lark sparrow density was greatest in large landscapes containing a great-

TABLE 6.24. Results of AIC_c-based submodel selection for vesper sparrow zero-inflated inflated negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + CFRST_{540m} + MIX_{3km} + RIP_{18km} + SALT_{270}$	-476.32	17	988.68	0.00	0.70
Abiotic	1	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + ELEV + ELEV^2 + TRI_{270} + TRI_{270}^{\ 2}$	-482.54	17	1,001.11	0.00	0.69
Disturbance	1	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + PIPE_{1km} + RDdens_{3km}$	-492.45	13	1,012.09	0.00	0.25
	2	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + AG_{250} + PIPE_{1km} + RDdens_{3km}$	-490.60	15	1,012.78	0.69	0.17
	3	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + AG_{250} + PIPE_{1km} + RDdens_{3km} + WELL_{1km}$	-488.95	17	1,013.95	1.85	0.10

[a] Variable definitions provided in Table 4.2

er proportion of all big sagebrush, as well as mixed shrubs. Additionally, these birds showed moderate avoidance of conifer forest; but when present in sagebrush landscapes, abundance increased in the presence of coniferous forest, although the effect was small. This is consistent with other studies that have shown selection for desert-shrub and juniper-sagebrush mixed shrub communities (Knopf 1996, Martin and Parrish 2000). Occurrence of lark sparrows was correlated with greater vegetation productivity (higher maximum NDVI values) in the WBEA area, particularly within sagebrush habitats, but once present in these habitats, NDVI had little effect on abundance. These findings suggest that lark sparrows select denser structural cover within shrub steppe communities, consistent with research elsewhere (Martin and Parrish 2000).

No previous studies have addressed the response of lark sparrows to anthropogenic developments. We found only marginal response to proximity to wells and agricultural land for both occurrence and abundance. Given these responses and the fact that lark sparrow populations are currently stable, we suggest that lark sparrows will persist within the Wyoming Basins into the foreseeable future.

Sage sparrow

Sage sparrow density was predicted to be the highest across the central portion of the WBEA area, with high densities occurring within sagebrush habitats in southwest Wyoming and northeastern Utah, and those in northern Wyoming associated with the Bighorn River basin. The occurrence portion of the zero-inflated Poisson count model explained most of the variation in the model (based on log-likelihood estimates), suggesting presence-absence relationships were overwhelming. Despite having small home ranges (0.65 to 7.06 ha; Rich 1980, Reynolds 1981, Wiens and Rotenberry 1985), we found sage sparrow habitat associations at large spatial scales.

Survey blocks where sage sparrows were detected had ~5% more sagebrush habitat, but our count-based density model suggested a negative relationship with both the occurrence and abundance of all sagebrush. At first, this result was counterintuitive, but responses to other variables, such as increased occurrence with both lower productivity at a large spatial scale and increased proportion salt-desert shrubland at a moderate scale, likely counteracted these effects; abundance appears unaffected by productivity or proportion of salt-desert shrubland (large coefficient SEs). The dose response curve illustrates that predicted sage sparrow density across the WBEA area increased with proportion of sagebrush, with highest predicted densities occurring in large landscapes containing more than ~40% sagebrush land cover, despite the negative model coefficients. Configuration of sagebrush was also important. When contagion of sagebrush habitat increased, sage sparrows were more likely to occur; effects on abundance were again limited. This landscape-scale association with sagebrush is consistent with previous research (Wiens and Rotenberry 1981, Knick and Rotenberry 1995, Vander Haegen et al. 2000). Because sage sparrows also select open shrubland sites with patchy shrub distributions (Rich 1978, Rotenberry and Wiens 1978, Wiens and Rotenberry 1981, Smith et al. 1984, Wiens 1985), the observed relationship with salt-desert shrubland is consistent with previous research. Also consistent with previous research is the negative relationship between mixed shrub habitat and sage sparrow abundance, because sage sparrows preferentially forage in patches of sagebrush over yellow rabbitbrush (Rotenberry and Wiens 1998).

Rotenberry and Knick (1995) found no relationship between measured anthropogenic factors and the occurrence of sage sparrows, although this may not reflect demographic processes (Misenhelter and Rotenberry 2000, Bock and Jones 2004) or recent, broad-scale ecosystem changes (Bradley et al. 2006). Introduced invasive alien plants, particularly cheatgrass (*Bromus tectorum*), which can lead to altered fire frequencies and loss of sagebrush, can displace sage sparrows (Wiens 1985, Rogers et al. 1988). Mechanical or chemical removal of sagebrush also leads to degradation of sage sparrow habitat through similar structural changes (Braun et al. 1976, Wiens and Rotenberry 1985, Wiens et al. 1986, Rogers et al. 1988). However, we found limited responses of sage sparrows to anthropogenic features, which included road density and proximity to oil and gas wells. Although abundance of sage sparrows was effectively independent of roads (large coefficient SEs), occurrence was negatively impacted by high road densities. Ingelfinger and Anderson (2004) found reductions in abundance of sage sparrows of up to 76% along low traffic volume roads (within 100 m and up to 697 cars/day) associated with natural gas developments in Wyoming. The 100-m zone tested, however, was not always significant for all energy haul roads, suggesting that impacts are highly variable and other factors may be important. Similarly, Gilbert and Chalfoun (2011) found reductions in sage sparrow abundance with increasing well density in three oil fields in Wyoming, although relationships were only significant at one of these sites. The reductions in sage sparrow abundance that we observed with greater road densities coupled with continued landscape-scale loss of sagebrush and associated habitats from development are likely to result in declining sage sparrow occurrence and density with increasing human activities.

Sage thrasher

Sage thrashers were predicted to occur throughout much of the WBEA study area, with the highest densities occurring throughout southcentral Wyoming. Sage thrashers were positively associated with all big sagebrush vegetation at moderate

TABLE 6.25. Results of AIC_c-based model selection for the combined vesper sparrow zero-inflated inflated negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence, whereas Section (B) includes the count portion of the model.

Rank	Intercept	$BIGSAGE_{18km}$	$NDVI_{3km}$	$BIGSAGE_{18km} * NDVI_{3km}$	$CFRST_{540m}$	MIX_{3km}	RIP_{18km}
(A) Occurrence							
1	-90.04 (27.87)	131.77 (42.41)	311.45 (96.31)	-445.78 (142.04)	-132.39 (40.00)	73.23 (51.09)	-25.67 (16.19)
2	-96.44 (31.59)	140.96 (48.29)	326.05 (104.63)	-471.98 (157.91)	-133.61 (41.51)	71.85 (54.17)	-24.31 (15.79)
3	-87.02 (25.81)	126.85 (39.12)	305.55 (90.96)	-432.59 (132.92)	-131.87 (38.31)	76 (48.86)	-25.68 (16.09)
4	-87.49 (27.70)	127.06 (41.92)	304.99 (95.81)	-431.85 (140.97)	-131.28 (40.32)	79.63 (50.90)	-24.53 (16.25)
5	-189.12 (157.24)	124.72 (104.81)	439.69 (354.19)	-465.16 (369.43)	-269.79 (214.96)	38.88 (66.29)	
6	-233.20 (109.35)	154.40 (75.15)	537.09 (246.45)	-569.28 (266.10)	-327.73 (147.78)		
7	-311.33 (124.75)	263.15 (129.42)	794.60 (356.51)	-802.06 (407.83)		57.51 (179.57)	
8	-90.97 (25.51)	132.02 (38.54)	311.83 (87.79)	-444.60 (129.12)	-132.00 (36.46)	68.75 (47.06)	-21.55 (14.36)
9	-96.58 (29.32)	140.42 (44.68)	325.71 (96.53)	-469.62 (145.92)	-132.51 (37.89)	62.64 (45.72)	-21.07 (14.27)
10	-111.93 (52.99)	164.66 (81.70)	366.08 (167.84)	-539.16 (261.01)	-144.99 (60.81)	77.23 (72.90)	
11	-328.31 (118.78)	280.20 (123.43)	849.78 (330.41)	-850.11 (394.60)			
12	-136.20 (33.97)	157.87 (38.98)	393.45 (94.71)	-551.97 (135.78)	-163.49 (38.77)		-42.14 (15.95)
13	-71.04 (20.80)	100.51 (31.37)	247.75 (73.57)	-343.06 (107.45)	-107.72 (30.86)	63.21 (36.66)	-17.70 (15.20)
14	-70.27 (20.73)	99.22 (31.18)	242.70 (72.76)	-337.49 (106.29)	-104.67 (30.41)	60.71 (35.43)	-16.69 (14.84)
15	-133.17 (34.25)	156.33 (39.74)	385.74 (95.99)	-544.24 (137.84)	-159.23 (39.37)		-40.71 (15.83)
16	-213.94 (102.49)	146.35 (70.13)	507.09 (243.87)	-537.50 (256.31)	-311.76 (152.58)	68.89 (86.28)	
17	-214.74 (87.34)	96.47 (59.60)	385.67 (169.76)	-274.09 (194.68)			
18	-82.16 (37.05)	118.42 (56.93)	277.37 (119.70)	-394.83 (180.86)	-116.96 (47.10)	81.28 (53.38)	
19	-245.26 (147.07)	187.38 (126.13)	609.49 (368.56)	-624.78 (433.10)	-348.06 (213.89)		-62.03 (39.86)
20	-195.38 (89.15)	95.40 (60.16)	365.05 (171.61)	-277.33 (196.25)		52.63 (94.93)	
(B) Abundance							
1	-1.31 (0.65)	-1.91 (1.08)	0.51 (1.13)	7.05 (2.90)	-1.53 (1.38)	10.09 (4.61)	9.31 (3.02)
2	-1.08 (0.72)	-2.04 (1.19)	0.90 (1.18)	6.27 (3.08)	-1.17 (1.38)	9.88 (4.62)	8.66 (3.03)
3	-1.10 (0.63)	-1.80 (1.09)	0.47 (1.13)	6.90 (2.92)	-1.64 (1.38)	9.63 (4.62)	10.36 (2.98)
4	-1.00 (0.69)	-1.62 (1.16)	1.01 (1.16)	5.44 (3.05)	-1.20 (1.37)	9.04 (4.57)	9.89 (2.95)
5	-6.26 (2.86)	-2.24 (1.54)	0.04 (1.26)	4.64 (3.54)	-0.02 (1.66)	9.26 (5.33)	
6	-5.65 (2.70)	-2.09 (1.29)	0.09 (1.25)	4.26 (3.29)	0.16 (1.70)		
7	-7.92 (2.48)	-3.20 (1.18)	-0.18 (1.17)	5.26 (3.00)		10.85 (4.84)	
8	-1.43 (0.66)	-2.17 (1.09)	0.58 (1.15)	7.76 (2.95)	-1.47 (1.41)	10.54 (4.68)	10.23 (3.07)
9	-1.24 (0.73)	-2.27 (1.20)	0.98 (1.20)	6.95 (3.15)	-1.16 (1.41)	10.43 (4.69)	9.64 (3.08)
10	-0.14 (0.67)	-3.10 (1.18)	0.23 (1.22)	7.29 (3.22)	-1.83 (1.45)	9.76 (4.99)	
11	-7.74 (2.44)	-2.83 (1.18)	0.02 (1.18)	4.56 (3.02)			

TABLE 6.25. Extended

SALT$_{270}$	PIPE$_{1km}$	RDdens$_{3km}$	TRI$_{270}^{b}$	TRI$_{270}^{2b}$	ELEV*	ELEV^{2c}	LL	K	AIC$_{c}$	ΔAIC$_{c}$	Σw_{i}
-0.44 (3.50)	-3.02 (1.32)	0.52 (0.53)					-469.45	21	984.02	0.00	0.201
0.12 (3.63)	-3.40 (1.55)	0.85 (0.63)	10.13 (6.81)	-0.21 (0.11)			-464.88	25	984.22	0.19	0.384
-0.67 (3.48)	-2.63 (1.13)						-472.17	19	984.89	0.86	0.515
-0.16 (3.62)	-2.60 (1.17)		2.74 (7.17)	-0.04 (0.13)			-468.61	23	986.97	2.94	0.561
17.09 (18.94)			-33.24 (23.79)	0.40 (0.36)	8.18 (6.87)	-0.22 (0.18)	-468.67	23	987.10	3.07	0.604
22.65 (15.59)			-39.11 (19.1)	0.49 (0.31)	10.12 (4.87)	-0.27 (0.13)	-471.09	21	987.30	3.28	0.643
	-9.03 (4.88)	-2.73 (1.48)	-113.6 (52.7)	2.36 (1.07)	11.05 (4.33)	-0.33 (0.13)	-468.88	23	987.52	3.50	0.678
	-3.11 (1.24)	0.65 (0.54)					-473.79	19	988.13	4.10	0.704
	-3.51 (1.50)	0.97 (0.65)	8.44 (6.78)	-0.20 (0.11)			-469.23	23	988.22	4.20	0.729
1.05 (3.83)	-4.73 (2.91)	1.31 (1.40)	13.55 (12.19)	-0.28 (0.27)			-469.33	23	988.41	4.39	0.751
	-9.67 (4.50)	-2.87 (1.47)	-125.73 (45.09)	2.59 (0.93)	11.48 (4.25)	-0.34 (0.12)	-471.75	21	988.61	4.59	0.771
-1.15 (3.40)	-2.52 (1.09)				3.17 (1.58)	-0.09 (0.04)	-471.76	21	988.64	4.62	0.791
1.11 (3.67)							-476.32	17	988.68	4.66	0.811
1.52 (3.67)		0.29 (0.40)					-474.18	19	988.91	4.89	0.828
-0.88 (3.40)	-2.69 (1.13)	0.29 (0.48)			2.98 (1.61)	-0.08 (0.04)	-469.73	23	989.22	5.19	0.843
		-1.10 (0.77)	-32.93 (16.05)	0.42 (0.26)	9.06 (4.58)	-0.24 (0.12)	-469.92	23	989.60	5.58	0.856
30.61 (16.42)				1.76 (0.78)		-0.31 (0.14)	-474.54	19	989.63	5.61	0.868
1.19 (3.79)	-3.12 (2.11)	0.51 (0.82)	-81.06 (33.61)		11.6 (5.17)		-474.57	19	989.69	5.67	0.880
	-4.73 (3.38)	-1.49 (1.16)		1.19 (0.67)		-0.27 (0.17)	-467.65	25	989.76	5.73	0.891
26.27 (15.48)			-63.95 (32.01)	1.60 (0.80)	9.66 (5.98)	-0.27 (0.14)	-472.43	21	989.98	5.95	0.901
-4.12 (1.73)	-0.10 (0.27)	0.16 (0.09)	-75.12 (35.09)				-469.45	21	984.02	0.00	0.201
-4.13 (1.67)	-0.15 (0.27)	0.17 (0.09)	-0.63 (1.26)	-0.01 (0.01)			-464.88	25	984.22	0.19	0.384
-4.31 (1.76)	-0.12 (0.28)						-472.17	19	984.89	0.86	0.515
-4.42 (1.73)	-0.17 (0.27)		-0.23 (1.25)	-0.01 (0.01)			-468.61	23	986.97	2.94	0.561
-5.72 (1.52)			1.53 (1.54)	-0.03 (0.02)	0.61 (0.26)	-0.01 (0.01)	-468.67	23	987.10	3.07	0.604
-6.00 (1.51)			1.12 (1.31)	-0.03 (0.02)	0.57 (0.25)	-0.01 (0.01)	-471.09	21	987.30	3.28	0.643
	-0.08 (0.28)	0.29 (0.09)	0.27 (1.33)	-0.03 (0.02)	0.77 (0.23)	-0.02 (0.01)	-468.88	23	987.52	3.50	0.678
	-0.13 (0.28)	0.17 (0.09)					-473.79	19	988.13	4.10	0.704
	-0.17 (0.28)	0.18 (0.09)	-0.50 (1.30)	-0.01 (0.01)			-469.23	23	988.22	4.20	0.729
-4.52 (1.65)	-0.04 (0.28)	0.22 (0.09)	-0.70 (1.29)	-0.01 (0.01)			-469.33	23	988.41	4.39	0.751
	-0.03 (0.28)	0.29 (0.10)	0.04 (1.34)	-0.02 (0.02)	0.76 (0.23)	-0.02 (0.01)	-471.75	21	988.61	4.59	0.771

TABLE 6.25. Continued

Rank	Intercept	$BIGSAGE_{18km}$	$NDVI_{3km}$	$BIGSAGE_{18km} * NDVI_{3km}$	$CFRST_{540m}$	MIX_{3km}	RIP_{18km}
12	-6.40 (2.45)	-2.32 (1.18)	-0.08 (1.17)	8.22 (3.03)	-0.24 (1.53)		8.98 (3.01)
13	-1.17 (0.63)	-1.52 (1.07)	0.59 (1.12)	6.29 (2.92)	-1.60 (1.36)	8.57 (4.55)	10.33 (2.97)
14	-1.39 (0.64)	-1.53 (1.06)	0.65 (1.12)	6.27 (2.90)	-1.49 (1.35)	8.75 (4.51)	9.35 (2.99)
15	-6.44 (2.44)	-2.29 (1.17)	0.01 (1.17)	8.12 (3.00)	-0.23 (1.51)		8.01 (3.02)
16	-8.10 (2.56)	-2.30 (1.27)	0.58 (1.25)	5.00 (3.28)	0.00 (1.68)	10.53 (4.86)	
17	-4.61 (2.51)	-2.79 (1.20)	-0.60 (1.15)	4.01 (3.08)			
18	-0.36 (0.64)	-2.66 (1.30)	-0.18 (1.18)	7.36 (3.28)	-2.20 (1.42)	8.79 (5.37)	
19	-7.58 (2.42)	-1.40 (1.29)	1.23 (1.29)	3.29 (3.16)	-0.04 (1.66)		7.23 (3.12)
20	-5.10 (2.51)	-3.07 (1.23)	-0.75 (1.15)	4.61 (3.13)		9.06 (4.97)	

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^2
[c] Coefficients and standard errors multiplied by 10^4

scales, consistent with previous research (Petersen and Best 1991, Knick and Rotenberry 1995, Erickson 2011). Based on our model, habitats containing >50% big sagebrush land cover provide suitable habitat for sage thrashers. Although the quantity of sagebrush was important, we did not find an influence of sagebrush configuration on either presence or abundance of sage thrashers across the WBEA area. Previous studies in Idaho found that sagebrush configuration and increased sagebrush cover are important factors influencing sage thrasher habitat, and probability of site occupancy increased with patch size and habitat similarity within a 1-km radius (Knick and Rotenberry 1995, 1997). These results suggest that any fragmentation of sagebrush habitats may be important in determining habitat quality for sage thrashers. Compared to other areas of the western U.S., many sampled sagebrush habitats in the Wyoming Basins are extensive, suggesting that configuration of sagebrush may not currently be limiting but may become more important when landscape cover of sagebrush habitat is reduced.

Sage thrashers avoided areas with increased proportion of mixed shrubland, and abundance decreased with increasing amounts of conifer forest. This was not surprising for a sagebrush-obligate species to avoid non-sagebrush habitat types, particularly the conifer forest type with dramatic differences in ecosystem structure and function. Both occurrence and abundance were greatest in areas with low topographic ruggedness, suggesting larger patches of flat and contiguous habitat (sagebrush) represent high-quality habitat for sage thrasher. In addition, proximity to intermittent water sources and increases in riparian habitat increased sage thrasher occurrence, and increased vegetation productivity resulted in increased sage thrasher density. These results are comparable to other work in Wyoming, where increased soil moisture and vegetation productivity enhanced sage thrasher densities (Erickson 2011).

No obvious anthropogenic impacts were identified in our assessment, suggesting that sage thrasher abundance in the Wyoming Basins was related more to habitat factors than land use. Previous assessments of local road impacts also suggest little to no impact to the occurrence or abundance of sage thrashers (Knick and Rotenberry 1995, Ingelfinger and Anderson 2004),

TABLE 6.25. Extended

$SALT_{270}$	$PIPE_{1km}$	$RDdens_{3km}$	$TRI_{270}{}^{b}$	$TRI_{270}{}^{2b}$	$ELEV^{*}$	$ELEV^{2c}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
-4.11 (1.75)	-0.07 (0.28)				0.56 (0.24)	-0.01 (0.01)	-471.76	21	988.64	4.62	0.791
-5.18 (1.74)							-476.32	17	988.68	4.66	0.811
-5.10 (1.72)		0.15 (0.09)					-474.18	19	988.91	4.89	0.828
-4.00 (1.74)	-0.06 (0.27)	0.15 (0.09)			0.53 (0.24)	-0.01 (0.01)	-469.73	23	989.22	5.19	0.843
		0.28 (0.09)	1.68 (1.29)	-0.04 (0.02)	0.69 (0.25)	-0.02 (0.01)	-469.92	23	989.60	5.58	0.856
-6.46 (1.53)			-0.28 (1.27)	-0.02 (0.02)	0.57 (0.23)	-0.01 (0.01)	-474.54	19	989.63	5.61	0.868
-4.79 (1.82)	0.02 (0.29)	0.21 (0.09)					-474.57	19	989.69	5.67	0.880
	-0.06 (0.28)	0.26 (0.10)	0.78 (1.37)	-0.03 (0.02)	0.59 (0.24)	-0.01 (0.01)	-467.65	25	989.76	5.73	0.891
-6.23 (1.51)			0.02 (1.28)	-0.02 (0.02)	0.61 (0.23)	-0.02 (0.01)	-472.43	21	989.98	5.95	0.901

and more recent work in Wyoming found no significant relationships between sage thrasher abundance and well density (Gilbert and Chalfoun 2011). Regardless of the neutral direct responses to anthropogenic activities, landscape-scale loss of sagebrush is expected to result in reductions in sage thrasher habitat, which has also been suggested to have greater impacts on sage thrashers because of their larger territory size requirements (Reynolds 1981, Reynolds et al. 1999, Erickson 2011).

Vesper sparrow

Occurrence of vesper sparrows was strongly correlated with the quantity of big sagebrush at large scales. Vesper sparrows are moderate habitat generalists (Jones and Cornely 2002), often associated with short or sparse vegetation cover occurring in open areas such as grasslands or those within shrub steppe habitats (Rotenberry and Wiens 1980, Kantrud and Kologiski 1983). Accordingly, predicted occurrence was greatest in the grassland-shrub interface in the eastern portions of the WBEA area with moderate occurrence in the sagebrush dominated Upper Green River Basin in southwest Wyoming. Vesper sparrows avoid tall and dense vegetation but select for increased structural complexity provided by sagebrush or other shrubs (Dechant et al. 2003). We found abundance of vesper sparrows increased with greater portions of mixed shrubland at large scales but decreased with less productive salt desert shrub communities. Occurrence has been positively correlated with cover of yellow rabbitbrush and antelope bitterbrush (*Purshia tridentata*) (Wiens and Rotenberry 1981), both of which are contained within our mixed shrub habitat class. Vesper sparrows occur at greater densities in montane shrub sites where meadows provide abundant forbs (Rotenberry and Wiens 1980). Similarly, we found occurrence to increase with habitat productivity, although sagebrush sites with high productivity were avoided (negative interaction term). However, when present, abundance increased when higher elevation sagebrush habitats had greater productivity (positive interaction term), although strong avoidance of conifer forests was evident. These relationships likely capture vesper sparrows selection for forb-rich habitats within more structural and heterogeneous shrub communities (Rotenberry and Wiens 1980). Accordingly, increased drought condi-

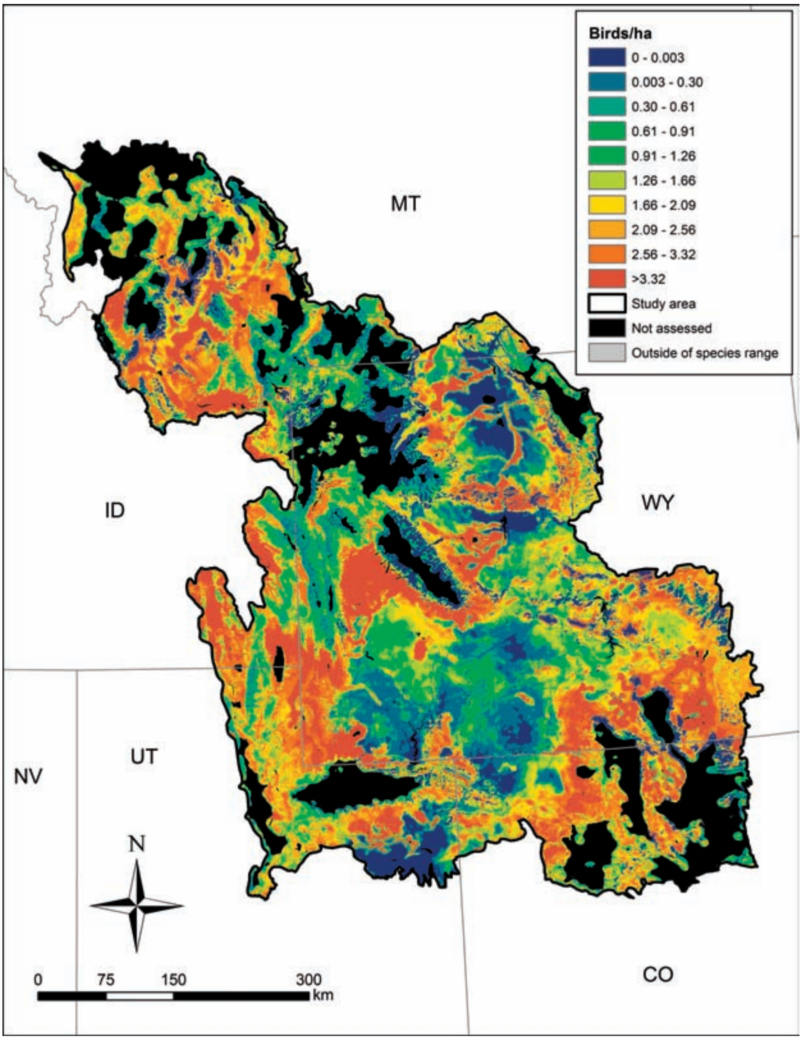

FIG. 6.17. Predicted density estimates (birds/ha) for vesper sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one vesper sparrow, the lowest density that could support a viable territory is 0.12 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

tions may be important factors reducing habitat suitability for vesper sparrows (George et al. 1992).

Relationships with anthropogenic developments have rarely been assessed for vesper sparrows. However, the only significant anthropogenic response in the WBEA area was avoidance of habitats in proximity to pipelines. This avoidance may be a function of construction efforts which result in the loss of sagebrush cover and revegetation efforts on pipeline rights-of-way, ultimately leading to exotic grasslands (Booth and Cox 2009). In a recent study assessing songbird density at three oil fields in Wyoming, Gilbert and Chalfoun (2011) found no significant relationship between vesper sparrow abundance and well density. Vesper sparrows avoided urbanized landscapes in Colorado, and had

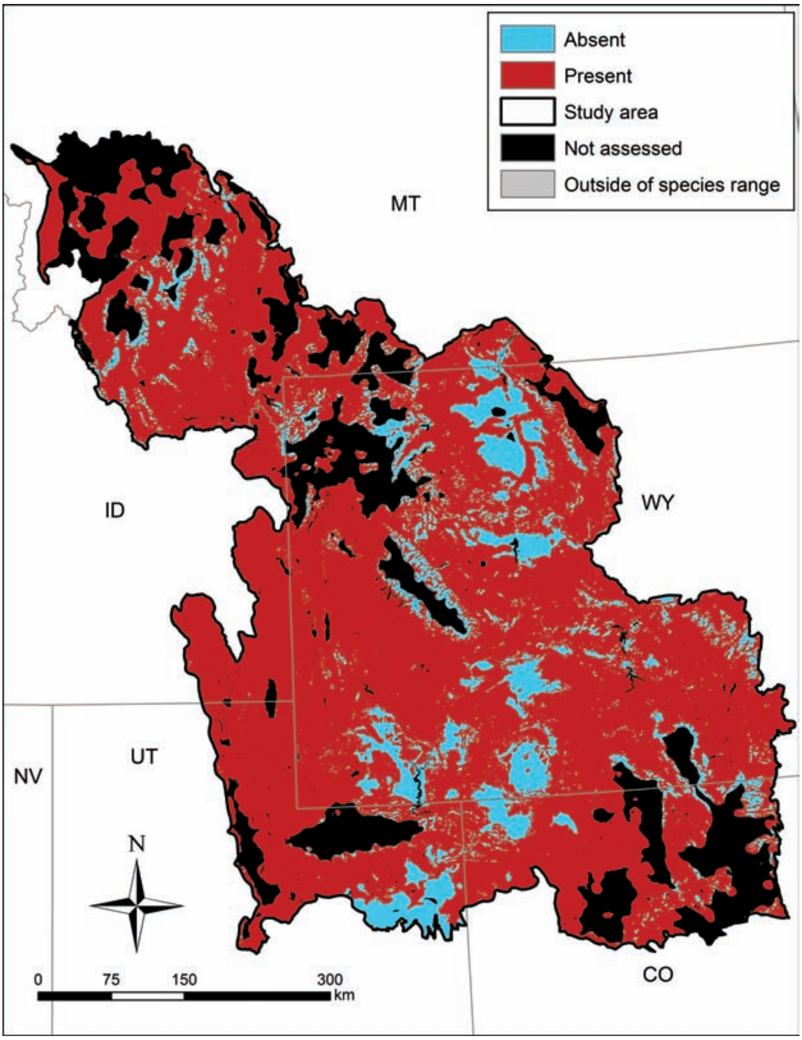

FIG 6.18. Distribution of vesper sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.12 birds/ha), the largest territory size required to support one vesper sparrow. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

greater abundance in more interior habitat locations (Bock et al. 1999, Jones and Bock 2002). Schaid et al. (1983) found that populations of vesper sparrows declined in proximity to mining operations, with effects lasting beyond reclamation activities, likely due to the direct loss of sagebrush. Although direct effects of human disturbance on the occurrence or abundance of vesper sparrows was limited in our study, loss of sagebrush and shrub steppe habitats could have lasting effects on populations of vesper sparrows within the Wyoming Basins.

CONCLUSIONS

Our models identified key habitat relationships for six songbird species of concern that depend on sagebrush habi-

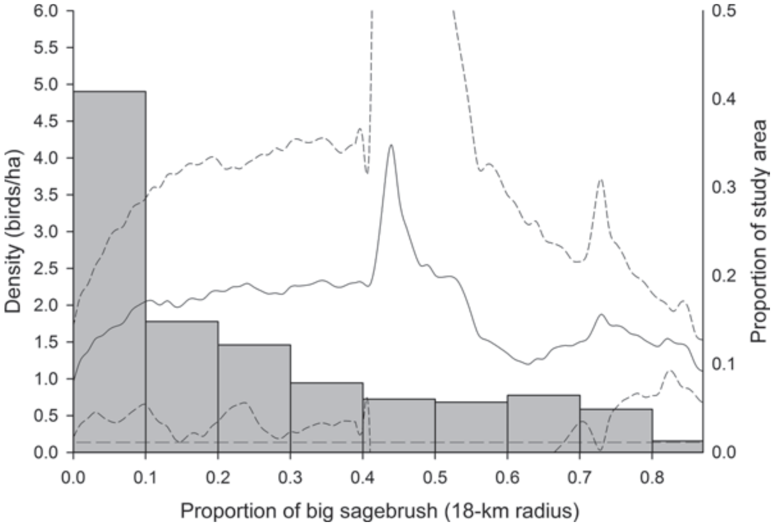

FIG. 6.19. Vesper sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of big sagebrush (*Artemisia tridentata* spp.) within an 18-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of big sagebrush within an 18-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.12 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of big sagebrush within 18 km.

tats. These relationships were biologically intuitive, and in most cases, represent the first such landscape-level assessment for each species. The majority of songbird species examined across the WBEA area had positive relationships between occurrence and/or abundance and the quantity, and to a lesser extent, the configuration, of sagebrush habitats across the range of spatial extents (0.27-km to 18-km radii). The limited response of songbirds to anthropogenic disturbances aligns with previous findings in these systems (Knick and Rotenberry 1995, Rotenberry and Knick 1995, Ingelfinger and Anderson 2004, Gilbert and Chalfoun 2011) and should not be interpreted as a lack of response to anthropogenic developments. Time since disturbance, type of development, and activities associated with developments can mask direct effects on songbirds (Ingelfinger and Anderson 2004, Gilbert and Chalfoun 2011), and we were unable to incorporate a time component into our analysis of human disturbance factors. We also likely had low statistical power to detect changes in bird abundance as a function of human disturbance because our surveys were designed to sample both disturbance and habitat gradients across the broad extent of the entire WBEA area. We suggest that repeated, long-term monitoring of a selected subset of sites currently experiencing or expected to experience increased human disturbance in the future (see Gilbert and Chalfoun 2011, Erickson 2011), as well as control sites for comparison where human disturbances have been and are likely to continue to be minimal, be conducted to fully assess long-term impacts of landscape change to key sagebrush species of conservation concern. Moreover, assessment of fitness (nest success, fledging success, adult survival) may be necessary to fully understand influences of human disturbances and habitat conditions (Misenhelter and Rotenberry 2000, Bock and Jones 2004, Chalfoun and Martin 2007), although density may prove suitable for more targeted studies (Erickson 2011). Although we found limited or weak direct effects of human disturbance on the occurrence or abundance of six songbird species, loss of shrub steppe habitats could have lasting effects on songbird populations, reducing their future persistence within the Wyoming Basins.

Although sample sizes were low for some species, and relationships between abundance/occurrence and some predictor variables were weak, our approach of incorporating detectability directly into count-based GLMs with an offset term (Buckland et al. 2009) improved our ability to model species-resource relationships. However, some limitations were evident with this modeling approach, such as our inability to incorporate detectability for the green-tailed towhee model, a species for which we could only model occurrence. For count-based models, application of a mean offset to sites with no detections (Buckland et al. 2009) may introduce biases into models where a limited sample of detections exists for a given species. Similarly, we had to apply a mean offset to all pixels in order to apply models spatially, which may mask some true relationships in predicted maps. However, our models generally predicted 'raw' (uncorrected for detectability) count data collected in 2005 and 2006 along BSS routes. Count data summarized across entire 40-km routes validated our models and confirmed their utility as management tools. Two models (green-tailed towhee and lark sparrow) did not correlate with BBS data very well. These two species had a low number of survey blocks with detections that possibly limited our ability to accurately model their distribution and abundance. Despite those limitations, reasonable predictor variables were selected and the spatial application of the final models (maps) captured expected distributions across the WBEA area.

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APPENDIX 6.1

Descriptive statistics for explanatory variables used to model Brewer's sparrow abundance. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 6.2

Descriptive statistics for explanatory variables used to model green-tailed towhee abundance. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 6.3

Descriptive statistics for explanatory variables used to model lark sparrow abundance. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 6.4

Descriptive statistics for explanatory variables used to model sage sparrow abundance. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 6.5

Descriptive statistics for explanatory variables used to model sage thrasher. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value.

This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 6.6

Descriptive statistics for explanatory variables used to model vesper sparrow abundance. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

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Chapter 7: Occurrence and Abundance of Ants, Reptiles, and Mammals

Steven E. Hanser, Matthias Leu, Cameron L. Aldridge, Scott E. Nielsen, Mary M. Rowland, and Steven T. Knick

Abstract. Sagebrush (*Artemisia* spp.)-associated wildlife are threatened by habitat loss and fragmentation and by impacts associated with anthropogenic disturbances, including energy development. Understanding how species of concern as well as other wildlife including insects, reptiles, and mammals respond to type and spatial scale of disturbance is critical to managing future land uses and identifying sites that are important for conservation. We developed statistical models to describe species occurrence or abundance, based on area searches in 7.29-ha survey blocks, across the Wyoming Basins Ecoregional Assessment (WBEA) area for six shrub steppe-associated species: harvester ant (*Pogonomyrmex* spp.), thatch ant (*Formica* spp.), short-horned lizard (*Phrynosoma hernandesi*), white-tailed jackrabbit (*Lepus townsendii*), cottontail (*Sylvilagus* spp.) and least chipmunk (*Tamius minimus*). We modeled patterns in occupancy or abundance relative to multi-scale measures of vegetation type and pattern, abiotic site characteristics, and anthropogenic disturbance factors. Sagebrush habitat was a strong predictor of occurrence for short-horned lizards and white-tailed jackrabbits, but weak for the other four species. Vegetation and abiotic characteristics were strong determinants of species occurrence, although the scale of response was not consistent among species. All species, with the exception of the short-horned lizard, responded to anthropogenic disturbance, although responses again varied as a function of scale and direction (negative and positive influences). Our results improve our understanding of how environmental and anthropogenic factors affect species distributions across the WBEA area and facilitate a multi-species approach to management of this sagebrush ecosystem.

Key words: abundance, anthropogenic disturbance, cottontail, habitat, harvester ant, least chipmunk, occurrence, pygmy rabbit, short-horned lizard, thatch ant, white-tailed jackrabbit.

Fragmentation and loss of sagebrush (*Artemisia* spp.) has been implicated in declines in abundance and distribution of sagebrush-obligate wildlife species (Paige and Ritter 1999, Knick et al. 2003, Dobkin and Sauder 2004, Schroeder et al. 2004). These declines have prompted petitions for the listing of several species, including the pygmy rabbit (*Brachylagus idahoensis,* [U.S. Department of the Interior 2003, 2005a, 2008]) and greater sage-grouse (*Centrocercus urophasianus*, [U.S. Department of the Interior 2005b, 2010]) as threatened or endangered species. Identifying causes for species declines has led to an examination of multi-scale environmental factors affecting the distribution and abundance of >350 other wildlife species that occur in sagebrush habitats during all or part of their life cycle (Wisdom et al. 2005).

Declines in abundance or loss of species can affect other species due to the influence individual species have on their environment or through cascading trophic interactions. Many species create, modify, or maintain their environment and through these actions influence ecosystem processes (Jones et al. 1994). For example, pygmy rabbit and least chipmunk (*Tamias minimus*) modify the soil profile through construction of burrows. Harvester ants (*Pogonomyrmex* spp.) alter soil characteristics through nest construction (Mandel and Sorenson 1982, Carlson and Whitford 1991) and also change plant distributions by preferentially harvesting and distributing seeds (Whitford 1978). Harvester ants may consume 10-26% of total seed bank, up to 100% of seed production of their preferred plant species (Crist and MacMahon 1992), and influence the distribution of exotic plant species in sagebrush habitats (Mull and MacMahon 1996).

Direct trophic interactions may also be influenced by changing habitat conditions (Clark et al. 1997, Grabowski 2004). Ants, including harvester ants, are the primary food source of the short-horned lizard (*Phrynosoma hernandesi*; Powell and Russell 1985), a species of conservation concern (U.S. Department of the Interior 2002). Changes in the environment that influence the distribution of ants can alter short-horned lizard distribution and abundance (Suarez and Case 2002). Similarly, interactions between raptors, including golden eagle (*Aquila chrysaetos*) and ferruginous hawk (*Buteo regalis*), and their mammalian prey such as white-tailed jackrabbit (*Lepus townsendii*) and cottontail (*Sylvilagus* spp.) (McGahan, 1967), can be disrupted by natural or human disturbances that alter their environment. Construction of power lines can increase the number of nesting raptors in an area (Steenhof et al. 1993) potentially leading to increased predation pressure on local mammal and bird populations. Human disturbance may also have indirect effects (Leu et al. 2008) on prey species that change abundance of food for predator populations.

We developed spatially explicit models of occurrence and abundance for multiple ant, reptile, and mammal species in the Wyoming Basins Ecoregional Assessment (WBEA). We used field surveys conducted throughout the Wyoming Basins (Ch. 4) to derive relationships between species occurrence and abundance and Geographic Information System (GIS)-derived habitat and disturbance variables measured across multiple extents. Our models provide a multi-species view of the sagebrush ecosystem that can improve our ability to adapt management actions to ecosystem changes. Additionally, these models are useful for assessing effects of proposed or future development across the WBEA area on more common species or those of less perceived conservation priority, but which still play important roles in ecological processes.

METHODS

Field Surveys

We conducted two rounds of field surveys within 7.29 ha survey blocks sampled in 2005 and 2006 (Ch. 4) using a plot-search technique to sample ants, lizards, snakes, pygmy rabbits, and small to medium-sized mammals. We randomly selected the order in which survey blocks were surveyed each day and the starting location within each survey block (NE, NW, SE, and SW corner of each survey block). For each survey, we noted start time and measured sampling effort (min). We sampled survey blocks by walking parallel transects spaced 30 m apart for a total length of 2.16 km (Fig. 4.2). The first round of surveys was conducted from 28 April through 21 June between 0800 and 1000 hr during which we focused on sampling ants, pygmy rabbits, and other medium-sized mammals. The second round, focused on reptiles and medium-sized mammals, was conducted from 6 July through 2 September on sunny days between 0800 hr (actual start time varied with air temperature) and 1800 hr.

Ants

We counted ant mounds on survey blocks while walking transects (McIver et al. 1997). We differentiated between mound types based on mound characteristics (Beever and Herrick 2006). Mounds built of sand or pebbles were designated as harvester ant mounds (*P. occidentalis* and *P. owyheei*) and those constructed of thatch were thatch ant mounds (*Formica haemorrhoidulis, F. obscuripes, F.obscuriventris* and *F. oreas*; Wheeler and Wheeler 1988). While walking transects, observers tallied mounds detected by type within 15 m of the transect line.

Reptiles

We used visual encounter surveys to sample lizards and snakes. Surveys were conducted during peak activity hours of lizard and snake species to maximize detectability (Diller and Johnson 1982; Guyer and Linder 1985). Observers tracked time of sampling effort. Transects were walked slowly, carefully checking the understory vegetation and sagebrush canopy for basking lizards, noting reptiles detected within 15 m (Germaine and Wakeling 2001). When possible, we used binoculars to identify species. We recorded the perpendicular distance from the transect to each observation.

Pygmy rabbits

Observers looked for burrow locations while walking transects and scanned the surrounding area for pygmy rabbits. Observers tracked time of sampling effort. Total number of rabbits seen and number of burrows detected were recorded within each of five burrow categories (modified from Ulmschneider 2004, Himes and Drohan 2007): (1) active with pellets (brown pellets near a burrow, at least one entrance open without cobwebs or debris indicating lack of use, usually shows a trail); (2) active without pellets (burrow entrance is not collapsed but no pellets found; also burrows in snow where no tracks or pellets are visible); (3) inactive with pellets (burrow entrances have cobwebs, grass seeds, or other debris in entrance, but with brown pellets; may show transitory use); (4) inactive without pellets (burrow seems right for pygmy rabbit; burrow entrances have cobwebs, grass seeds, or other debris in entrance but no pellets or recent activity present); and (5) undetermined (burrow characteristics suggested pygmy rabbit, but pellets were confusing or absent, it was not in association with other pygmy rabbit burrows [identified by pellets or sightings], or burrow status was unknown due to weather damage).

We only considered actual sightings and active burrows to indicate presence of pygmy rabbits (burrow categories one and two above) for analyses. We excluded all other detection categories because burrows could have been dug or maintained by other fossorial mammals and because contemporary habitat use could not be determined from inactive burrows. We also restricted the dataset to the known range of the species (Ch. 2).

Medium-sized mammals

We surveyed small to medium-sized mammal species on survey blocks concurrent with both sampling rounds. For each survey, individual mammals detected within 15 m of the transect line were recorded by species to assess occurrence and abundance on survey blocks. Survey blocks were considered occupied if an individual was detected in one or both sampling periods.

Abundance Categories and Detection Probability

We classified abundance levels according to three classes for species that had a minimum of 100 occurrences (Ch. 4). Survey blocks with zero detections were categorized as absent. Histograms of survey blocks with counts > 0 were used to categorize survey blocks into two abundance classes (low and high) based on patterns in the frequency distribution.

We used program DISTANCE (Thomas et al. 2006) to calculate detection probability for species with distance estimated for each detection and an adequate number of detections ($n > 60$). Detections were

TABLE 7.1. Summary of ant surveys during 2005 and 2006 on 326 survey blocks in the Wyoming Basins Ecoregional Assessment area. Shown are harvester and thatch ant occurrence (total detections) in relation to road juxtaposition, by year, and total detections for both years.

Survey block type	Harvester ant						Thatch ant					
	2005		2006		Total		2005		2006		Total	
On road	28	(775)	31	(962)	59	(1,737)	19	(69)	20	(162)	39	(231)
Near road	35	(797)	34	(675)	69	(1,472)	20	(148)	26	(180)	46	(328)
Far road	26	(1,105)	23	(397)	49	(1,502)	162	(32)	25	(112)	41	(144)
Total	89	(2,677)	88	(2,034)	177	(4,711)	55	(249)	71	(454)	126	(703)

entered in DISTANCE using distance intervals dependent upon the detection curve for the species. We considered the half-normal and hazard rate key functions using simple polynomial and cosine series expansions and selected models with the lowest AIC value. We did not fit other covariates to the detectability function.

Our data for medium-sized mammals did not meet assumptions necessary to calculate detection probability (Mackenzie et al. 2006), but we did have multiple surveys at each location. On survey blocks where we detected a species, we calculated the proportion of blocks with detections in one or both survey bouts as an informal assessment of detectability. Species that, when detected, are recorded during both survey bouts on a survey block are likely to have higher detectability.

Model Selection

Variables included in the model selection process for all species in this chapter included the standard candidate predictor set (Table 4.2). We did not consider mountain sagebrush (*A. tridentata* ssp. *vaseyana*) or four soil variables (pH, salinity, bulk density, and available water capacity), which were not directly associated with these species. We also excluded the other four soil variables (sand, silt, clay, and soil depth) from the candidate predictor set for non-fossorial species (white-tailed jackrabbit and cottontail). We calculated descriptive statistics for all predictor variables within presence/absence or abundance classes for each species. We also determined the number of survey blocks with predictor variable values > 0 within each abundance class and excluded from model development all variables/scales with <20 survey blocks in a class. We excluded correlated predictor variables from potential analyses, prior to model development (Ch. 4).

We used a hierarchical multi-stage modeling approach (Ch. 4) assessing all

TABLE 7.2. Reptile species detected in the Wyoming Basins Ecoregional Assessment area during area searches in 2005 and 2006 on 324 survey blocks. Shown are occurrences (detections) by year and totals for both years.

Species	Scientific name	2005		2006		Total	
Bull snake	*Pituophis catenifer sayi*	1	(1)	0	(0)	1	(1)
Garter snake	*Thamnophis* spp.	1	(1)	1	(1)	2	(2)
Great basin gopher snake	*Pituophus melanoleucus deserticola*	0	(0)	1	(1)	1	(1)
Sagebrush lizard	*Sceloporus graciosus*	15	(22)	12	(13)	27	(35)
Prairie-lined racerunner	*Cnemidophorus sexlineatus viridis*	1	(1)	0	(0)	1	(1)
Short-horned lizard	*Phrynosoma hernandesi*	30	(36)	33	(39)	63	(75)

model subsets using logistic or generalized ordered logistic regression (GOLOGIT2 within Stata 10.1, Stata Corporation, College Station, TX, USA; Williams 2006) modeling approaches. We first examined scatterplots and histograms of sagebrush, NDVI, and abiotic variables to look for non-linearities and interactions and, if detected, included them in analyses. We used Akaike's Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002). We first evaluated each sagebrush and NDVI variable and identified circular moving window radius (extent) and combinations that had the strongest relationship to species occurrence. We used these selected sagebrush and NDVI variables as a base model and tested the relationship between species occurrence and all spatial extents for each vegetation, abiotic, and disturbance variable to identify the best spatial extent for each variable using AIC_c values. We then allowed the best spatial extent for each variable to compete with all possible combinations of other variables within the same category to identify the AIC_c-selected top model within that category. To avoid overfitting in generalized ordered logistic and logistic regression models, we limited the number of variables in all competing models to 10% (one variable per 10 survey blocks in the lowest frequency class) of the sample size in the lowest frequency class (Hosmer and Lemeshow 2000). After identifying the AIC_c-selected top model within vegetation, abiotic, and disturbance categories, we allowed variables within these models to compete both within and across submodels to develop the best overall composite model, holding sagebrush and NDVI base model constant. In order to incorporate model uncertainty, we used a weighted average of coefficients from models with a cumulative AIC_c weight of just ≥ 0.9 (Burnham and Anderson 2002). Coefficients were set to zero when a model did not contain a particular vari-

TABLE 7.3. Summary of pygmy rabbit surveys in the Wyoming Basins Ecoregional Assessment area on 329 survey blocks in 2005 and 2006 in relation to road proximity. Shown are occurrence and (total count) for sightings, active burrows with or without feces, undetermined activity burrows, and inactive burrows with or without feces.

	2005				2006				
	On road	Near road	Far road	Total	On road	Near road	Far road	Total	Study total
Sightings	1 (1)	1 (1)	0 (0)	2 (2)	3 (5)	3 (4)	4 (4)	10 (13)	12 (15)
Active burrows with feces	2 (4)	4 (8)	1 (2)	7 (14)	3 (4)	3 (4)	3 (4)	9 (12)	16 (26)
Active burrows without feces	4 (4)	3 (4)	1 (3)	8 (11)	1 (1)	4 (4)	0 (0)	5 (5)	13 (16)
Undetermined	3 (15)	5 (9)	3 (4)	11 (28)	1 (1)	1 (1)	1 (6)	3 (8)	14 (36)
Inactive burrows with feces	4 (19)	3 (9)	2 (3)	9 (31)	7 (10)	3 (5)	4 (4)	14 (19)	23 (50)
Inactive burrows without feces	4 (10)	4 (14)	4 (12)	12 (36)	5 (10)	8 (14)	4 (7)	17 (31)	29 (67)

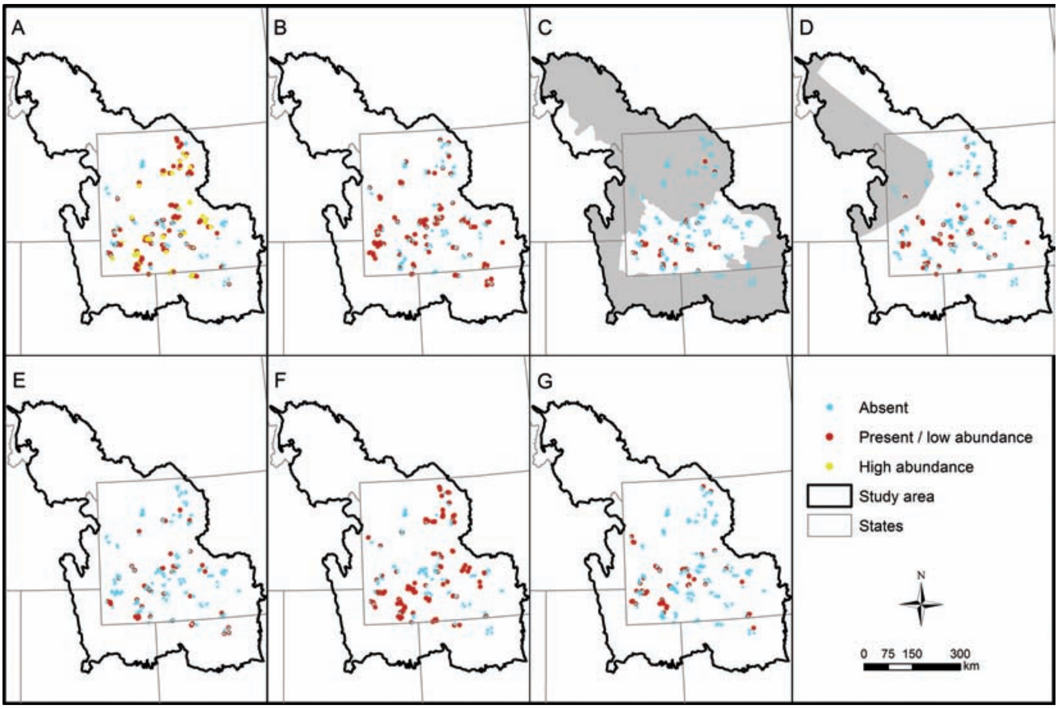

FIG. 7.1. Distribution of survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for (A) harvester ants, (B) thatch ants, (C) pygmy rabbits, (D) short-horned lizards, (E) white-tailed jackrabbits, (F) cottontails, and (G) least chipmunks. Ant mounds were an indicator of harvester ant abundance and survey blocks were designated as absent (blue, zero roost piles), low abundance (red, 1-ant mounds), or high abundance (yellow, >18 ant mounds). For all other species, survey blocks were designated as present (red, ≥1 detection) or absent (blue, no detection). The gray shaded areas are outside the current range of the species (Ch. 2; Patterson et al. 2003).

able. Accuracy of statistical models was evaluated with receiver operating characteristic (ROC) plots estimating area under the curve (AUC, Metz 1978). We determined an optimal cutoff threshold for predicting presence-absence of each species (i.e., habitat or non-habitat) using a sensitivity-specificity equality approach (Liu et al. 2005) and applied this threshold to assess predictive capacity for each model (Nielsen et al. 2004).

Spatial Application and Dose Response

We predicted species occurrence in a GIS at a 90-m resolution (pixel size) using the final model coefficients in ArcGIS raster calculator (ESRI 2006) and displayed final model predictions in 10% probability classes. Masks of non-sagebrush habitats (areas with <3% sagebrush habitat in a 5-km moving window) and those areas outside the known range of each species (pygmy rabbit: Ch. 2; all other species: Patterson et al. 2003) were used to identify areas where predictions were either not possible or where extrapolations occurred with high uncertainty. Probability of occurrence maps were subsequently converted to binary presence/absence maps based on sensitivity-specificity equality thresholds to maximize prediction success for each model. Where applicable, probability of occurrence output from generalized ordered logistic regression models were combined into a composite three-class abundance surface, predicting absent, low, and high abundance. The bin breakpoint separating absent from low/high abundance habitat was based on the sensitivity-specificity equality threshold to maximize prediction success for each model. Within low/high abundance habitat, the threshold was set at the point where predicted probability of high abundance habitat exceeded the probability of being low abundance habitat. Presence-absence maps allowed us to quantify proportion of WBEA area containing habitat likely to support populations of a species. For species with multiple abundance classes, we also assessed proportion of WBEA area likely to support low and high abundance populations of a given species.

Following development of species models, we plotted predicted probability of occurrence relative to changes in sagebrush metrics to assess critical levels of sagebrush required for a species to be present and to characterize response to losses or fragmentation of sagebrush habitat. We calculated these values using the Dose Response Calculator for ArcGIS (Hanser et al. 2011). We used the optimal cut-off threshold to identify the sagebrush threshold value above which the species was likely to occur.

Model Evaluation

We evaluated model fit for species for which we were able to obtain independent data by comparing observed proportion of locations in each probability bin against expected proportion of locations from the model using regression analysis (Johnson et al. 2006). A model with good fit should have a high R^2 value, a slope not different from 1.0, and an intercept not different from zero (Johnson et al. 2006).

RESULTS

Field Surveys

We sampled 329 survey blocks (165 in 2005 and 164 in 2006), of which 125 (65 in 2005, 60 in 2006) were on-road survey blocks, 103 (50 in 2005 and 53 in 2006) near-road survey blocks, and 101 (50 in 2005 and 51 in 2006) far-road survey blocks (Ch. 4). The number of survey blocks included in analyses varied depending on species surveyed.

Ants

We sampled 326 survey blocks for ant mounds. Harvester ants were detected at 54% and thatch ants at 38% of survey blocks (Table 7.1, Fig. 7.1). Occurrence of harvester ants did not differ between 2005 and 2006; thatch ants occurred more frequently in 2006. Harvester ants were more abundant with nearly seven times the number of mounds ($\overline{x}$= 2.01 mounds/ha; range: 0–41.7) detected than for thatch ants ($\overline{x}$ = 0.30; range: 0–12.1). In relation to stratified road distances, harvester ants were most numerous at on-road survey blocks whereas thatch ants were most numerous at near-road survey blocks.

Reptiles

We sampled 324 survey blocks for reptiles, including 156 in 2005 and 168 in 2006. No reptiles were detected on 74% of survey blocks. Where reptiles were detected, we observed 115 individual reptiles representing six species. The vast majority (95%) were lizards. Short-horned lizards were the most common species; we counted 64 individuals at 16% of the survey plots (Fig. 7.1, Table 7.2). We detected three snake species.

Pygmy rabbits

We surveyed 326 survey blocks for pygmy rabbits and their signs. We detected only 19 separate occurrences (Fig. 7.1c) within the known pygmy rabbit range, defined as a survey block with either a sighting or active burrows with feces. Small sample sizes precluded development of predictive models of pygmy rabbit distributions. Sightings were higher in 2006 (12 of 171) than in 2005 (2 of 155) (Table 7.3). One pygmy rabbit sighting in the Worland

TABLE 7.4. Summary of mammal surveys in the Wyoming Basins Ecoregional Assessment area during 2005 and 2006 on 329 survey blocks. Shown are occurrence (survey blocks detected), total detection in relation to road juxtaposition, and total detections for both years.

		2005			
			Total Detections		
Common name	Scientific name	Occurrence	On road	Near road	Far road
Golden-mantled ground squirrel	*Spermophilus lateralis*	0	0	0	0
Least chipmunk	*Tamias minimus*	46	50	25	40
Least weasel	*Mustela erminea*	1	0	1	0
Long-tailed weasel	*Mustela frenata*	1	0	2	0
Cottontail	*Sylvilagus* spp.	69	166	75	101
Red squirrel	*Tamiasciurus hudsonicus*	0	0	0	0
Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*	5	1	1	4
Uinta ground squirrel	*Spermophilus armatus*	0	0	0	0
White-tailed jackrabbit	*Lepus townsendii*	29	23	12	13
White-tailed prairie dog	*Cynomys leucurus*	17	30	26	27
Wyoming ground squirrel	*Spermophilus elegans*	17	11	19	9

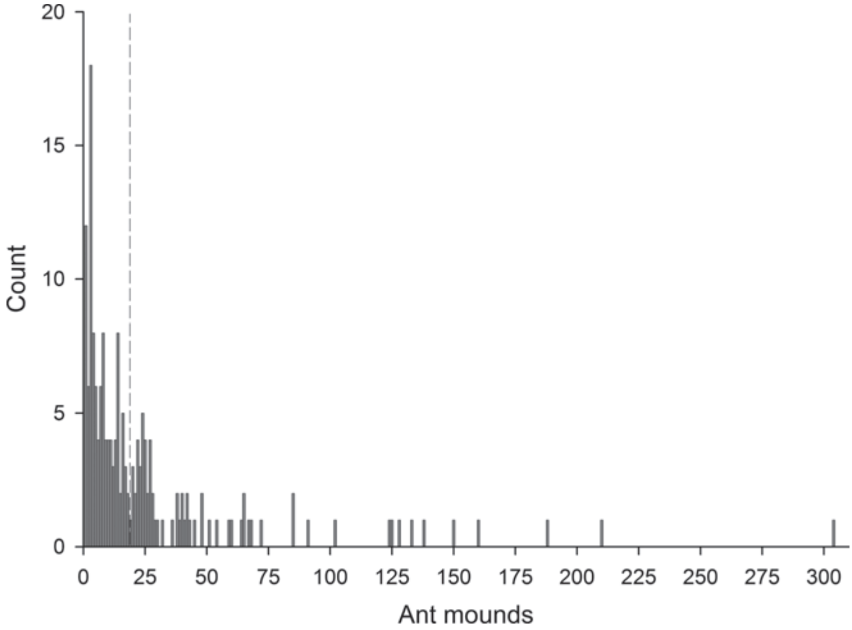

FIG. 7.2. Histogram of survey blocks (n = 177) in the Wyoming Basins Ecoregional Assessment area surveyed for harvester ant mounds where the number of mounds was > 0. Abundance at each survey block was represented by the total number of mounds. Survey blocks with zero mounds were classified as absent, survey blocks with 1-18 mounds as low abundance, and >18 mounds as high abundance. The dashed vertical line indicates the boundary between low and high abundance classes.

TABLE 7.4. Extended

2006				Total				
	Total Detections				Total Detections			
Occurrence	On road	Near road	Far road	Occurrence	On road	Near road	Far road	Total
3	1	1	3	3	1	1	3	5
10	5	4	8	56	55	29	48	132
0	0	0	0	1	0	1	0	1
0	0	0	0	1	0	2	0	2
76	150	116	105	145	316	191	206	713
3	0	12	1	3	0	12	1	13
29	22	19	18	34	23	20	22	65
13	5	6	47	13	5	6	47	58
42	25	18	18	71	48	30	31	109
2	1	0	1	19	31	26	28	85
16	8	8	17	33	19	27	26	72

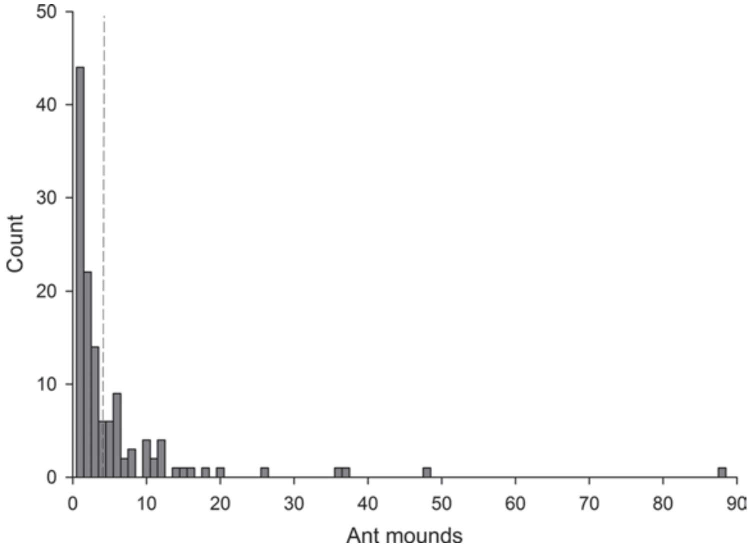

FIG. 7.3. Histogram of survey blocks (n = 126) in the Wyoming Basins Ecoregional Assessment area surveyed for thatch ant mounds (*Formica* spp.) where the number of mounds was >0. Abundance at each survey block is represented by the total number of mounds. The dashed vertical line indicates the selected boundary (4 mounds) between low and high abundance classes. There were 40 survey blocks above this selected boundary.

TABLE 7.5. Results of AIC_c-based model selection for harvester ant occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ALLSAGE_{5km} + NDVI_{1km}$	-303.19	4	614.50	0.00	0.18
2	$ALLSAGE_{5km} + NDVI_{1km} + NDVI_{1km}^2$	-302.31	5	614.82	0.32	0.15
3	$BIGSAGE_{18km} + NDVI_{1km} + NDVI_{1km}^2$	-301.04	7	616.43	1.94	0.07

[a] Variable definitions provided in Table 4.2

TABLE 7.6. Evaluation statistics from AIC_c-based univariate model selection for harvester ant occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran generalized ordered logistic models with all sagebrush (5-km radius) and NDVI (1-km radius) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which harvester ants respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{3km}$	-301.85	5	614.08	0.00	0.34
	$CFRST_{5km}$	-302.00	5	614.37	0.29	0.29
	$CFRST_{1km}$	-302.60	5	615.58	1.50	0.16
	$CFRST_{540}$	-302.90	5	616.18	2.10	0.12
	$CFRST_{270}$	-303.19	5	616.75	2.67	0.09
	$GRASS_{3km}$	-302.55	5	615.47	0.00	1.00
	MIX_{5km}	-301.93	5	614.23	0.00	0.77
	MIX_{18km}	-303.16	5	616.70	2.47	0.23
	RIP_{1km}	-302.48	5	615.34	0.00	0.26
	RIP_{5km}	-302.93	5	616.23	0.89	0.17
	RIP_{540}	-302.94	5	616.26	0.91	0.16
	RIP_{3km}	-302.96	5	616.29	0.95	0.16
	RIP_{18km}	-303.19	5	616.75	1.40	0.13
	RIP_{270}	-303.19	5	616.75	1.40	0.13
	$SALT_{1km}$	-302.81	5	616.00	0.00	0.20
	$SALT_{18km}$	-302.94	5	616.25	0.24	0.18
	$SALT_{540}$	-303.04	5	616.45	0.44	0.16
	$SALT_{5km}$	-303.05	5	616.47	0.47	0.16
	$SALT_{270}$	-303.08	5	616.53	0.53	0.16
	$SALT_{3km}$	-303.17	5	616.72	0.72	0.14
	$EDGE_{5km}$	-293.91	6	600.35	0.00	0.49
	$CONTAG_{1km}$	-297.39	6	607.30	6.94	0.02
	$EDGE_{1km}$	-298.24	6	609.01	8.66	0.01
	$CONTAG_{3km}$	-298.68	6	609.89	9.54	0.00

TABLE 7.6. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	EDGE$_{3km}$	-302.87	5	616.11	15.76	0.00
Abiotic	CTI	-302.44	5	615.26	0.00	0.71
	CTI^{2b}	-302.24	6	617.01	1.75	0.29
	ELEV^{2b}	-267.45	8	551.82	0.00	0.93
	ELEV	-272.25	6	557.03	5.22	0.07
	iH2Od$_{500}^{c}$	-298.44	6	609.41	0.00	0.42
	iH2Od$_{1km}^{c}$	-298.47	6	609.46	0.04	0.41
	iH2Od$_{250}^{c}$	-300.38	5	611.13	1.72	0.18
	pH2Od$_{1km}^{c}$	-302.64	5	615.66	0.00	0.43
	pH2Od$_{250}^{c}$	-303.06	5	616.49	0.83	0.29
	pH2Od$_{500}^{c}$	-303.07	5	616.51	0.85	0.28
	SOLAR	-302.61	5	615.59	0.00	0.59
	SOLAR^{2b}	-301.91	6	616.35	0.76	0.41
	Tmin^{2b}	-290.83	7	596.37	0.00	0.57
	Tmin	-292.20	6	596.92	0.55	0.43
	TRI$_{1km}$	-295.94	7	606.59	0.00	0.78
	TRI$_{540}$	-297.66	7	610.02	3.43	0.14
	TRI$_{18km}$	-298.53	7	611.76	5.17	0.06
	TRI$_{270}$	-301.95	5	614.27	7.68	0.02
	CLAY	-301.25	5	612.87	0.00	1.00
	SOIL$_{cm}$	-299.94	5	610.26	0.00	1.00
	SAND	-296.42	6	605.36	0.00	1.00
Disturbance	AG$_{1km}^{c}$	-301.41	5	613.19	0.00	0.55
	AG$_{500}^{c}$	-302.00	5	614.38	1.19	0.30
	AG$_{250}^{c}$	-302.73	5	615.83	2.63	0.15
	MjRD$_{1km}^{c}$	-301.38	5	613.13	0.00	0.43
	MjRD$_{500}^{c}$	-301.55	5	613.48	0.35	0.36
	MjRD$_{250}^{c}$	-302.05	5	614.47	1.34	0.22
	PIPE$_{1km}^{c}$	-297.75	5	605.88	0.00	0.79
	PIPE$_{500}^{c}$	-299.28	5	608.94	3.07	0.17
	PIPE$_{250}^{c}$	-300.63	5	611.63	5.75	0.04
	POWER$_{1km}^{c}$	-302.14	5	614.65	0.00	0.41
	POWER$_{500}^{c}$	-302.44	5	615.26	0.61	0.30
	POWER$_{250}^{c}$	-302.51	5	615.40	0.75	0.28
	RDdens$_{5km}$	-302.83	5	616.04	0.00	0.14
	RDdens$_{3km}$	-302.92	5	616.22	0.17	0.13

TABLE 7.6. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{270}$	-303.06	5	616.50	0.46	0.11
	$RDdens_{1km}$	-303.08	5	616.54	0.50	0.11
	$2RD_{1km}^{c}$	-303.10	5	616.57	0.53	0.11
	$RDdens_{18km}$	-303.11	5	616.59	0.55	0.11
	$2RD_{500}^{c}$	-303.14	5	616.65	0.60	0.10
	$RDdens_{540}$	-303.15	5	616.68	0.63	0.10
	$2RD_{250}^{c}$	-303.17	5	616.71	0.67	0.10
	$WELL_{250}^{c}$	-300.90	5	612.17	0.00	0.56
	$WELL_{500}^{c}$	-301.52	5	613.41	1.23	0.30
	$WELL_{1km}^{c}$	-302.27	5	614.92	2.75	0.14

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function (e$^{(\text{Euclidean distance from feature/-distance parameter})}$)

Basin was 100 km outside of the known range of the species, thus extending its known range.

Medium-sized mammals

We detected 1,255 individuals of 11 mammal species (Table 7.4) on 329 survey blocks. Occurrence was highest for cottontails (44%; for scientific names see Table 7.4), followed by white-tailed jackrabbits (22%), least chipmunks (17%), and thirteen-lined ground squirrels (10%) (Fig. 7.1). Ranking of occurrence by survey block did not follow ranking of total detections. Total detections were highest for cottontails, followed by least chipmunks, white-tailed jackrabbits, and white-tailed prairie dogs. Thirteen-lined and Wyoming ground squirrels occurred on more survey blocks and at higher total detections than Uinta ground squirrels. The least common species were long- and short-tailed weasels, and mammals (red squirrels and golden-mantled ground squirrels) that are not commonly found in shrubland ecosystems. Counts did not differ between years for the two lagomorph species. Counts for least chipmunks and white-tailed prairie dogs were higher in 2005 than in 2006; the reverse was true for the Uinta and thirteen-lined ground squirrels. Total counts were higher on on-road survey blocks for the two lagomorph species compared to the near-roads and far-road survey blocks. The reverse was true for the Uinta ground squirrel. For the thirteen-lined ground squirrels and white-tailed prairie dogs, abundance did not differ among road proximity strata.

Abundance Categories and Detection Probabilities

Survey blocks with no harvester ant mound detections were classified as absent, those with 1-18 harvester ant mounds per site as low abundance and >18 ant mounds per site as high abundance (Fig. 7.1 and 7.2). Thatch ant abundance appeared in three abundance categories based on ant mound density (Fig. 7.3) but only 40 survey blocks were classified as high abundance plots. Thus, we were limited to only modeling occurrence for the thatch ant model.

Only one species of reptile, short-horned lizard, had sufficient distance estimates and detections (n = 64) to assess detection probability using program DISTANCE. Detections were recorded in 1-m intervals, so we grouped detections into three distance bands (0-1.5, 1.5-2.5, and 2.5-3.5 m) with individuals between 0 and 1 m recorded as 1 m. The best model fit was the half-normal cosine with good model fit ($\chi^2_1 = 1.19$, $p < 0.28$) and an estimated probability of detection of 0.52. Only eight of 64 plots had >1 individual detected on a survey block (maximum of three detections), so we used a logistic regression for this species.

We did not have sufficient observations or data that met the assumptions for developing formal detection probability estimates for pygmy rabbits, medium-sized mammals and ants. Our informal analysis indicated that we had a high detection rate for cottontails, with 46% of occurrence survey blocks having detections in both rounds and single detection occurrence blocks occurring primarily during the first survey round. A high proportion of least chipmunk occurrences (0.82) were detected only in the first round of surveys; white-tailed jackrabbit detections were evenly spread between rounds one (0.39) and two (0.48), with only 13% of detections occurring in both.

Model Selection, Spatial Application, and Dose Response

Two variables from the pool of *a priori* variables for all species, mixed shrubland (0.27 km) and riparian (0.27 km), were excluded from model selection because they were present on <20 survey blocks. Slope, precipitation, mean annual maximum temperature, and soil silt content also were removed from consideration for all species owing to correlation with other variables.

Harvester ants

Four *a priori* variables were excluded because they contained values >0 on <20 survey blocks in the least frequent abundance category (high). These variables included proportion of coniferous forest (0.27, 0.54, and 1 km) and mixed shrubland (0.54 km). Coniferous forest (18 km), all sagebrush contagion (5 km), and all sage-

TABLE 7.7. Results of AIC_c-based submodel selection for harvester ant occurrence in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ALLSAGE_{5km} + NDVI_{1km} + GRASS_{3km} + SALT_{1km} + RIP_{1km} + EDGE_{5km}$	-287.45	9	593.47	0.00	0.20
	2	$ALLSAGE_{5km} + NDVI_{1km} + GRASS_{3km} + SALT_{1km} + RIP_{1km} + EDGE_{5km} + MIX_{5km}$	-285.37	11	593.59	0.12	0.19
	3	$ALLSAGE_{5km} + NDVI_{1km} + GRASS_{3km} + SALT_{1km} + RIP_{1km} + EDGE_{5km} + CFRST_{3km}$	-286.99	10	594.69	1.22	0.11
	4	$ALLSAGE_{5km} + NDVI_{1km} + GRASS_{3km} + SALT_{1km} + EDGE_{5km} + MIX_{5km}$	-287.30	10	595.30	1.83	0.08
Abiotic	1	$ALLSAGE_{5km} + NDVI_{1km} + Tmin + Tmin^2 + CLAY + SAND + SOIL_{cm}$	-276.83	10	574.37	0.00	0.31
	2	$ALLSAGE_{5km} + NDVI_{1km} + Tmin + Tmin^2 + CLAY + SAND + iH2Od_{500}$	-276.85	10	574.39	0.03	0.31
Disturbance	1	$ALLSAGE_{5km} + NDVI_{1km} + PIPE_{1km} + WELL_{250} + AG_{1km}$	-292.76	7	599.87	0.00	0.19
	2	$ALLSAGE_{5km} + NDVI_{1km} + PIPE_{1km} + WELL_{250}$	-293.95	6	600.16	0.29	0.16
	3	$ALLSAGE_{5km} + NDVI_{1km} + PIPE_{1km} + WELL_{250} + AG_{1km} + RDdens_{5km}$	-292.61	8	601.68	1.82	0.08

[a] Variable definitions provided in Table 4.2

brush mean patch size (1, 3, and 5 km) were removed from consideration due to correlation with other variables. Several variables caused instability (i.e., non-convergence of likelihood estimates) in the generalized ordered logistic regression model and were therefore removed from submodel development: grassland (0.27, 0.54, 1, 5, and 18 km), mixed shrubland (1, and 3 km) land cover, elevation, and topographic ruggedness index (survey block, 3 and 5 km). Non-linear relationships were not evident between harvester ant occurrence and the sagebrush variables, although non-linearities with NDVI at all extents were apparent. Also, interactions between sagebrush and NDVI variables were not supported.

The AIC_c-selected top sagebrush/NDVI model consisted of all sagebrush within 5 km ($ALLSAGE_{5km}$) and NDVI within 1 km ($NDVI_{1km}$), Table 7.5). Within a 5-km radius, there was on average 2.1% more sagebrush at high abundance sites (69.5%, SE = 1.8) and 4.5% more at low abundance sites (71.9%, SE = 1.4) compared to unused sites (67.4%, SE = 2.1) (Appendix 7.1).

After assessing individual multi-scale covariates (Table 7.6) and developing submodels, the top vegetation submodel for harvester ants consisted of grassland within 3 km ($GRASSLAND_{3km}$), riparian within 1 km (RIP_{1km}), salt desert shrubland within 1 km ($SALT_{1km}$), and all sagebrush edge density within 5 km ($EDGE_{5km}$) in addition to the sagebrush/NDVI base model (Table 7.7). Soil depth ($SOIL_{cm}$), percent soil clay content (CLAY), percent soil sand content (SAND), and mean minimum temperature in quadratic form ($Tmin + Tmin^2$) were selected as important abiotic predictors of harvester ant occurrence (Table 7.7). Three disturbance factors, 1-km distance decay from agriculture (AG_{1km}), 1-km distance decay from pipelines ($PIPE_{1km}$), and 0.25-km distance decay from oil/gas wells ($WELL_{250}$) were included in the top disturbance submodel (Table 7.7).

The AIC_c-selected top model for harvester ants was a combination of vegetation, abiotic, and disturbance factors. Harvester ants were positively associated with increased minimum temperature, higher percent soil sand content, and proximity to pipelines. In contrast, harvester ants were negatively associated with highly productive habitats, large expanses of sagebrush, and increased percent clay and sand soil content (Table 7.8). However, weight of evidence for the top model was low (w_i = 0.18) indicating there were other suitable candidate models. Variables in the other candidate models with cumulative Akaike weights of just ≥ 0.9 indicate that harvester ant locations also were positively associated with increased sagebrush edge density (all sagebrush types within 5 km), increased soil depth, and proximity to agricultural land, but negatively associated with salt desert shrubland and grassland land cover and proximity to oil/gas development (Table 7.8). The final composite model-averaged linear predictors of occurrence for the low (Eq. 7.1) and high (Eq. 7.2) abundance categories are listed below.

$$Prob_{low} = 1 / (1 + (exp(-(4.07 - 1.88 * ALLSAGE_{5km} - 7.99 * NDVI_{1km} + 0.68 * Tmin + 0.06 * Tmin^2 - 0.02 * CLAY + 0.03 * SAND + 1.21 * PIPE_{1km} - 0.90 * WELL_{250} + 0.005 * EDGE_{5km} + 0.001 * SOIL_{cm} - 0.04 * RIP_{1km} - 0.83 * GRASS_{3km} + 0.10 * AG_{1km} - 0.02 * SALT_{1km})))) \tag{7.1}$$

$$Prob_{high} = 1 / (1 + (exp(-(4.07 - 1.88 * ALLSAGE_{5km} - 7.99 * NDVI_{1km} + 0.48* Tmin + 0.06 * Tmin^2 + -0.02 * CLAY + 0.03 * SAND + 1.21 * PIPE_{1km} - 0.90 * WELL_{250} + 0.001 * EDGE_{5km} + 0.001 * SOIL_{cm} - 0.04 * RIP_{1km} - 0.83 * GRASS_{3km} + 0.10 * AG_{1km} - 0.02 * SALT_{1km})))) \tag{7.2}$$

The model averaged predictor of harvester ant occurrence had excellent model accuracy (ROC AUC = 0.84) when predicting harvester ant presence and was a slight improvement over the AIC$_c$-selected top model (ROC AUC = 0.83). Our model of harvester ant occurrence had an optimal sensitivity-specificity equality threshold of 0.53 when determining presence/absence, which resulted in correct classification of 79.7% of survey blocks.

Harvester ant occurrence was predicted to be highest in the central part of the WBEA (Fig. 7.4). Based on our optimal cutoff point and a binary presence/absence classification, 99,555 km^2 (34.4%) of suitable harvester ant habitat was predicted within the Wyoming Basins (Fig. 7.5). Roughly one quarter (26.0%) of predicted presence was considered high-density habitat (25,869 km^2, Fig. 7.5). Harvester ants were more likely to occur in areas that contained between 63 and 75% all sagebrush landcover within a 5-km radius (Fig. 7.6).

Thatch ants

Three predictor variables, salt desert shrubland (0.27, 0.54, and 1 km), were excluded because they were present on <20 survey blocks in the least frequent category (absent). Variables excluded owing to correlations with other variables included coniferous forest (3, 5, and 18 km), salt desert shrubland (3 and 5 km), all sagebrush mean patch size (1, 3, and 5 km), and distance decay from perennial water (0.25-, 0.50,- and 1-km distance parameter). We visually inspected sagebrush/NDVI interactions and quadratic functions for the NDVI variables but non-linearities were not apparent for sagebrush.

Based on logistic regression analyses, the AIC$_c$-selected top sagebrush/NDVI model included all sagebrush within 3 km (ALLSAGE$_{3km}$) and quadratic form of NDVI with 5 km (NDVI$_{5km}$ + NDVI$_{5km}{}^2$) (Table 7.9). Within 3 km, there was 5.9% more all sagebrush at presence sites (74.5 %, SE = 1.7) than at absence sites (68.6 %, SE = 1.6; Appendix 7.2).

After assessing individual multi-scale covariates (Table 7.10) and developing submodels, the top vegetation submodel for thatch ants consisted of grassland within 0.54-km (GRASS$_{540}$), mixed shrubland within 18-km (MIX$_{18km}$), riparian within 5-km (RIP$_{5km}$), all sagebrush contagion within 5km (CONTAG$_{5km}$), and salt desert shrubland within 18-km (SALT$_{18km}$) in addition to the sagebrush/NDVI base model (Table 7.11). Compound Topographic Index (CTI) together with the quadratic form of elevation (ELEV + ELEV^2) and solar radiation (SOLAR + SOLAR^2) were important abiotic predictors (Table 7.11). Five disturbance factors, 1-km distance decay from agriculture (AG$_{1km}$), 1-km distance decay from interstate/major highways (MjRD$_{1km}$), 1-km distance decay from power lines (POWER$_{1km}$), 1-km distance decay from oil/gas wells (WELL$_{1km}$), and road density within 18-km (RDdens$_{18km}$) were included in the top disturbance submodel (Table 7.11).

The AIC$_c$-selected top model for thatch ants was a combination of vegetation and abiotic factors. Thatch ants were positively associated with large expanses of all sagebrush land cover, areas with moderate to high productivity, increased proportion of riparian land cover, increased topographic moisture, and moderate to high elevation and solar radiation, but negatively associated with increased proportion of grassland and mixed shrubland (Table 7.12). The weight of evidence for the AIC$_c$-selected top model was low (w_i = 0.02) with 217 other models included within the cumulative Akaike weights of just ≥ 0.9. The other candidate models showed that, in addition to factors in the AIC$_c$-selected top model, thatch ant locations were positively associated with proximity to power lines and agriculture and negatively associated with all sagebrush contagion, salt desert shrubland

TABLE 7.8. Results of AIC$_c$-based model selection for the combined harvester ant model[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and cumulative Akaike weight [Σw_i]). Models are shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Constant	ALLSAGE$_{5km}$	NDVI$_{1km}$	Tmin	Tmin^2	SAND	CLAY	PIPE$_{1km}$
1	present: 4.89 (0.91) high: 2.24 (0.86)	-1.98 (0.75)	-8.07 (1.76)	present: 0.82 (0.22) high: 0.57 (0.21)	0.07 (0.03)	0.04 (0.01)	-0.04 (0.02)	1.33 (0.42)
2	present: 5.74 (1.03) high: 3.05 (0.98)	-3.06 (0.85)	-9.51 (1.76)	present: 0.89 (0.22) high: 0.63 (0.21)	0.08 (0.03)	0.03 (0.01)		1.55 (0.42)
3	present: 4.85 (0.91) high: 2.20 (0.87)	-2.10 (0.75)	-9.38 (1.75)	present: 0.89 (0.22) high: 0.64 (0.21)	0.09 (0.03)	0.03 (0.01)		1.69 (0.43)
4	present: 4.93 (0.92) high: 2.28 (0.88)	-2.17 (0.76)	-10.18 (1.87)	present: 0.82 (0.22) high: 0.56 (0.21)	0.07 (0.03)	0.03 (0.01)		1.42 (0.42)
5	present: 3.06 (1.39) high: 0.40 (1.38)	-1.63 (0.85)	-8.15 (1.80)	present: 0.79 (0.22) high: 0.53 (0.21)	0.07 (0.03)	0.03 (0.01)		1.43 (0.42)
6	present: 4.65 (0.92) high: 2.04 (0.88)	-1.48 (0.76)	-8.63 (1.79)	present: 0.84 (0.21) high: 0.59 (0.21)	0.08 (0.03)		-0.07 (0.02)	1.15 (0.42)
7	present: 4.80 (0.91) high: 2.15 (0.87)	-2.28 (0.74)	-9.13 (1.74)	present: 0.84 (0.22) high: 0.58 (0.21)	0.07 (0.03)	0.03 (0.01)		1.49 (0.42)
8	present: 1.04 (1.29) high: 0.50 (1.35)	-0.99 (0.86)	-8.28 (1.76)			0.03 (0.01)	-0.05 (0.02)	1.30 (0.43)
9	present: 5.17 (0.90) high: 2.59 (0.85)	-2.05 (0.76)	-9.21 (1.77)	present: 0.79 (0.22) high: 0.56 (0.21)	0.07 (0.03)	0.02 (0.01)	-0.08 (0.02)	
10	present: 4.66 (0.92) high: 2.02 (0.88)	-2.30 (0.75)	-9.42 (1.78)	present: 0.86 (0.22) high: 0.61 (0.21)	0.08 (0.03)	0.03 (0.01)		1.49 (0.42)
11	present: 4.74 (0.91) high: 2.09 (0.87)	-2.20 (0.75)	-8.84 (1.77)	present: 0.84 (0.22) high: 0.58 (0.21)	0.07 (0.03)	0.03 (0.01)		1.48 (0.42)
12	present: 5.29 (1.13) high: 2.64 (1.10)	-2.60 (0.86)	-9.79 (1.97)	present: 0.83 (0.22) high: 0.57 (0.21)	0.07 (0.03)	0.03 (0.01)		1.46 (0.42)
13	present: 1.57 (1.36) high: 1.14 (1.41)	-2.04 (0.92)	-9.64 (1.77)			0.03 (0.01)		1.50 (0.43)
14	present: 5.70 (0.90) high: 3.10 (0.84)	-1.94 (0.77)	-10.04 (1.84)	present: 0.70 (0.22) high: 0.46 (0.21)	0.05 (0.03)	0.03 (0.01)	-0.06 (0.02)	
15	present: 3.21 (1.35) high: 0.62 (1.34)	-1.26 (0.86)	-7.39 (1.80)	present: 0.66 (0.22) high: 0.42 (0.21)	0.05 (0.03)	0.04 (0.01)	-0.06 (0.02)	
16	present: 1.35 (1.32) high: 0.84 (1.38)	-1.75 (0.91)	-8.28 (1.76)			0.03 (0.01)	-0.05 (0.02)	1.12 (0.42)
17	present: 0.98 (1.33) high: 0.44 (1.39)	-0.59 (0.90)	-8.69 (1.77)				-0.07 (0.02)	1.11 (0.43)
18	present: 2.80 (1.40) high: 0.23 (1.38)	-0.64 (0.90)	-8.01 (1.81)	present: 0.71 (0.21) high: 0.48 (0.21)	0.07 (0.03)		-0.09 (0.02)	

TABLE 7.8. Extended

$GRASS_{3km}$	$WELL_{250}$	AG_{1km}	$EDGE_{5km}$	$SOIL_{CM}$	RIP_{1km}	$SALT_{1km}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
							-274.69	10	570.07	0	0.184
-4.56 (2.26)							-275.02	10	570.73	0.66	0.316
	-4.29 (2.27)						-275.10	10	570.91	0.84	0.437
		1.22 (0.73)					-275.89	10	572.48	2.41	0.492
			0.02 (0.01)				-275.96	10	572.62	2.55	0.543
				0.02 (0.005)			-276.12	10	572.94	2.87	0.587
							-277.3	9	573.17	3.1	0.626
	-4.81 (2.10)		present: 0.04 (0.01) high: 0.01 (0.01)				-276.43	10	573.55	3.48	0.658
				0.01 (0.01)			-276.83	10	574.37	4.3	0.68
				0.004 (0.005)			-276.9	10	574.51	4.43	0.7
					-1.85 (2.50)		-277.02	10	574.74	4.67	0.718
						-1.04 (1.41)	-277.03	10	574.76	4.69	0.735
-4.87 (2.32)	-4.84 (2.13)		present: 0.05 (0.01) high: 0.01 (0.01)				-277.13	10	574.96	4.89	0.751
		1.64 (0.72)					-277.17	10	575.03	4.96	0.766
			0.02 (0.01)				-277.22	10	575.14	5.07	0.781
-4.79 (2.32)			present: 0.05 (0.01) high: 0.02 (0.01)				-277.29	10	575.27	5.2	0.795
	-4.64 (2.10)		present: 0.04 (0.01) high: 0.01 (0.01)	0.02 (0.005)			-277.33	10	575.36	5.29	0.808
			0.02 (0.01)	0.02 (0.005)			-277.37	10	575.44	5.37	0.82

TABLE 7.8. Continued

Rank	Constant	ALLSAGE$_{5km}$	NDVI$_{1km}$	Tmin	Tmin^2	SAND	CLAY	PIPE$_{1km}$
19	present: 0.48 (1.33) high: -0.13 (1.39)	-1.03 (0.88)	-8.33 (1.76)			0.02 (0.01)	-0.07 (0.02)	0.98 (0.42)
20	present: 6.40 (1.01) high: 3.81 (0.95)	-2.82 (0.84)	-9.28 (1.77)	present: 0.77 (0.22) high: 0.53 (0.21)	0.06 (0.03)	0.04 (0.01)	-0.05 (0.02)	
21	present: 5.38 (0.92) high: 2.80 (0.86)	-1.45 (0.78)	-10.44 (1.88)	present: 0.75 (0.21) high: 0.51 (0.20)	0.06 (0.03)		-0.08 (0.02)	
22	present: 0.84 (1.32) high: 0.22 (1.38)	-0.88 (0.89)	-8.94 (1.75)			0.02 (0.01)	-0.08 (0.02)	
23	present: 1.01 (1.31) high: 0.46 (1.37)	-0.98 (0.89)	-9.21 (1.87)			0.03 (0.01)	-0.05 (0.02)	1.03 (0.42)
24	present: 1.11 (1.32) high: 0.65 (1.37)	-1.40 (0.85)	-9.48 (1.76)			0.03 (0.01)		1.47 (0.43)
25	present: 2.79 (1.51) high: 2.34 (1.55)	-3.22 (1.06)	-11.24 (2.01)			0.03 (0.01)		1.23 (0.42)
26	present: 1.84 (1.31) high: 1.34 (1.37)	-1.65 (0.92)	-8.98 (1.75)			0.03 (0.01)	-0.06 (0.02)	
27	present: 1.12 (1.34) high: 0.66 (1.39)	-1.22 (0.89)	-10.45 (1.90)			0.03 (0.01)		1.41 (0.43)
28	present: 4.84 (0.93) high: 2.25 (0.88)	-1.73 (0.74)	-9.98 (1.79)	present: 0.90 (0.22) high: 0.65 (0.21)	0.10 (0.03)			1.61 (0.43)
29	present: 5.31 (0.91) high: 2.77 (0.85)	-1.54 (0.76)	-9.64 (1.79)	present: 0.81 (0.21) high: 0.58 (0.21)	0.08 (0.03)		-0.08 (0.02)	
30	present: 0.96 (1.29) high: 0.42 (1.34)	-1.17 (0.85)	-8.18 (1.75)			0.03 (0.01)	-0.05 (0.02)	1.10 (0.42)
31	present: 5.54 (0.88) high: 2.98 (0.83)	-2.13 (0.75)	-8.85 (1.74)	present: 0.72 (0.21) high: 0.49 (0.20)	0.05 (0.03)	0.04 (0.01)	-0.05 (0.02)	
32	present: 0.81 (1.33) high: 0.38 (1.38)	-1.17 (0.87)	-8.83 (1.80)			0.03 (0.01)		1.43 (0.43)
33	present: 5.64 (0.89) high: 3.08 (0.83)	-2.02 (0.75)	-9.08 (1.75)	present: 0.75 (0.22) high: 0.52 (0.21)	0.06 (0.03)	0.03 (0.01)	-0.06 (0.02)	
34	present: 5.19 (0.90) high: 2.65 (0.85)	-1.65 (0.76)	-9.37 (1.78)	present: 0.77 (0.21) high: 0.54 (0.20)	0.07 (0.03)		-0.08 (0.02)	
35	present: 0.77 (1.35) high: 0.15 (1.40)	-0.79 (0.92)	-9.80 (1.86)			0.02 (0.01)	-0.08 (0.02)	
36	present: 1.12 (1.36) high: 0.54 (1.42)	-1.48 (0.94)	-8.88 (1.75)			0.02 (0.01)	-0.08 (0.02)	

[a] Variable definitions provided in Table 4.2

TABLE 7.8. Extended

$GRASS_{3km}$	$WELL_{250}$	AG_{1km}	$EDGE_{5km}$	$SOIL_{CM}$	RIP_{1km}	$SALT_{1km}$	LL	K	AIC_c	ΔAIC_c	Σw_i
			present: 0.04 (0.01) high: 0.02 (0.01)	0.01 (0.01)			-277.44	10	575.58	5.51	0.832
-4.13 (2.27)							-277.89	10	576.48	6.41	0.839
		1.47 (0.74)		0.02 (0.005)			-277.92	10	576.55	6.47	0.847
	-3.56 (1.98)		present: 0.05 (0.01) high: 0.02 (0.01)	0.01 (0.01)			-278.23	10	577.17	7.1	0.852
		1.17 (0.71)	present: 0.04 (0.01) high: 0.01 (0.01)				-278.34	10	577.39	7.32	0.857
	-4.65 (2.12)		present: 0.04 (0.01) high: 0.01 (0.01)				-278.51	10	577.72	7.65	0.861
-6.47 (2.62)			present: 0.05 (0.01) high: 0.02 (0.01)			-3.06 (1.57)	-278.52	10	577.75	7.67	0.865
-5.08 (2.43)	-3.93 (1.98)		present: 0.05 (0.01) high: 0.02 (0.01)				-278.53	10	577.75	7.68	0.869
	-4.65 (2.13)	1.07 (0.72)	present: 0.04 (0.01) high: 0.01 (0.01)				-279.64	9	577.84	7.77	0.872
	-4.52 (2.24)			0.01 (0.004)			-278.58	10	577.87	7.79	0.876
	-3.15 (2.14)			0.02 (0.005)			-278.59	10	577.88	7.81	0.88
			present: 0.04 (0.01) high: 0.01 (0.01)				-278.62	10	577.95	7.88	0.883
							-279.72	9	578.01	7.94	0.887
	-4.67 (2.14)		present: 0.04 (0.01) high: 0.01 (0.01)		-3.51 (2.51)		-279.75	9	578.07	8	0.89
	-2.86 (2.15)						-278.73	10	578.15	8.08	0.893
				0.02 (0.005)			-278.78	10	578.26	8.19	0.896
		1.18 (0.72)	present: 0.05 (0.01) high: 0.02 (0.01)	0.01 (0.01)			-278.8	10	578.3	8.23	0.899
-3.73 (2.41)			present: 0.05 (0.01) high: 0.02 (0.01)	0.01 (0.01)			-279.87	9	578.3	8.23	0.902

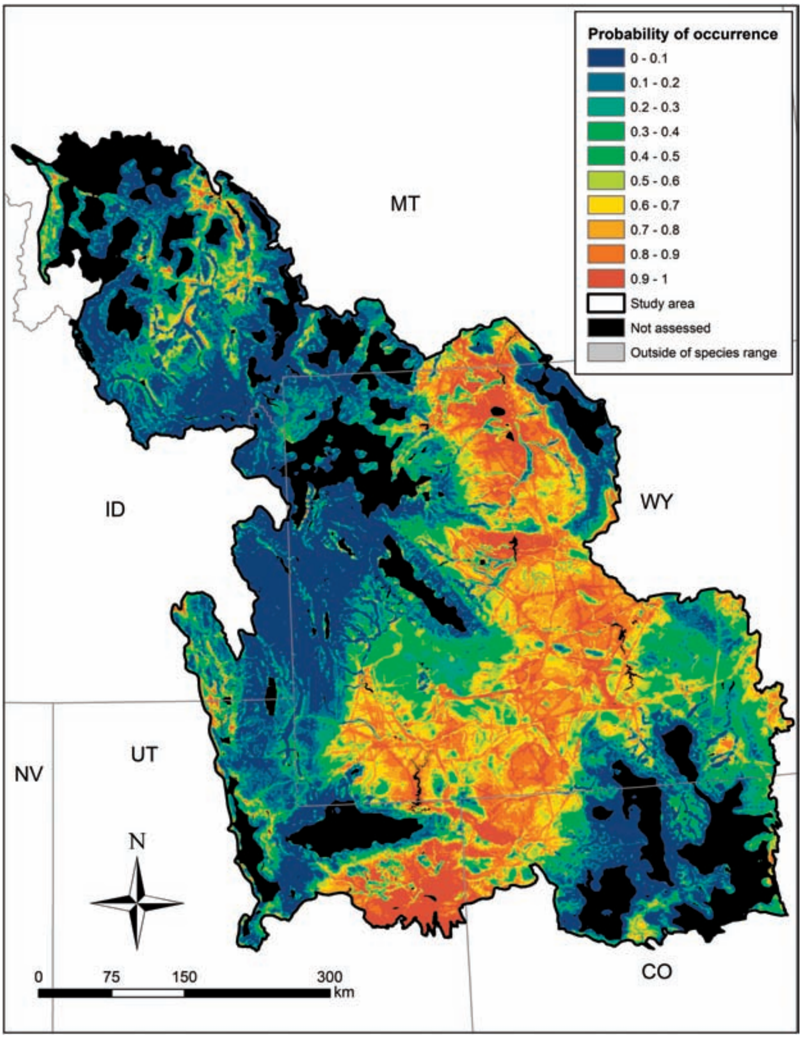

FIG. 7.4. Harvester ant probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Harvester ants are likely to occur in areas with probability > 0.53.

land cover, proximity to oil/gas wells and interstates/major highways (Table 7.12). The final composite probability of occurrence model is below.

(7.3)

$$\mathrm{Prob} = 1 / (1 + (\exp(-(-19.30 + 1.39 * \mathrm{ALLSAGE}_{3km} + 15.22 * \mathrm{NDVI}_{5km} - 9.18 * \mathrm{NDVI}_{5km}^{2} - 4.61 * \mathrm{GRASS}_{540} - 40.84 * \mathrm{MIX}_{18km} + 5.65 * \mathrm{RIP}_{5km} + 0.09 * \mathrm{CTI} + 0.006 * \mathrm{ELEV} - 0.000001 * \mathrm{ELEV}^{2} + 0.11 * \mathrm{SOLAR} - 0.0005 * \mathrm{SOLAR}^{2} + 0.26 * \mathrm{POWER}_{1km} - 0.005 * \mathrm{CONTAG}_{5km} - 2.74 * \mathrm{SALT}_{18km} + 0.20 * \mathrm{RDdens}_{18km} - 0.62 * \mathrm{WELL}_{1km} - 0.13 * \mathrm{MjRD}_{1km} + 0.009 * \mathrm{AG}_{1km}))))$$

The composite model of thatch ant occurrence had excellent model accuracy (ROC AUC = 0.81), which was similar to the $\mathrm{AIC_c}$-selected top model only (ROC AUC = 0.81). The optimal cutoff probability for predicting thatch ant occurrence based on

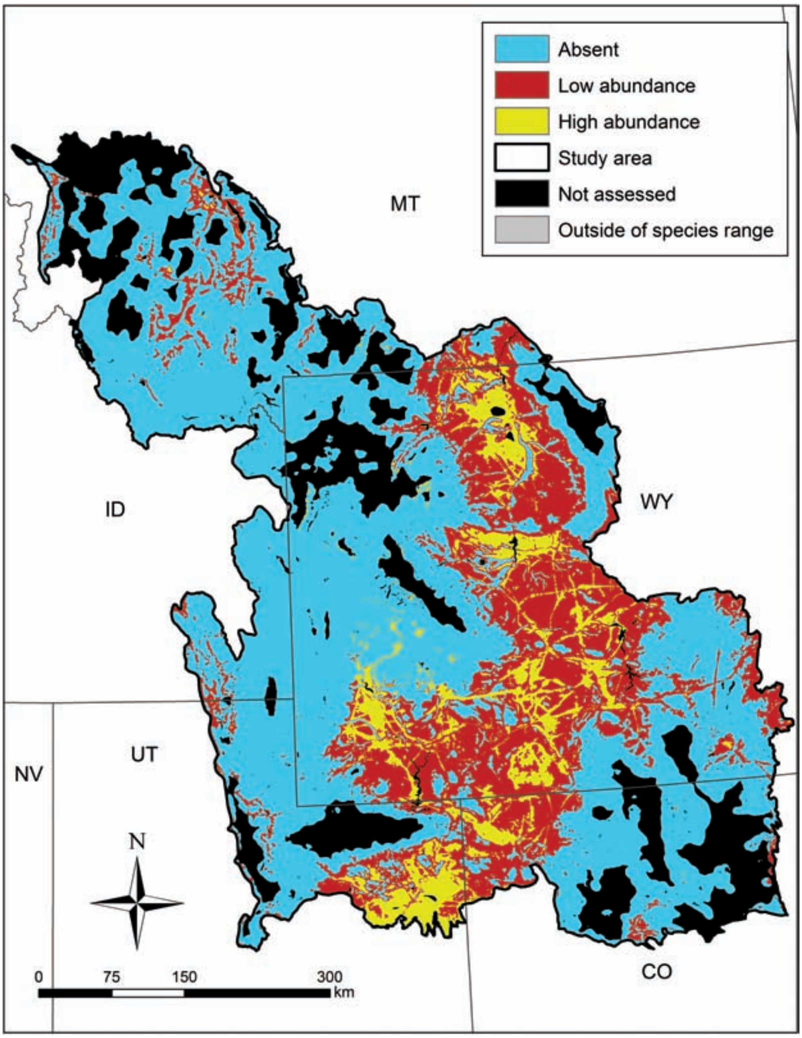

FIG. 7.5. Distribution of harvester ants estimated from ant mound abundance in the Wyoming Basins Ecoregional Assessment area based on optimum probability cutoff threshold of 0.53. Low abundance areas have an expected harvester ant mound abundance between >0 and 2.47 mounds/ha and >2.47 mounds/ha for the high class. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

the sensitivity-specificity equality threshold was 0.38 resulting in an overall percent correctly classified accuracy of 70.5%.

Thatch ant occurrence was predicted to be highest in higher elevation shrubland areas of the south east and western portions of the WBEA area (Fig. 7.7). Based on our optimal cutoff point and a binary presence/absence classification, 58.2% (201,031 km^2) of the Wyoming Basins was predicted as thatch ant habitat (Fig. 7.8). Thatch ants were likely to occur across the range of ALLSAGE$_{3km}$ values (Fig. 7.9).

Short-horned lizards

Four predictor variables were excluded because they contained values > 0 on <20 survey blocks in the least frequent abundance category (present). These variables included proportion of coniferous forest

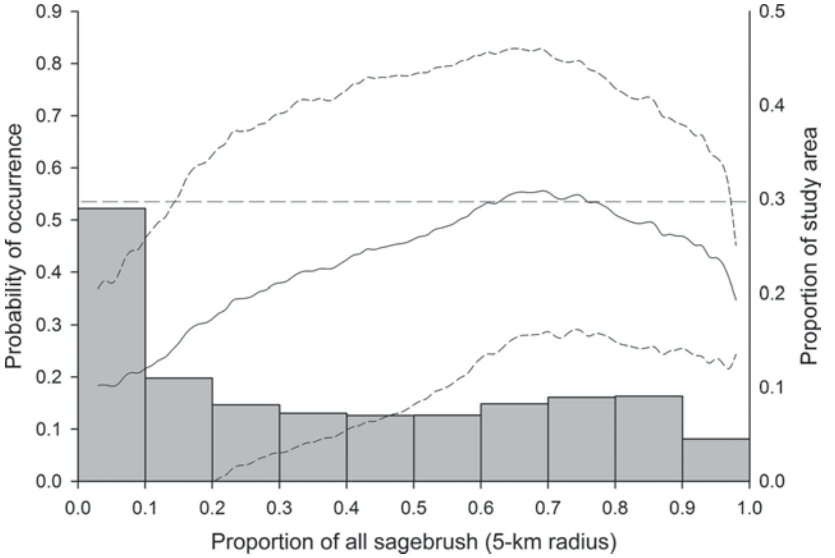

FIG. 7.6. Distribution of harvester ant probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all sagebrush (*Artemesia* spp.) within a 5-km radius. Mean probability of occurrence (black line, ±1 SD [dashed lines]) values were calculated in each one percent increment of all sagebrush within a 5-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.53), above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all sagebrush within 5 km.

(0.27, 0.54, and 1 km) and mixed shrubland (0.54 km). Coniferous forest (3, 5, and 18 km), all sagebrush mean patch size (1, 3, and 5 km), and salt desert shrub (3, 5, and 18 km) were removed from consideration owing to correlations with other variables. No interactions or non-linear relationships were evident for sagebrush or NDVI variables.

Based on logistic regression analyses, the AIC_c-selected top sagebrush/NDVI model included all big sagebrush (*A. tridentata*) within 5-km ($ABIGSAGE_{5km}$) and NDVI within 18-km ($NDVI_{18km}$) (Table 7.13). All models with $\Delta AIC_c \leq 2$ contained $NDVI_{18km}$ and either all big sagebrush or all sagebrush as the sagebrush component at multiple scales. Within 5-km, there was

TABLE 7.9. Results of AIC_c-based model selection for thatch ant occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2$	-193.12	4	394.49	0.00	0.09
2	$ALLSAGE_{5km} + NDVI_{5km} + NDVI_{5km}^2$	-193.61	4	395.48	0.98	0.05
3	$ALLSAGE_{3km} + NDVI_{5km} + ALLSAGE_{3km}\_NDVI_{5km}$	-193.62	4	395.49	0.99	0.05
4	$ALLSAGE_{5km} + NDVI_{5km} + ALLSAGE_{5km}\_NDVI_{5km}$	-193.76	4	395.78	1.28	0.05
5	$ALLSAGE_{18km} + NDVI_{18km}$	-194.94	3	396.02	1.53	0.04

[a] Variable definitions provided in Table 4.2

TABLE 7.10. Evaluation statistics from AIC_c -based univariate model selection for thatch ant occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran logistic models with all sagebrush (3-km radius) and NDVI (5-km radius; in quadratic form) variables as a base model for all variables tested. We used AIC_c to identify the scale at which thatch ants respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-193.12	5	396.61	0.00	0.33
	$CFRST_{270}$	-193.12	5	396.61	0.00	0.33
	$CFRST_{540}$	-193.12	5	396.61	0.00	0.33
	$GRASS_{540}$	-190.79	5	391.95	0.00	0.32
	$GRASS_{1km}$	-190.89	5	392.15	0.21	0.28
	$GRASS_{270}$	-190.97	5	392.32	0.37	0.26
	$GRASS_{3km}$	-192.38	5	395.14	3.19	0.06
	$GRASS_{5km}$	-192.81	5	396.00	4.05	0.04
	$GRASS_{18km}$	-193.02	5	396.42	4.48	0.03
	MIX_{18km}	-189.32	5	389.02	0.00	0.77
	MIX_{5km}	-190.92	5	392.22	3.20	0.16
	MIX_{3km}	-192.42	5	395.22	6.20	0.03
	MIX_{540}	-193.01	5	396.40	7.38	0.02
	MIX_{1km}	-193.10	5	396.57	7.55	0.02
	RIP_{5km}	-187.33	5	385.03	0.00	0.35
	RIP_{18km}	-187.34	5	385.05	0.03	0.34
	RIP_{3km}	-188.20	5	386.77	1.75	0.14
	RIP_{1km}	-188.28	5	386.94	1.92	0.13
	RIP_{540}	-189.53	5	389.44	4.41	0.04
	$CONTAG_{5km}$	-192.37	5	395.11	0.00	0.31
	$CONTAG_{1km}$	-192.58	5	395.53	0.43	0.28
	$EDGE_{3km}$	-192.74	5	395.85	0.74	0.24
	$EDGE_{1km}$	-192.83	5	396.04	0.93	0.22
	$EDGE_{5km}$	-192.93	5	396.24	1.13	0.20
	$CONTAG_{3km}$	-193.02	5	396.42	1.32	0.18
	$SALT_{18km}$	-191.07	5	392.51	0.00	1.00
Abiotic	CLAY	-193.00	5	396.38	0.00	0.68
	$CLAY^{2b}$	-192.69	6	397.91	1.52	0.32
	CTI	-190.83	5	392.04	0.00	1.00
	$ELEV^{2b}$	-187.78	6	388.09	0.00	0.91
	ELEV	-191.20	5	392.77	4.68	0.09
	$iH2Od_{1km}^{c}$	-192.39	5	395.15	0.00	0.45
	$iH2Od_{500}^{c}$	-192.71	5	395.80	0.65	0.32
	$iH2Od_{250}^{c}$	-193.08	5	396.53	1.39	0.22

TABLE 7.10. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$SOIL_{cm}$	-192.99	5	396.35	0.00	1.00
	SAND	-193.03	5	396.43	0.00	0.70
	$SAND^{2b}$	-192.78	6	398.09	1.67	0.30
	$SOLAR^{2b}$	-186.66	6	385.84	0.00	0.79
	SOLAR	-189.04	5	388.45	2.61	0.21
	Tmin	-190.17	5	390.72	0.00	1.00
	TRI_{270}	-190.11	5	390.59	0.00	0.25
	TRI	-190.29	5	390.95	0.36	0.21
	TRI_{18km}	-190.50	5	391.38	0.79	0.17
	TRI_{540}	-190.58	5	391.53	0.94	0.16
	TRI_{5km}	-191.09	5	392.56	1.97	0.10
	TRI_{1km}	-191.64	5	393.65	3.06	0.06
	TRI_{3km}	-191.70	5	393.77	3.18	0.05
Disturbance	AG_{1km}^{c}	-192.16	5	394.69	0.00	0.42
	AG_{500}^{c}	-192.44	5	395.25	0.56	0.32
	AG_{250}^{c}	-192.65	5	395.67	0.98	0.26
	$MjRD_{1km}^{c}$	-192.71	5	395.79	0.00	0.37
	$MjRD_{500}^{c}$	-192.74	5	395.86	0.07	0.36
	$MjRD_{250}^{c}$	-193.02	5	396.41	0.62	0.27
	$PIPE_{500}^{c}$	-192.42	5	395.22	0.00	0.37
	$PIPE_{1km}^{c}$	-192.52	5	395.41	0.19	0.33
	$PIPE_{250}^{c}$	-192.61	5	395.60	0.38	0.30
	$POWER_{1km}^{c}$	-191.32	5	393.02	0.00	0.55
	$POWER_{500}^{c}$	-192.04	5	394.46	1.44	0.27
	$POWER_{250}^{c}$	-192.42	5	395.21	2.19	0.18
	$RDdens_{18km}$	-192.55	5	395.48	0.00	0.17
	$RDdens_{3km}$	-192.94	5	396.26	0.78	0.12
	$RDdens_{5km}$	-193.01	5	396.40	0.93	0.11
	$2RD_{250}^{c}$	-193.02	5	396.42	0.94	0.11
	$RDdens_{270}$	-193.06	5	396.49	1.01	0.10
	$2RD_{1km}^{c}$	-193.09	5	396.55	1.07	0.10
	$RDdens_{1km}$	-193.11	5	396.60	1.12	0.10
	$2RD_{500}^{c}$	-193.12	5	396.62	1.14	0.10
	$RDdens_{540}$	-193.12	5	396.62	1.14	0.10
	$WELL_{1km}^{c}$	-191.03	5	392.43	0.00	0.39
	$WELL_{500}^{c}$	-191.25	5	392.87	0.45	0.31

TABLE 7.10. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$WELL_{250}$[c]	-191.31	5	392.99	0.56	0.30

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function ($e^{(\text{Euclidean distance from feature /-distance parameter})}$)

10.7% more all big sagebrush at presence sites (76.4% SE = 1.8) than at absence sites (65.7% SE = 1.3; Appendix 7.3).

After assessing individual multi-scale covariates (Table 7.14) and developing submodels, the top vegetation submodel for short-horned lizard consisted of sagebrush contagion within 5 km ($CONTAG_{5km}$) in addition to the sagebrush/NDVI base model (Table 7.15). Compound topographic index (CTI) and topographic ruggedness index within 5 km (TRI_{5km}) were important abiotic predictors of short-horned lizard occurrence (Table 7.15). None of the disturbance factors were included in the top disturbance submodel (all big sagebrush/NDVI base model only; Table 7.15).

The AIC_c-selected top model for short-horned lizards was a combination of vegetation and abiotic factors. Short-horned lizards were positively associated with large contiguous expanses of big sagebrush and negatively associated with areas of high productivity, rugged terrain, and increased topographic moisture (Table 7.16). All candidate models with cumulative Akaike weights of just ≥ 0.9 (five total) were subsets of the AIC_c-selected top model (Table 7.16). The final composite probability of occurrence model is below.

$$\text{Prob} = 1 / (1 + (\exp(-(1.03 + 1.23 * ABIGSAGE_{5km} - 4.22 * NDVI_{18km} + 0.012 * CONTAG_{5km} - 0.18 * CTI - 0.04 * TRI_{5km})))) \quad (7.4)$$

The composite model of short-horned lizard occurrence had good model accuracy (ROC AUC = 0.72), which was slightly less than AIC_c-selected top model prediction (ROC AUC = 0.73). The optimal cutoff probability for predicting short-horned lizard occurrence, based on the sensitivity-specificity equality threshold, was 0.22 resulting in an overall percent correctly classified accuracy of 68.3%.

Short-horned lizard occurrence was predicted throughout the central portion of the Wyoming Basins (Fig. 7.10). Based on our optimal cutoff point and a binary presence-absence prediction, 46,648 km^2 (20.6%) of the range of the species in the Wyoming Basins was predicted to be short-horned lizard habitat (Fig. 7.11). Short-horned lizards were likely to occupy sites with >81% all big sagebrush land cover within 5 km (Fig. 7.12).

White-tailed jackrabbits

Four predictor variables were excluded because they contained values > 0 on <20 survey blocks in the least frequent abundance category (present). These variables included proportion of coniferous forest (0.27, 0.54, and 1 km) and mixed shrubland (0.54 km). None of the sagebrush or NDVI variables had non-linear relationships or evidence of interactions.

Based on logistic regression analyses, the AIC_c-selected top sagebrush/NDVI model included big sagebrush (*A. t.* ssp. *tridentata*, *A. t.* ssp. *wyomingensis*) within 0.27 km ($BIGSAGE_{270}$; Table 7.17). All models with $\Delta AIC_c \leq 2$ contained $BIGSAGE_{270}$ with NDVI at multiple radii. There was 13.6% more big sagebrush within 0.27-km at presence sites (70.3%, SE = 3.7) than at absent sites (56.7%, SE = 2.3; Appendix 7.4).

TABLE 7.11. Results of AIC_c -based submodel selection for thatch ant occurrence in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta\text{AIC}_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{GRASS}_{540} + \text{RIP}_{5km} + \text{SALT}_{18km} + \text{MIX}_{18km} + \text{CONTAG}_{5km}$	-180.61	9	380.36	0.00	0.11
	2	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{GRASS}_{540} + \text{RIP}_{5km} + \text{SALT}_{18km} + \text{MIX}_{18km}$	-181.77	8	380.46	0.09	0.10
	3	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{GRASS}_{540} + \text{RIP}_{5km} + \text{SALT}_{18km} + \text{CONTAG}_{5km}$	-182.04	8	380.99	0.63	0.08
	4	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{GRASS}_{540} + \text{RIP}_{5km} + \text{MIX}_{18km}$	-183.16	7	381.03	0.67	0.08
	5	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{GRASS}_{540} + \text{SALT}_{18km} + \text{MIX}_{18km} + \text{CONTAG}_{5km}$	-182.35	8	381.61	1.24	0.06
	6	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{GRASS}_{540} + \text{RIP}_{5km} + \text{SALT}_{18km}$	-183.59	7	381.88	1.52	0.05
	7	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{GRASS}_{540} + \text{RIP}_{5km} + \text{SALT}_{18km} + \text{MIX}_{18km} + \text{CONTAG}_{5km} + \text{CFRST}_{1km}$	-180.32	10	382.04	1.68	0.05
Abiotic	1	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI}$	-179.27	9	377.67	0.00	0.05
	2	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2}$	-180.58	8	378.06	0.39	0.04
	3	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI} + \text{Tmin}$	-178.40	10	378.20	0.53	0.03
	4	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{Tmin}$	-179.64	9	378.42	0.75	0.03
	5	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI} + \text{SOIL}_{cm}$	-178.68	10	378.75	1.08	0.03
	6	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI} + \text{SAND}$	-178.87	10	379.14	1.47	0.02
	7	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI} + \text{iH2Od}_{1km}$	-178.89	10	379.17	1.50	0.02
	8	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI} + \text{Tmin} + \text{SOIL}_{cm}$	-177.83	11	379.33	1.66	0.02
	9	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{TRI}_{270}$	-180.20	9	379.54	1.87	0.02
	10	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI} + \text{Tmin} + \text{SAND}$	-177.94	11	379.55	1.88	0.02
	11	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{ELEV} + \text{ELEV}^{2} + \text{SOLAR} + \text{SOLAR}^{2} + \text{CTI} + \text{Tmin} + \text{iH2Od}_{1km}$	-177.99	11	379.65	1.98	0.02
Distrubance	1	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{POWER}_{1km} + \text{WELL}_{1km} + \text{MjRD}_{1km} + \text{AG}_{1km} + \text{RDdens}_{18km}$	-185.45	9	390.03	0.00	0.06
	2	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{POWER}_{1km} + \text{WELL}_{1km} + \text{MjRD}_{1km} + \text{AG}_{1km}$	-186.66	8	390.23	0.20	0.05
	3	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{POWER}_{1km} + \text{WELL}_{1km} + \text{MjRD}_{1km} + \text{RDdens}_{18km}$	-186.88	8	390.66	0.63	0.04
	4	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{POWER}_{1km} + \text{WELL}_{1km} + \text{AG}_{1km} + \text{RDdens}_{18km} + \text{PIPE}_{500}$	-185.80	9	390.74	0.71	0.04
	5	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{POWER}_{1km} + \text{WELL}_{1km} + \text{MjRD}_{1km}$	-188.08	7	390.87	0.84	0.04
	6	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{POWER}_{1km} + \text{WELL}_{1km} + \text{RDdens}_{18km}$	-188.13	7	390.97	0.94	0.04
	7	$\text{ALLSAGE}_{3km} + \text{NDVI}_{5km} + \text{NDVI}_{5km}^{2} + \text{POWER}_{1km} + \text{WELL}_{1km} + \text{MjRD}_{1km} + \text{AG}_{1km} + \text{RDdens}_{18km} + \text{PIPE}_{500}$	-184.83	10	391.05	1.01	0.03

TABLE 7.11. Continued

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
	8	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + WELL_{1km} + AG_{1km} + RDdens_{18km}$	-187.10	8	391.11	1.07	0.03
	9	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + WELL_{1km} + AG_{1km} + PIPE_{500}$	-187.17	8	391.25	1.21	0.03
	10	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + WELL_{1km}$	-189.36	6	391.26	1.22	0.03
	11	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + WELL_{1km} + RDdens_{18km} + PIPE_{500}$	-187.18	8	391.28	1.24	0.03
	12	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + MjRD_{1km} + WELL_{1km} + AG_{1km} + PIPE_{500}$	-186.12	9	391.38	1.35	0.03
	13	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + WELL_{1km} + AG_{1km}$	-188.35	7	391.39	1.36	0.03
	14	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + AG_{1km} + PIPE_{500}$	-188.42	7	391.54	1.50	0.03
	15	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + WELL_{1km} + AG_{1km} + RDdens_{18km}$	-188.48	7	391.66	1.63	0.02
	16	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + WELL_{1km} + PIPE_{500}$	-188.51	7	391.72	1.69	0.02
	17	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + RDdens_{18km} + WELL_{1km}$	-189.61	6	391.75	1.72	0.02
	18	$ALLSAGE_{3km} + NDVI_{5km} + NDVI_{5km}^2 + POWER_{1km} + PIPE_{500}$	-189.73	6	391.98	1.95	0.02

[a] Variable definitions provided in Table 4.2

After assessing individual multi-scale covariates (Table 7.18) and developing submodels, the top vegetation submodel for white-tailed jackrabbit consisted of grassland within 0.54 km ($GRASS_{540}$) and salt desert shrubland within 3-km ($SALT_{3km}$), in addition to the sagebrush base model (Table 7.19). Topographic ruggedness within 0.54 km (TRI_{540}) was the only important abiotic predictor of white-tailed jackrabbit occurrence (Table 7.19). Four disturbance factors, 1-km distance decay from interstate/major highways ($MjRD_{1km}$), 0.5-km distance decay from pipelines ($PIPE_{500}$), 0.5-km distance decay from power lines ($POWER_{500}$), and road density within 3 km ($RDdens_{3km}$), were included in the top disturbance submodel (Table 7.19).

The AIC_c-selected top model for white-tailed jackrabbits was a combination of vegetation, abiotic, and disturbance factors. White-tailed jackrabbits were positively associated with small-scale big sagebrush and grassland land cover, and large-scale salt desert shrubland land cover, and negatively associated with rugged terrain and proximity to interstates and major highways (Table 7.20). The weight of evidence for the AIC_c-selected top model was low (w_i = 0.07) indicating other candidate models also were suitable. Variables in the other 59 candidate models with cumulative Akaike weights of just ≥ 0.9 showed that, in addition to factors in the top model, white-tailed jackrabbit locations were positively associated with proximity to pipelines and negatively associated with proximity to power lines and areas of high road density (Table 7.20). The final composite model-averaged probability of occurrence is below.

$$\text{Prob} = 1 / (1 + (\exp(-(-1.55 + 1.12 * BIGSAGE_{270} + 2.16 * GRASS_{540} + 2.07 * SALT_{3km} - 0.02 * TRI_{540} - 1.54 * MjRD_{1km} + 0.34 * PIPE_{500} - 0.773 * POWERDIST_{500} - 0.12 * RDdens_{3km})))) \quad (7.5)$$

TABLE 7.12. Results of AIC$_c$-based model selection for the combined vegetation, abiotic, and disturbance thatch ant occurrence model[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$value from the top model [ΔAIC$_c$], and cumulative Akaike weight [$\sum w_i$]). Models are shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Intercept	ALLSAGE$_{3km}$	NDVI$_{5km}$	NDVI$_{5km}$[b]	GRASS$_{540}$	MIX$_{18km}$	RIP$_{5km}$	CTI	ELEV[c]	ELEV^{2}[d]	SOLAR
1	-23.29 (8.35)	1.18 (1.04)	16.89 (8.58)	-10.88 (9.67)	-4.18 (2.04)	-44.92 (21.18)	10.02 (4.30)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.10 (0.09)
2	-21.38 (8.09)	1.31 (1.05)	16.72 (8.55)	-10.94 (9.64)	-4.19 (2.05)	-47.74 (22.02)	9.50 (4.35)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.08 (0.09)
3	-22.89 (8.40)	1.31 (1.06)	17.04 (8.64)	-10.66 (9.73)	-4.27 (2.09)	-44.46 (21.40)	9.65 (4.33)	0.13 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
4	-22.24 (8.44)	1.87 (1.22)	15.66 (8.74)	-9.26 (9.92)	-4.41 (2.14)	-40.36 (21.32)	9.87 (4.30)	0.14 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
5	-10.62 (6.74)	1.60 (1.14)	10.54 (7.21)	-4.50 (8.28)	-6.07 (2.56)	-58.50 (22.19)		0.14 (0.06)			0.10 (0.09)
6	-22.06 (8.59)	0.75 (1.15)	15.94 (8.64)	-10.58 (9.69)	-4.69 (2.17)	-45.11 (21.30)	8.77 (4.46)	0.13 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.11 (0.09)
7	-23.65 (8.41)	1.14 (1.04)	17.00 (8.64)	-10.84 (9.74)	-4.13 (2.04)	-44.15 (21.05)	10.28 (4.31)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.10 (0.09)
8	-25.38 (8.42)	1.01 (1.05)	16.59 (8.46)	-11.01 (9.55)	-4.34 (2.03)	-39.43 (20.80)	9.48 (4.22)		0.11 (0.05)	-0.02 (0.01)	0.14 (0.09)
9	-23.19 (8.20)	1.17 (1.06)	16.39 (8.45)	-11.02 (9.53)	-4.34 (2.04)	-42.51 (21.72)	8.92 (4.27)		0.11 (0.05)	-0.02 (0.01)	0.11 (0.09)
10	-24.17 (8.64)	1.02 (1.07)	16.78 (8.62)	-10.62 (9.72)	-4.05 (2.04)	-47.31 (21.54)	9.11 (4.52)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.11 (0.09)
11	-20.72 (8.98)	1.32 (1.30)	18.49 (8.49)	-13.46 (9.52)	-5.74 (2.46)	-47.26 (21.29)		0.15 (0.07)	0.08 (0.05)	-0.02 (0.01)	0.11 (0.09)
12	-25.29 (8.27)	0.80 (1.04)	21.65 (8.05)	-15.78 (9.14)	-3.79 (2.03)	-65.00 (.0022)		0.11 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.10 (0.09)
13	-23.22 (8.39)	1.19 (1.04)	16.76 (8.76)	-10.82 (9.71)	-4.16 (2.05)	-44.70 (21.38)	10.00 (4.31)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.10 (0.09)
14	-12.59 (7.08)	1.47 (1.14)	11.41 (7.17)	-5.23 (8.24)	-6.29 (2.54)	-52.93 (21.25)		0.14 (0.06)			0.13 (0.09)
15	-10.84 (6.81)	1.68 (1.14)	11.13 (7.24)	-4.78 (8.28)	-5.99 (2.57)	-58.38 (22.35)		0.14 (0.06)			0.10 (0.09)
16	-10.73 (6.55)	1.91 (1.09)	10.24 (7.29)	-4.08 (8.36)	-6.06 (2.53)	-44.36 (21.38)	6.49 (4.26)	0.15 (0.06)			0.11 (0.09)
17	-11.38 (6.41)	1.54 (1.01)	9.79 (7.21)	-3.55 (8.23)	-5.26 (2.32)	-47.50 (21.27)	8.27 (4.10)	0.14 (0.06)			0.11 (0.09)
18	-25.00 (8.48)	1.15 (1.07)	16.77 (8.51)	-10.80 (9.60)	-4.40 (2.08)	-38.97 (21.01)	9.13 (4.25)		0.10 (0.05)	-0.02 (0.01)	0.14 (0.09)
19	-21.11 (8.29)	1.95 (1.21)	14.10 (8.70)	-7.35 (9.90)	-4.54 (2.14)		11.82 (4.18)	0.13 (0.06)	0.08 (0.05)	-0.02 (0.01)	0.10 (0.09)
20	-10.96 (6.63)	1.90 (1.08)	13.22 (7.02)	-7.51 (8.02)	-6.58 (2.55)	-50.05 (21.17)		0.15 (0.06)			0.11 (0.09)
21	-22.76 (8.24)	1.30 (1.07)	16.55 (8.49)	-10.81 (9.58)	-4.41 (2.09)	-42.23 (21.95)	8.58 (4.31)		0.10 (0.05)	-0.02 (0.01)	0.11 (0.09)
22	-18.35 (8.74)	1.57 (1.29)	11.72 (8.92)	-5.87 (10.06)	-5.55 (2.41)		9.68 (4.37)	0.14 (0.06)	0.06 (0.05)	-0.01 (0.01)	0.10 (0.09)
23	-9.15 (6.39)	2.06 (1.09)	12.85 (7.03)	-7.30 (8.03)	-6.52 (2.57)	-53.70 (21.85)		0.15 (0.06)			0.09 (0.09)
24	-10.53 (6.79)	1.63 (1.15)	10.02 (7.28)	-3.77 (8.38)	-6.15 (2.59)	-56.93 (22.13)		0.14 (0.06)			0.10 (0.09)
25	-22.35 (8.16)	1.06 (1.03)	15.56 (8.51)	-9.28 (9.61)	-4.22 (2.01)		12.32 (4.16)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
26	-24.43 (8.48)	0.88 (1.08)	16.07 (8.53)	-10.44 (9.61)	-4.07 (2.03)	-48.39 (22.48)	7.02 (4.51)		0.11 (0.05)	-0.02 (0.01)	0.12 (0.09)
27	-22.09 (8.40)	0.53 (1.14)	21.16 (8.07)	-16.59 (9.01)	-4.95 (2.22)	-59.40 (21.80)		0.13 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.09 (0.09)
28	-24.47 (7.98)	1.17 (1.02)	24.14 (7.80)	-18.66 (8.86)	-4.14 (2.05)	-60.86 (21.73)		0.12 (0.06)	0.12 (0.05)	-0.03 (0.01)	0.09 (0.09)
29	-18.99 (8.06)	2.13 (1.22)	13.73 (8.68)	-7.18 (9.86)	-4.57 (2.16)		11.44 (4.21)	0.13 (0.06)	0.08 (0.05)	-0.01 (0.01)	0.07 (0.09)
30	-11.61 (6.50)	1.67 (1.02)	10.61 (7.27)	-3.98 (8.27)	-5.25 (2.34)	-47.60 (21.53)	7.77 (4.13)	0.14 (0.06)			0.11 (0.09)
31	-26.95 (8.40)	0.66 (1.05)	20.76 (7.97)	-15.20 (9.07)	-3.90 (2.02)	-60.06 (21.67)			0.12 (0.05)	-0.03 (0.01)	0.13 (0.09)
32	-9.69 (6.21)	1.68 (1.01)	9.71 (7.21)	-3.67 (8.23)	-5.25 (2.33)	-50.98 (22.02)	7.75 (4.13)	0.14 (0.06)			0.09 (0.08)
33	-11.65 (6.57)	1.05 (1.04)	10.94 (7.12)	-5.03 (8.10)	-5.15 (2.32)	-65.45 (22.14)		0.13 (0.06)			0.11 (0.09)
34	-9.01 (6.33)	2.05 (1.09)	10.19 (7.29)	-4.23 (8.36)	-6.05 (2.55)	-47.83 (22.10)	5.99 (4.29)	0.15 (0.06)			0.08 (0.08)
35	-24.06 (8.67)	0.35 (1.13)	21.80 (8.08)	-17.08 (9.03)	-4.98 (2.22)	-55.77 (21.02)		0.13 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.12 (0.09)
36	-23.99 (8.04)	1.30 (1.04)	24.15 (7.82)	-18.25 (8.89)	-4.27 (2.11)	-59.91 (21.97)		0.12 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.09 (0.09)
37	-10.35 (6.67)	1.67 (1.15)	9.47 (7.37)	-3.28 (8.46)	-5.87 (2.55)	-54.52 (22.80)	3.24 (4.64)	0.14 (0.06)			0.10 (0.09)
38	-21.94 (8.21)	1.18 (1.04)	15.69 (8.57)	-9.02 (9.68)	-4.32 (2.07)		11.87 (4.20)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)

TABLE 7.12. Extended

SOLAR^{2c}	WELL$_{1km}$	POWER$_{1km}$	CONTAG$_{5km}$	SALT$_{18km}$	RDdens$_{18km}$	MjRD$_{1km}$	AG$_{1km}$	LL	K	AIC$_c$	ΔAIC$_c$	$\sum w_i$
0.05 (0.03)								-169.09	12	364.16	0.00	0.018
0.04 (0.03)	-1.28 (0.91)							-168.02	13	364.38	0.21	0.034
0.05 (0.03)		0.79 (0.60)						-168.24	13	364.81	0.65	0.048
0.04 (0.03)			-0.01 (0.01)					-168.38	13	365.09	0.93	0.059
0.04 (0.03)	-1.70 (0.95)		-0.02 (0.01)	-8.27 (2.82)	0.91 (0.48)			-168.52	13	365.37	1.21	0.070
0.05 (0.03)				-2.60 (2.72)				-168.59	13	365.51	1.35	0.079
0.05 (0.03)						-0.53 (0.58)		-168.66	13	365.66	1.49	0.089
0.06 (0.03)								-171.16	11	366.01	1.85	0.096
0.05 (0.03)	-1.32 (0.90)							-170.02	12	366.03	1.87	0.104
0.05 (0.03)					0.30 (0.49)			-168.90	13	366.12	1.96	0.112
0.05 (0.03)			-0.02 (0.01)	-5.69 (3.06)				-169.02	13	366.37	2.20	0.118
0.05 (0.03)	-1.82 (0.96)				0.82 (0.48)			-169.02	13	366.38	2.21	0.125
0.05 (0.03)							0.06 (0.88)	-169.08	13	366.50	2.33	0.131
0.05 (0.03)			-0.02 (0.01)	-8.61 (2.83)	0.73 (0.47)			-170.27	12	366.54	2.38	0.137
0.04 (0.03)	-1.68 (0.95)	0.65 (0.61)	-0.02 (0.01)	-8.03 (2.84)	0.87 (0.48)			-167.95	14	366.61	2.44	0.143
0.05 (0.03)			-0.01 (0.01)	-7.06 (2.98)				-170.34	12	366.68	2.51	0.149
0.05 (0.03)				-5.16 (2.56)				-171.51	11	366.70	2.53	0.155
0.06 (0.03)		0.76 (0.59)						-170.36	12	366.71	2.54	0.161
0.04 (0.03)			-0.01 (0.01)					-170.36	12	366.72	2.55	0.167
0.05 (0.03)			-0.02 (0.01)	-8.47 (2.91)				-171.53	11	366.73	2.57	0.173
0.05 (0.03)	-1.33 (0.91)	0.76 (0.59)						-169.21	13	366.74	2.58	0.178
0.04 (0.03)			-0.02 (0.01)	-4.35 (3.08)				-169.21	13	366.74	2.58	0.184
0.04 (0.03)	-1.32 (0.91)		-0.02 (0.01)	-8.20 (2.91)				-170.40	12	366.79	2.63	0.190
0.04 (0.03)	-1.70 (0.94)		-0.02 (0.01)	-8.31 (2.80)	0.92 (0.48)	-0.55 (0.58)		-168.06	14	366.82	2.65	0.196
0.04 (0.03)								-171.60	11	366.88	2.72	0.201
0.05 (0.03)	-1.60 (0.94)				0.61 (0.50)			-169.28	13	366.90	2.74	0.207
0.04 (0.03)	-1.45 (0.93)			-3.93 (2.68)				-169.29	13	366.91	2.75	0.213
0.04 (0.03)	-1.50 (0.93)							-170.50	12	367.00	2.83	0.218
0.03 (0.03)	-1.23 (0.89)		-0.02 (0.01)					-169.34	13	367.02	2.85	0.223
0.05 (0.03)		0.84 (0.60)		-5.14 (2.60)				-170.52	12	367.04	2.87	0.229
0.06 (0.03)	-1.87 (0.95)				0.88 (0.47)			-170.52	12	367.04	2.88	0.234
0.04 (0.03)	-1.20 (0.90)			-5.07 (2.57)				-170.55	12	367.10	2.94	0.239
0.05 (0.03)	-1.75 (0.94)			-6.20 (2.47)	0.88 (0.47)			-170.56	12	367.11	2.95	0.244
0.04 (0.03)	-1.20 (0.91)		-0.01 (0.01)	-6.94 (2.98)				-169.41	13	367.15	2.98	0.249
0.05 (0.03)				-4.13 (2.70)				-170.60	12	367.18	3.02	0.254
0.04 (0.03)	-1.49 (0.94)	0.88 (0.60)						-169.44	13	367.22	3.05	0.259
0.04 (0.03)	-1.57 (0.96)		-0.02 (0.01)	-7.57 (2.97)	0.77 (0.52)			-168.28	14	367.25	3.09	0.264
0.04 (0.03)		0.83 (0.60)						-170.64	12	367.28	3.12	0.269

TABLE 7.12. Continued

Rank	Intercept	ALLSAGE$_{3km}$	NDVI$_{5km}$	NDVI$_{5km}$[b]	GRASS$_{540}$	MIX$_{18km}$	RIP$_{5km}$	CTI	ELEV[c]	ELEV^{2}[d]	SOLAR
39	-24.75 (8.77)	0.08 (1.16)	17.95 (8.24)	-13.21 (9.22)	-4.62 (2.18)	-58.51 (21.74)			0.11 (0.05)	-0.03 (0.01)	0.14 (0.09)
40	-25.47 (8.57)	1.13 (1.07)	16.90 (8.60)	-10.60 (9.72)	-4.35 (2.08)	-37.71 (20.94)	9.45 (4.28)		0.11 (0.05)	-0.02 (0.01)	0.14 (0.09)
41	-20.51 (7.94)	1.19 (1.03)	15.19 (8.49)	-9.10 (9.58)	-4.24 (2.02)		11.97 (4.19)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.08 (0.08)
42	-11.39 (6.74)	1.97 (1.08)	13.90 (7.05)	-7.80 (8.02)	-6.44 (2.55)	-50.18 (21.41)		0.15 (0.06)			0.11 (0.09)
43	-25.81 (8.48)	0.97 (1.05)	16.70 (8.52)	-10.98 (9.61)	-4.31 (2.03)	-38.72 (20.72)	9.72 (4.24)		0.11 (0.05)	-0.03 (0.01)	0.14 (0.09)
44	-26.59 (8.28)	1.02 (1.02)	24.90 (7.82)	-19.23 (8.87)	-4.14 (2.04)	-57.61 (20.91)		0.12 (0.06)	0.12 (0.05)	-0.03 (0.01)	0.11 (0.09)
45	-9.90 (6.29)	1.79 (1.02)	10.48 (7.27)	-4.04 (8.26)	-5.26 (2.36)	-51.17 (22.27)	7.28 (4.16)	0.14 (0.06)			0.09 (0.08)
46	-23.57 (8.25)	1.12 (1.05)	16.50 (8.51)	-11.01 (9.59)	-4.30 (2.03)	-41.62 (21.63)	9.16 (4.30)		0.11 (0.05)	-0.03 (0.01)	0.11 (0.09)
47	-24.32 (8.62)	0.64 (1.15)	15.68 (8.52)	-10.67 (9.56)	-4.78 (2.15)	-39.53 (20.91)	8.38 (4.38)		0.10 (0.05)	-0.02 (0.01)	0.14 (0.09)
48	-11.81 (6.67)	1.20 (1.05)	11.66 (7.15)	-5.35 (8.12)	-5.15 (2.35)	-64.74 (22.32)		0.13 (0.06)			0.11 (0.09)
49	-24.76 (8.48)	1.53 (1.22)	15.74 (8.59)	-9.88 (9.74)	-4.51 (2.10)	-35.70 (21.04)	9.34 (4.22)		0.10 (0.05)	-0.02 (0.01)	0.14 (0.09)
50	-22.41 (8.28)	1.71 (1.24)	15.51 (8.57)	-9.87 (9.71)	-4.51 (2.11)	-38.29 (21.99)	8.78 (4.28)		0.10 (0.05)	-0.02 (0.01)	0.11 (0.09)
51	-22.33 (8.29)	1.17 (1.04)	15.86 (8.67)	-8.82 (9.81)	-4.25 (2.08)		12.19 (4.22)	0.12 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
52	-22.80 (8.05)	2.30 (0.98)	15.43 (8.41)	-8.59 (9.45)		-46.13 (21.18)	9.78 (4.23)	0.14 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.09 (0.08)
53	-25.07 (8.99)	0.00 (1.16)	20.00 (8.28)	-14.91 (9.28)	-4.74 (2.20)	-58.32 (21.07)		0.12 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.13 (0.10)
54	-11.03 (6.63)	1.97 (1.09)	10.90 (7.34)	-4.39 (8.38)	-5.95 (2.54)	-44.65 (21.61)	6.27 (4.27)	0.15 (0.06)			0.11 (0.09)
55	-9.51 (6.49)	2.12 (1.09)	13.49 (7.06)	-7.55 (8.04)	-6.40 (2.57)	-53.88 (22.09)		0.15 (0.06)			0.09 (0.09)
56	-26.16 (8.37)	1.16 (1.04)	24.95 (7.84)	-18.83 (8.90)	-4.25 (2.10)	-56.58 (21.16)		0.13 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.11 (0.09)
57	-20.83 (8.33)	1.98 (1.22)	14.32 (8.74)	-7.28 (9.93)	-4.60 (2.18)		11.47 (4.21)	0.13 (0.06)	0.08 (0.05)	-0.01 (0.01)	0.09 (0.09)
58	-26.45 (8.45)	0.81 (1.07)	20.76 (7.99)	-14.82 (9.10)	-4.01 (2.08)	-59.03 (21.86)			0.12 (0.05)	-0.03 (0.01)	0.13 (0.09)
59	-12.89 (7.17)	1.57 (1.14)	12.07 (7.20)	-5.58 (8.25)	-6.18 (2.55)	-52.76 (21.44)		0.14 (0.06)			0.13 (0.10)
60	-22.21 (8.43)	0.81 (1.16)	15.49 (8.52)	-10.67 (9.54)	-4.76 (2.16)	-42.92 (21.83)	7.85 (4.44)		0.10 (0.05)	-0.02 (0.01)	0.12 (0.09)
61	-23.70 (8.74)	0.55 (1.15)	21.95 (8.11)	-16.74 (9.06)	-5.03 (2.26)	-55.10 (21.26)		0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.12 (0.09)
62	-26.58 (8.75)	0.80 (1.08)	16.46 (8.52)	-10.66 (9.61)	-4.19 (2.03)	-42.66 (21.21)	8.33 (4.43)		0.11 (0.05)	-0.02 (0.01)	0.15 (0.09)
63	-24.24 (8.22)	0.91 (1.03)	15.48 (8.42)	-9.62 (9.51)	-4.36 (2.01)		11.60 (4.08)		0.10 (0.05)	-0.02 (0.01)	0.13 (0.09)
64	-23.04 (8.06)	1.94 (1.22)	22.93 (7.92)	-17.07 (9.06)	-4.40 (2.16)	-54.81 (21.98)		0.13 (0.06)	0.11 (0.05)	-0.02 (0.01)	0.08 (0.09)
65	-10.65 (6.80)	1.60 (1.14)	10.59 (7.36)	-4.51 (8.29)	-6.08 (2.59)	-58.57 (22.29)		0.14 (0.06)			0.10 (0.09)
66	-11.62 (6.59)	1.72 (1.02)	9.94 (7.32)	-2.87 (8.36)	-5.23 (2.36)	-45.56 (21.40)	8.30 (4.18)	0.14 (0.06)			0.11 (0.09)
67	-20.95 (7.78)	2.42 (0.98)	15.29 (8.37)	-8.69 (9.41)		-48.95 (22.01)	9.24 (4.28)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.06 (0.08)
68	-12.04 (6.74)	1.56 (1.13)	8.85 (7.11)	-3.02 (8.18)	-6.03 (2.52)	-52.78 (21.77)					0.14 (0.09)
69	-20.12 (7.97)	1.30 (1.05)	15.30 (8.55)	-8.83 (9.64)	-4.34 (2.09)		11.54 (4.23)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.08 (0.09)
70	-10.90 (6.49)	1.28 (1.06)	9.17 (7.27)	-3.00 (8.29)	-5.01 (2.32)	-57.14 (22.81)	5.63 (4.43)	0.13 (0.06)			0.10 (0.09)
71	-26.05 (8.51)	1.39 (1.24)	19.27 (8.14)	-13.24 (9.32)	-4.12 (2.11)	-53.95 (21.87)			0.11 (0.05)	-0.02 (0.01)	0.13 (0.09)
72	-12.07 (6.96)	1.60 (1.14)	9.73 (7.35)	-3.35 (8.45)	-5.98 (2.54)	-48.08 (21.69)	4.66 (4.56)	0.14 (0.06)			0.12 (0.09)
73	-21.57 (8.36)	1.96 (1.21)	14.12 (8.79)	-7.14 (10.01)	-4.47 (2.14)		12.07 (4.19)	0.13 (0.06)	0.08 (0.05)	-0.02 (0.01)	0.10 (0.09)
74	-10.67 (6.60)	1.94 (1.09)	9.59 (7.35)	-3.19 (8.45)	-6.14 (2.56)	-42.54 (21.26)	6.78 (4.29)	0.15 (0.06)			0.11 (0.09)
75	-22.16 (8.04)	1.05 (1.04)	15.05 (8.42)	-9.37 (9.49)	-4.37 (2.02)		11.24 (4.12)		0.10 (0.05)	-0.02 (0.01)	0.11 (0.08)
76	-12.55 (7.13)	1.50 (1.14)	10.87 (7.24)	-4.48 (8.34)	-6.39 (2.58)	-51.54 (21.16)		0.15 (0.06)			0.13 (0.09)
77	-27.73 (8.63)	0.69 (1.04)	23.12 (8.03)	-17.08 (9.13)	-3.89 (2.03)	-60.15 (20.96)		0.12 (0.06)	0.12 (0.05)	-0.03 (0.01)	0.13 (0.09)
78	-11.01 (6.74)	2.06 (1.10)	10.14 (7.39)	-3.16 (8.49)	-5.99 (2.57)	-42.16 (21.47)	6.68 (4.32)	0.15 (0.06)			0.11 (0.09)

TABLE 7.12. Extended

$SOLAR^{2c}$	$WELL_{1km}$	$POWER_{1km}$	$CONTAG_{5km}$	$SALT_{18km}$	$RDdens_{18km}$	$MjRD_{1km}$	AG_{1km}	LL	K	AIC_c	ΔAIC_c	Σw_i
0.06 (0.03)	-1.83 (0.95)			-3.56 (2.59)	0.89 (0.48)			-169.47	13	367.28	3.12	0.274
0.06 (0.03)		1 (0.62)				-0.81 (0.62)		-169.48	13	367.30	3.13	0.279
0.04 (0.03)	-1.17 (0.89)							-170.67	12	367.33	3.17	0.284
0.05 (0.03)		0.75 (0.60)	-0.02 (0.01)	-8.18 (2.93)				-170.74	12	367.47	3.30	0.289
0.06 (0.03)						-0.52 (0.58)		-170.76	12	367.52	3.35	0.293
0.05 (0.03)								-171.92	11	367.53	3.36	0.297
0.04 (0.03)	-1.19 (0.91)	0.83 (0.60)		-5.05 (2.60)				-169.60	13	367.53	3.37	0.302
0.05 (0.03)	-1.32 (0.90)					-0.53 (0.58)		-169.60	13	367.54	3.37	0.306
0.06 (0.03)				-2.32 (2.71)				-170.78	12	367.54	3.38	0.311
0.05 (0.03)	-1.71 (0.95)	0.83 (0.60)		-6.10 (2.50)	0.83 (0.47)			-169.61	13	367.55	3.38	0.315
0.06 (0.03)			-0.01 (0.01)					-170.78	12	367.55	3.39	0.320
0.05 (0.03)	-1.33 (0.90)		-0.01 (0.01)					-169.61	13	367.56	3.39	0.324
0.04 (0.03)		1.10 (0.63)				-0.87 (0.62)		-169.62	13	367.57	3.41	0.329
0.04 (0.03)								-171.95	11	367.59	3.42	0.333
0.06 (0.03)				-4.12 (2.64)	0.65 (0.47)			-169.63	13	367.59	3.42	0.338
0.05 (0.03)		0.71 (0.60)	-0.01 (0.01)	-6.83 (3.01)				-169.64	13	367.62	3.45	0.342
0.04 (0.03)	-1.31 (0.92)	0.74 (0.60)	-0.02 (0.01)	-7.92 (2.93)				-169.65	13	367.62	3.46	0.347
0.05 (0.03)		0.89 (0.59)						-170.82	12	367.63	3.47	0.351
0.04 (0.03)		0.72 (0.60)	-0.01 (0.01)					-169.65	13	367.63	3.47	0.356
0.06 (0.03)	-1.87 (0.96)	0.79 (0.59)			0.84 (0.48)			-169.65	13	367.63	3.47	0.360
0.05 (0.03)		0.67 (0.60)	-0.02 (0.01)	-8.35 (2.86)	0.69 (0.47)			-169.65	13	367.64	3.48	0.365
0.05 (0.03)	-1.31 (0.91)			-2.23 (2.70)				-169.66	13	367.65	3.48	0.369
0.05 (0.03)		0.83 (0.60)		-3.93 (2.75)				-169.66	13	367.65	3.49	0.374
0.06 (0.03)					0.39 (0.49)			-170.84	12	367.68	3.51	0.378
0.05 (0.03)								-173.15	10	367.69	3.53	0.383
0.04 (0.03)	-1.50 (0.93)		-0.01 (0.01)					-169.70	13	367.72	3.56	0.387
0.04 (0.03)	-1.70 (0.95)		-0.02 (0.01)	-8.26 (2.82)	0.91 (0.48)		-0.03 (0.86)	-168.52	14	367.74	3.58	0.392
0.05 (0.03)		1.08 (0.63)		-4.90 (2.57)		-0.77 (0.61)		-169.71	13	367.76	3.60	0.396
0.03 (0.03)	-1.26 (0.90)							-170.89	12	367.77	3.60	0.400
0.06 (0.03)	-1.78 (0.94)		-0.02 (0.01)	-7.77 (2.76)	0.99 (0.47)			-170.89	12	367.78	3.61	0.405
0.04 (0.03)	-1.17 (0.89)	0.83 (0.60)						-169.73	13	367.79	3.62	0.409
0.05 (0.03)	-1.52 (0.94)			-5.43 (2.55)	0.64 (0.50)			-169.74	13	367.81	3.65	0.413
0.05 (0.03)	-1.90 (0.95)		-0.01 (0.01)		0.96 (0.48)			-169.74	13	367.82	3.66	0.418
0.05 (0.03)			-0.02 (0.01)	-7.55 (2.99)	0.54 (0.50)			-169.75	13	367.83	3.66	0.422
0.04 (0.03)			-0.02 (0.01)			-0.64 (0.59)		-169.76	13	367.85	3.68	0.426
0.05 (0.03)			-0.02 (0.01)	-7.03 (2.97)		-0.59 (0.58)		-169.82	13	367.97	3.80	0.431
0.05 (0.03)	-1.20 (0.88)							-172.16	11	367.99	3.83	0.435
0.05 (0.03)			-0.02 (0.01)	-8.66 (2.82)	0.74 (0.47)	-0.53 (0.58)		-169.84	13	368.01	3.84	0.439
0.05 (0.03)					0.63 (0.47)			-171.01	12	368.02	3.85	0.443
0.05 (0.03)		0.96 (0.63)	-0.01 (0.01)	-6.71 (2.98)		-0.84 (0.62)		-168.66	14	368.03	3.87	0.447

TABLE 7.12. Continued

Rank	Intercept	ALLSAGE$_{3km}$	NDVI$_{5km}$	NDVI$_{5km}$^{b}	GRASS$_{540}$	MIX$_{18km}$	RIP$_{5km}$	CTI	ELEV^{c}	ELEV^{2d}	SOLAR
79	-11.37 (6.84)	2.04 (1.09)	13.29 (7.11)	-6.77 (8.13)	-6.50 (2.58)	-48.08 (21.27)		0.15 (0.06)			0.11 (0.09)
80	-9.28 (6.39)	2.11 (1.09)	10.82 (7.33)	-4.51 (8.37)	-5.95 (2.55)	-48.20 (22.33)	5.78 (4.30)	0.14 (0.06)			0.08 (0.09)
81	-23.86 (8.27)	1.04 (1.05)	15.61 (8.47)	-9.37 (9.57)	-4.42 (2.06)		11.18 (4.12)		0.10 (0.05)	-0.02 (0.01)	0.13 (0.09)
82	-21.18 (8.38)	0.61 (1.14)	14.55 (8.57)	-8.94 (9.62)	-4.74 (2.15)		11.08 (4.31)	0.12 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
83	-10.88 (6.67)	1.93 (1.08)	12.69 (7.08)	-6.78 (8.11)	-6.69 (2.58)	-48.54 (21.05)		0.16 (0.06)			0.11 (0.09)
84	-9.03 (6.43)	2.09 (1.09)	12.34 (7.09)	-6.59 (8.11)	-6.63 (2.60)	-52.06 (21.74)		0.15 (0.06)			0.09 (0.09)
85	-22.32 (8.07)	2.44 (0.99)	15.63 (8.45)	-8.41 (9.50)		-45.69 (21.41)	9.43 (4.27)	0.14 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.08 (0.08)
86	-26.04 (8.08)	1.05 (1.04)	23.40 (7.71)	-18.29 (8.77)	-4.28 (2.04)	-55.34 (21.36)			0.13 (0.05)	-0.03 (0.01)	0.12 (0.09)
87	-9.43 (6.57)	2.20 (1.09)	12.92 (7.12)	-6.58 (8.13)	-6.46 (2.60)	-51.66 (21.96)		0.15 (0.06)			0.09 (0.09)
88	-25.29 (8.35)	1.77 (1.21)	23.69 (7.94)	-17.62 (9.08)	-4.39 (2.15)	-52.19 (21.11)		0.13 (0.06)	0.11 (0.05)	-0.02 (0.01)	0.10 (0.09)
89	-22.74 (8.22)	1.03 (1.02)	15.74 (8.57)	-9.30 (9.69)	-4.17 (2.01)		12.58 (4.17)	0.11 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.10 (0.09)
90	-9.85 (6.35)	1.84 (1.02)	9.84 (7.32)	-2.98 (8.36)	-5.23 (2.37)	-48.97 (22.17)	7.81 (4.21)	0.14 (0.06)			0.09 (0.09)
91	-12.48 (6.75)	1.25 (1.06)	9.44 (7.25)	-3.07 (8.28)	-5.13 (2.31)	-50.76 (21.66)	6.97 (4.35)	0.14 (0.06)			0.12 (0.09)
92	-26.63 (8.75)	1.49 (1.22)	21.44 (8.21)	-14.86 (9.42)	-4.15 (2.14)	-54.31 (21.05)		0.13 (0.06)	0.11 (0.05)	-0.02 (0.01)	0.12 (0.10)
93	-25.31 (8.48)	1.02 (1.05)	16.48 (8.63)	-10.96 (9.58)	-4.33 (2.04)	-39.23 (21.01)	9.46 (4.23)		0.11 (0.05)	-0.02 (0.01)	0.14 (0.09)
94	-22.94 (8.26)	1.18 (1.06)	16.05 (8.61)	-10.89 (9.56)	-4.29 (2.04)	-41.89 (21.91)	8.84 (4.29)		0.11 (0.05)	-0.02 (0.01)	0.11 (0.09)
95	-10.52 (6.40)	1.72 (1.01)	13.72 (7.00)	-7.69 (7.93)	-5.56 (2.35)	-59.92 (21.98)		0.14 (0.06)			0.10 (0.09)
96	-12.92 (7.29)	1.64 (1.14)	11.49 (7.27)	-4.59 (8.36)	-6.23 (2.58)	-50.76 (21.34)		0.15 (0.07)			0.13 (0.10)
97	-11.37 (6.45)	1.55 (1.01)	9.28 (7.26)	-2.86 (8.30)	-5.27 (2.33)	-46.21 (21.17)	8.64 (4.14)	0.14 (0.06)			0.11 (0.09)
98	-23.95 (8.68)	0.81 (1.16)	15.86 (8.58)	-10.45 (9.62)	-4.81 (2.19)	-39.17 (21.12)	8.11 (4.41)		0.10 (0.05)	-0.02 (0.01)	0.14 (0.09)
99	-12.44 (6.64)	1.57 (1.00)	14.22 (6.99)	-8.02 (7.91)	-5.59 (2.33)	-56.12 (21.27)		0.14 (0.06)			0.12 (0.09)
100	-23.52 (8.31)	1.62 (1.21)	14.40 (8.57)	-8.19 (9.74)	-4.60 (2.10)		11.13 (4.10)		0.09 (0.05)	-0.02 (0.01)	0.13 (0.09)
101	-22.27 (8.08)	2.02 (1.02)	15.11 (8.45)	-8.33 (9.49)		-55.17 (22.78)	7.21 (4.52)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.08 (0.08)
102	-10.21 (6.28)	1.58 (1.00)	12.94 (6.97)	-7.38 (7.91)	-5.59 (2.33)	-60.29 (21.72)		0.14 (0.06)			0.10 (0.09)
103	-27.24 (8.71)	0.85 (1.06)	23.18 (8.06)	-16.75 (9.16)	-4.01 (2.09)	-58.91 (21.17)		0.12 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.12 (0.10)
104	-8.90 (6.38)	2.09 (1.09)	9.56 (7.34)	-3.37 (8.44)	-6.13 (2.58)	-45.83 (22)	6.29 (4.32)	0.15 (0.06)			0.08 (0.09)
105	-26.50 (8.43)	1.14 (1.03)	25.20 (7.94)	-18.77 (9.02)	-4.19 (2.11)	-55.68 (21.01)		0.13 (0.06)	0.12 (0.05)	-0.03 (0.01)	0.11 (0.09)
106	-22.73 (8.83)	1.25 (1.28)	13.91 (8.78)	-8.74 (9.87)	-5.25 (2.32)	-34.22 (21.15)	7.71 (4.41)		0.09 (0.05)	-0.02 (0.01)	0.15 (0.09)
107	-20.47 (7.79)	2.56 (1.00)	15.45 (8.41)	-8.50 (9.45)		-48.61 (22.24)	8.91 (4.31)	0.14 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.06 (0.08)
108	-11.02 (6.56)	1.41 (1.07)	9.88 (7.31)	-3.34 (8.32)	-5.03 (2.35)	-56.92 (23)	5.32 (4.45)	0.13 (0.06)			0.10 (0.09)
109	-26.15 (8.81)	0.95 (1.10)	16.59 (8.56)	-10.44 (9.66)	-4.25 (2.07)	-41.95 (21.38)	8.06 (4.45)		0.10 (0.05)	-0.02 (0.01)	0.15 (0.09)
110	-25.56 (8.15)	1.19 (1.05)	23.44 (7.73)	-17.90 (8.80)	-4.38 (2.10)	-54.52 (21.60)			0.12 (0.05)	-0.03 (0.01)	0.12 (0.09)
111	-22.77 (8.15)	2.40 (0.99)	15.65 (8.55)	-8.07 (9.63)		-44.19 (21.27)	9.75 (4.29)	0.14 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.08 (0.09)
112	-21.76 (8.07)	1.17 (1.06)	15.17 (8.46)	-9.12 (9.55)	-4.44 (2.07)		10.83 (4.15)		0.10 (0.05)	-0.02 (0.01)	0.10 (0.08)
113	-24.38 (8.37)	1.02 (1.05)	15.85 (8.57)	-9.27 (9.69)	-4.37 (2.06)		11.46 (4.14)		0.10 (0.05)	-0.02 (0.01)	0.13 (0.09)
114	-23.97 (8.45)	0.49 (1.14)	20.62 (7.98)	-16.33 (8.93)	-5.00 (2.20)	-53.79 (21.43)			0.12 (0.05)	-0.03 (0.01)	0.13 (0.09)
115	-24.49 (8.53)	1.57 (1.23)	16.03 (8.62)	-9.87 (9.77)	-4.54 (2.13)	-35.79 (21.30)	9.05 (4.25)		0.10 (0.05)	-0.02 (0.01)	0.14 (0.09)
116	-25.18 (9.32)	0.74 (1.30)	16 (8.62)	-10.78 (9.71)	-5.44 (2.39)	-44.67 (20.85)			0.09 (0.05)	-0.02 (0.01)	0.17 (0.10)
117	-21.17 (8.14)	1.82 (1.23)	13.94 (8.56)	-7.92 (9.71)	-4.62 (2.12)		10.74 (4.14)		0.09 (0.05)	-0.02 (0.01)	0.10 (0.08)
118	-13.63 (6.88)	0.95 (1.04)	11.84 (7.07)	-5.79 (8.06)	-5.35 (2.31)	-59.64 (21.13)		0.13 (0.06)			0.14 (0.09)

TABLE 7.12. Extended

$SOLAR^{2c}$	$WELL_{1km}$	$POWER_{1km}$	$CONTAG_{5km}$	$SALT_{18km}$	$RDdens_{18km}$	$MjRD_{1km}$	AG_{1km}	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
0.05 (0.03)		0.98 (0.63)	-0.02 (0.01)	-8.16 (2.92)		-0.79 (0.62)		-169.89	13	368.10	3.94	0.451
0.04 (0.03)	-1.19 (0.91)	0.71 (0.60)	-0.01 (0.01)	-6.71 (3)				-168.73	14	368.15	3.99	0.454
0.05 (0.03)		0.80 (0.59)						-172.25	11	368.18	4.01	0.458
0.05 (0.03)				-2.60 (2.68)				-171.09	12	368.18	4.01	0.462
0.05 (0.03)			-0.02 (0.01)	-8.53 (2.90)		-0.53 (0.58)		-171.10	12	368.18	4.02	0.466
0.04 (0.03)	-1.33 (0.91)		-0.02 (0.01)	-8.25 (2.90)		-0.55 (0.58)		-169.94	13	368.22	4.05	0.470
0.04 (0.03)		0.79 (0.60)						-171.11	12	368.22	4.05	0.473
0.05 (0.03)	-1.53 (0.92)							-172.27	11	368.22	4.05	0.477
0.04 (0.03)	-1.32 (0.91)	0.97 (0.63)	-0.02 (0.01)	-7.88 (2.91)		-0.80 (0.61)		-168.76	14	368.22	4.06	0.481
0.05 (0.03)			-0.01 (0.01)					-171.12	12	368.24	4.07	0.485
0.04 (0.03)						-0.57 (0.58)		-171.12	12	368.24	4.07	0.488
0.04 (0.03)	-1.20 (0.90)	1.07 (0.63)		-4.79 (2.57)		-0.77 (0.61)		-168.77	14	368.24	4.07	0.492
0.05 (0.03)				-5.42 (2.55)	0.42 (0.49)			-171.13	12	368.26	4.10	0.496
0.05 (0.03)			-0.01 (0.01)		0.72 (0.48)			-169.97	13	368.27	4.11	0.500
0.06 (0.03)							0.06 (0.87)	-171.16	12	368.32	4.15	0.504
0.05 (0.03)	-1.34 (0.91)						0.18 (0.87)	-170.00	13	368.33	4.16	0.507
0.04 (0.03)	-1.35 (0.92)	0.92 (0.59)		-5.97 (2.56)				-171.17	12	368.34	4.17	0.511
0.05 (0.03)		0.90 (0.63)	-0.02 (0.01)	-8.33 (2.84)	0.68 (0.47)	-0.78 (0.61)		-168.82	14	368.35	4.18	0.515
0.05 (0.03)				-5.02 (2.54)		-0.46 (0.58)		-171.18	12	368.35	4.18	0.518
0.06 (0.03)		0.74 (0.59)		-2.23 (2.76)				-170.01	13	368.35	4.19	0.522
0.05 (0.03)		0.94 (0.59)		-6.16 (2.56)				-172.34	11	368.37	4.20	0.526
0.05 (0.03)			-0.01 (0.01)					-172.35	11	368.39	4.22	0.529
0.04 (0.03)	-1.57 (0.94)				0.65 (0.50)			-170.03	13	368.40	4.24	0.533
0.04 (0.03)	-1.38 (0.91)			-6.07 (2.53)				-172.37	11	368.41	4.25	0.537
0.05 (0.03)		0.84 (0.60)			0.59 (0.47)			-170.04	13	368.41	4.25	0.540
0.04 (0.03)	-1.20 (0.90)		-0.02 (0.01)	-6.91 (2.97)		-0.60 (0.58)		-168.86	14	368.42	4.26	0.544
0.05 (0.03)		1.11 (0.62)				-0.75 (0.62)		-170.05	13	368.44	4.27	0.548
0.06 (0.03)			-0.01 (0.01)	-3.40 (3.00)				-170.06	13	368.46	4.30	0.551
0.03 (0.03)	-1.26 (0.90)	0.78 (0.61)						-170.07	13	368.46	4.30	0.555
0.04 (0.03)	-1.49 (0.95)	0.79 (0.60)		-5.38 (2.58)	0.60 (0.51)			-168.88	14	368.47	4.30	0.558
0.06 (0.03)		0.74 (0.59)			0.37 (0.49)			-170.07	13	368.48	4.31	0.562
0.05 (0.03)	-1.53 (0.93)	0.85 (0.59)						-171.25	12	368.50	4.34	0.566
0.04 (0.03)		1.06 (0.64)				-0.87 (0.62)		-170.09	13	368.50	4.34	0.569
0.05 (0.03)	-1.20 (0.89)	0.80 (0.59)						-171.26	12	368.51	4.35	0.573
0.05 (0.03)		1.06 (0.62)				-0.85 (0.62)		-171.27	12	368.53	4.36	0.576
0.06 (0.03)	-1.48 (0.92)			-3.58 (2.68)				-171.27	12	368.53	4.36	0.580
0.06 (0.03)		0.70 (0.59)	-0.01 (0.01)					-170.10	13	368.53	4.37	0.584
0.07 (0.03)			-0.02 (0.01)	-5.18 (2.92)	0.82 (0.48)			-170.11	13	368.56	4.40	0.587
0.05 (0.03)	-1.24 (0.88)		-0.01 (0.01)					-171.29	12	368.57	4.40	0.591
0.06 (0.03)				-6.43 (2.47)	0.69 (0.46)			-172.45	11	368.57	4.41	0.594

TABLE 7.12. Continued

Rank	Intercept	ALLSAGE$_{3km}$	NDVI$_{5km}$	NDVI$_{5km}^{b}$	GRASS$_{540}$	MIX$_{18km}$	RIP$_{5km}$	CTI	ELEV^{c}	ELEV^{2d}	SOLAR
119	-12.07 (6.50)	1.42 (0.99)	13.37 (6.95)	-7.67 (7.89)	-5.64 (2.31)	-56.54 (20.99)		0.14 (0.06)			0.12 (0.09)
120	-20.85 (7.98)	1.15 (1.03)	15.37 (8.56)	-9.12 (9.66)	-4.18 (2.02)		12.24 (4.21)	0.11 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.08 (0.09)
121	-24.99 (7.99)	1.70 (0.99)	20.01 (7.84)	-13.44 (8.86)		-66.81 (22.05)		0.12 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.08 (0.08)
122	-24.77 (7.99)	1.14 (1.02)	24.34 (7.87)	-18.75 (8.92)	-4.10 (2.05)	-60.32 (21.61)		0.12 (0.06)	0.12 (0.05)	-0.03 (0.01)	0.09 (0.09)
123	-9.64 (6.24)	1.69 (1.01)	9.21 (7.26)	-2.99 (8.30)	-5.26 (2.34)	-49.53 (21.94)	8.13 (4.17)	0.14 (0.06)			0.09 (0.08)
124	-11.82 (6.74)	1.24 (1.05)	11.28 (7.21)	-4.66 (8.21)	-5.14 (2.36)	-63.27 (22.27)		0.13 (0.06)			0.11 (0.09)
125	-20.82 (8.43)	0.77 (1.16)	14.71 (8.63)	-8.67 (9.68)	-4.79 (2.20)		10.75 (4.34)	0.12 (0.06)	0.08 (0.05)	-0.02 (0.01)	0.10 (0.09)
126	-13.86 (7.00)	1.13 (1.05)	12.67 (7.11)	-6.20 (8.08)	-5.32 (2.33)	-58.89 (21.36)		0.13 (0.06)			0.14 (0.09)
127	-22.16 (8.12)	2.95 (1.18)	14.40 (8.53)	-7.17 (9.66)		-42.24 (21.33)	9.63 (4.24)	0.15 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.08 (0.08)
128	-12.62 (6.83)	1.40 (1.07)	10.24 (7.30)	-3.49 (8.31)	-5.13 (2.34)	-50.50 (21.87)	6.61 (4.37)	0.14 (0.06)			0.12 (0.09)
129	-19.49 (8.18)	0.75 (1.15)	14.22 (8.55)	-8.73 (9.60)	-4.72 (2.16)		10.82 (4.34)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.08 (0.09)
130	-27.35 (8.45)	0.62 (1.05)	21.02 (8.04)	-15.37 (9.14)	-3.86 (2.02)	-59.61 (21.65)			0.13 (0.05)	-0.03 (0.01)	0.13 (0.09)
131	-24.42 (8.71)	0.29 (1.14)	21.95 (8.14)	-17.14 (9.10)	-4.97 (2.22)	-55.10 (20.89)		0.13 (0.06)	0.11 (0.05)	-0.03 (0.01)	0.12 (0.09)
132	-25.06 (8.43)	1.79 (1.22)	23.87 (7.96)	-17.45 (9.09)	-4.47 (2.19)	-51.87 (21.39)		0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.10 (0.09)
133	-12.27 (6.82)	1.65 (1.13)	9.50 (7.13)	-3.35 (8.18)	-5.94 (2.53)	-52.79 (21.95)					0.14 (0.09)
134	-22.21 (8.14)	1.16 (1.06)	15.43 (8.56)	-9.04 (9.67)	-4.38 (2.08)		11.11 (4.18)		0.10 (0.05)	-0.02 (0.01)	0.10 (0.09)
135	-12.74 (7.14)	1.48 (1.13)	11.70 (7.33)	-5.32 (8.25)	-6.36 (2.57)	-53.39 (21.39)		0.15 (0.06)			0.13 (0.09)
136	-12.75 (6.58)	1.07 (1.03)	9.31 (7.02)	-3.61 (8.01)	-5.17 (2.31)	-59.66 (21.75)					0.15 (0.09)
137	-21.62 (8.48)	1.87 (1.22)	13.89 (8.75)	-7.01 (9.97)	-4.47 (2.14)		11.26 (4.38)	0.13 (0.06)	0.08 (0.05)	-0.02 (0.01)	0.10 (0.09)
138	-21.55 (8.74)	1.28 (1.30)	18.10 (8.32)	-13.60 (9.32)	-5.56 (2.40)	-45.91 (21.80)			0.10 (0.05)	-0.02 (0.01)	0.12 (0.09)
139	-20.16 (7.86)	3.11 (1.19)	14.26 (8.49)	-7.28 (9.61)		-44.53 (22.18)	9.10 (4.28)	0.14 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.06 (0.08)
140	-23.27 (8.11)	2.24 (0.98)	15.48 (8.46)	-8.49 (9.52)		-45.19 (21.05)	10.03 (4.25)	0.14 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.09 (0.08)
141	-25.21 (8.54)	1.52 (1.22)	15.74 (8.66)	-9.69 (9.83)	-4.47 (2.10)	-34.70 (20.93)	9.59 (4.24)		0.11 (0.05)	-0.02 (0.01)	0.14 (0.09)
142	-10.93 (6.64)	1.92 (1.09)	10.57 (7.42)	-4.16 (8.37)	-6.13 (2.56)	-44.85 (21.48)	6.59 (4.28)	0.15 (0.06)			0.11 (0.09)
143	-21.34 (8.67)	1.30 (1.28)	12.36 (8.77)	-6.94 (9.87)	-5.43 (2.33)		9.27 (4.30)		0.08 (0.05)	-0.02 (0.01)	0.14 (0.09)
144	-28.45 (8.36)	0.88 (1.03)	24.16 (7.72)	-18.87 (8.78)	-4.29 (2.04)	-51.82 (20.47)			0.13 (0.05)	-0.03 (0.01)	0.15 (0.09)
145	-27.43 (9.03)	-0.10 (1.16)	19.32 (8.19)	-14.50 (9.19)	-4.79 (2.18)	-52.90 (20.65)			0.11 (0.05)	-0.03 (0.01)	0.17 (0.10)
146	-12.27 (7.04)	1.69 (1.14)	10.37 (7.39)	-3.68 (8.46)	-5.88 (2.54)	-47.98 (21.87)	4.61 (4.57)	0.14 (0.06)			0.12 (0.09)
147	-26.20 (8.86)	1.35 (1.23)	15.45 (8.67)	-9.28 (9.84)	-4.35 (2.10)	-38.94 (21.31)	7.94 (4.45)		0.10 (0.05)	-0.02 (0.01)	0.15 (0.09)
148	-11.34 (6.47)	1.54 (1.01)	9.73 (7.32)	-3.54 (8.23)	-5.25 (2.32)	-47.39 (21.39)	8.24 (4.14)	0.14 (0.06)			0.11 (0.09)
149	-26.22 (8.68)	0.28 (1.13)	21.23 (7.99)	-16.82 (8.93)	-5.04 (2.20)	-49.93 (20.58)			0.12 (0.05)	-0.03 (0.01)	0.15 (0.09)
150	-25.51 (8.94)	0.34 (1.19)	15.43 (8.59)	-10.25 (9.64)	-4.66 (2.15)	-43.28 (21.34)	6.91 (4.62)		0.10 (0.05)	-0.02 (0.01)	0.16 (0.09)
151	-11.05 (6.70)	1.90 (1.08)	13.38 (7.17)	-7.56 (8.03)	-6.62 (2.58)	-50.30 (21.30)		0.15 (0.06)			0.11 (0.09)
152	-29.81 (8.73)	0.52 (1.05)	22.29 (7.93)	-16.58 (9.03)	-4.02 (2.02)	-54.84 (20.53)			0.13 (0.05)	-0.03 (0.01)	0.16 (0.09)
153	-22.04 (8.16)	1.08 (1.03)	14.92 (8.68)	-9.01 (9.66)	-4.14 (2.01)		12.15 (4.18)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
154	-21.03 (8.30)	1.95 (1.21)	13.90 (8.84)	-7.28 (9.92)	-4.50 (2.15)		11.76 (4.20)	0.13 (0.06)	0.08 (0.05)	-0.02 (0.01)	0.09 (0.09)
155	-24.94 (8.53)	1.15 (1.07)	16.65 (8.69)	-10.75 (9.64)	-4.39 (2.09)	-38.76 (21.23)	9.11 (4.26)		0.10 (0.05)	-0.02 (0.01)	0.14 (0.09)
156	-12.62 (5.95)	2.43 (0.92)	11.96 (7.18)	-4.17 (8.28)	-4.23 (2.19)	-48.59 (21.25)	10.35 (4.01)	0.13 (0.06)			0.11 (0.08)
157	-24.09 (8.08)	2.55 (1.19)	18.45 (7.99)	-11.34 (9.11)		-60.73 (22.16)		0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.08 (0.09)
158	-11.64 (6.60)	1.04 (1.04)	10.64 (7.17)	-4.62 (8.17)	-5.16 (2.33)	-64.67 (22.11)		0.13 (0.06)			0.11 (0.09)

TABLE 7.12. Extended

$SOLAR^{2c}$	$WELL_{1km}$	$POWER_{1km}$	$CONTAG_{5km}$	$SALT_{18km}$	$RDdens_{18km}$	$MjRD_{1km}$	AG_{1km}	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
0.05 (0.03)				-6.26 (2.52)				-173.61	10	368.61	4.45	0.598
0.04 (0.03)	-1.18 (0.88)					-0.58 (0.58)		-170.16	13	368.65	4.49	0.601
0.04 (0.03)	-1.86 (0.94)				0.93 (0.48)			-171.34	12	368.67	4.50	0.605
0.04 (0.03)	-1.51 (0.93)					-0.47 (0.58)		-170.17	13	368.67	4.51	0.608
0.04 (0.03)	-1.21 (0.90)			-4.93 (2.55)		-0.48 (0.57)		-170.20	13	368.74	4.57	0.611
0.05 (0.03)	-1.71 (0.94)	1.04 (0.63)		-5.96 (2.48)	0.81 (0.47)	-0.64 (0.60)		-169.02	14	368.75	4.58	0.615
0.05 (0.03)		0.80 (0.60)		-2.45 (2.72)				-170.21	13	368.75	4.59	0.618
0.06 (0.03)		0.87 (0.59)		-6.33 (2.50)	0.63 (0.46)			-171.38	12	368.76	4.59	0.621
0.04 (0.03)			-0.01 (0.01)					-171.38	12	368.76	4.60	0.625
0.05 (0.03)		0.81 (0.60)		-5.38 (2.59)	0.38 (0.49)			-170.21	13	368.76	4.60	0.628
0.04 (0.03)	-1.13 (0.89)			-2.43 (2.66)				-170.22	13	368.78	4.61	0.631
0.06 (0.03)	-1.87 (0.94)				0.88 (0.48)	-0.44 (0.58)		-170.23	13	368.79	4.63	0.635
0.05 (0.03)				-4.16 (2.67)		-0.48 (0.58)		-170.25	13	368.82	4.66	0.638
0.05 (0.03)		0.80 (0.60)	-0.01 (0.01)					-170.25	13	368.83	4.66	0.641
0.06 (0.03)	-1.77 (0.94)	0.68 (0.60)	-0.02 (0.01)	-7.55 (2.79)	0.95 (0.47)			-170.25	13	368.84	4.67	0.645
0.05 (0.03)	-1.21 (0.88)	1.06 (0.63)				-0.86 (0.62)		-170.25	13	368.84	4.67	0.648
0.05 (0.03)			-0.02 (0.01)	-8.60 (2.84)	0.74 (0.47)		-0.17 (0.87)	-170.26	13	368.84	4.68	0.651
0.06 (0.03)	-1.82 (0.93)			-5.92 (2.43)	0.95 (0.46)			-172.60	11	368.88	4.71	0.654
0.04 (0.03)			-0.02 (0.01)		0.20 (0.49)			-170.28	13	368.89	4.73	0.658
0.05 (0.03)	-1.45 (0.92)		-0.01 (0.01)	-4.74 (2.96)				-170.28	13	368.90	4.74	0.661
0.03 (0.03)	-1.27 (0.89)		-0.01 (0.01)					-170.29	13	368.92	4.75	0.664
0.04 (0.03)						-0.57 (0.58)		-171.46	12	368.92	4.76	0.667
0.06 (0.03)			-0.01 (0.01)			-0.56 (0.59)		-170.31	13	368.95	4.79	0.670
0.05 (0.03)			-0.01 (0.01)	-7.01 (2.99)			-0.21 (0.86)	-170.31	13	368.95	4.79	0.674
0.06 (0.03)			-0.02 (0.01)	-3.74 (3.02)				-171.49	12	368.97	4.80	0.677
0.06 (0.03)								-173.79	10	368.97	4.80	0.680
0.07 (0.03)				-3.81 (2.62)	0.71 (0.47)			-171.49	12	368.98	4.82	0.683
0.05 (0.03)		0.67 (0.60)	-0.01 (0.01)	-7.30 (3.02)	0.50 (0.50)			-169.14	14	368.98	4.82	0.686
0.06 (0.03)			-0.01 (0.01)		0.47 (0.50)			-170.34	13	369.01	4.84	0.690
0.05 (0.03)				-5.18 (2.60)			0.04 (0.84)	-171.51	12	369.01	4.84	0.693
0.06 (0.03)				-3.80 (2.69)				-172.66	11	369.01	4.84	0.696
0.06 (0.03)				-2.59 (2.70)	0.45 (0.50)			-170.35	13	369.03	4.86	0.699
0.05 (0.03)			-0.02 (0.01)	-8.46 (2.91)			-0.09 (0.86)	-171.52	12	369.03	4.87	0.702
0.07 (0.03)					0.69 (0.47)			-172.68	11	369.03	4.87	0.705
0.04 (0.03)							0.34 (0.86)	-171.52	12	369.04	4.88	0.709
0.04 (0.03)			-0.01 (0.01)				0.11 (0.89)	-170.36	13	369.04	4.88	0.712
0.06 (0.03)		0.76 (0.59)					0.06 (0.87)	-170.36	13	369.04	4.88	0.715
0.05 (0.03)								-173.83	10	369.05	4.88	0.718
0.04 (0.03)	-1.89 (0.95)		-0.01 (0.01)		1.01 (0.48)			-170.36	13	369.05	4.89	0.721
0.05 (0.03)	-1.75 (0.94)			-6.14 (2.45)	0.88 (0.47)	-0.36 (0.57)		-170.36	13	369.06	4.89	0.724

TABLE 7.12. Continued

Rank	Intercept	ALLSAGE_{3km}	NDVI_{5km}	$\text{NDVI}_{5km}{}^{b}$	GRASS_{540}	MIX_{18km}	RIP_{5km}	CTI	ELEV^{c}	ELEV^{2d}	SOLAR
159	-24.71 (8.28)	0.87 (1.03)	15.68 (8.48)	-9.68 (9.58)	-4.32 (2.01)		11.82 (4.10)		0.11 (0.05)	-0.02 (0.01)	0.13 (0.09)
160	-21.39 (7.84)	2.37 (0.98)	15.35 (8.43)	-8.62 (9.49)		-47.88 (21.89)	9.49 (4.30)	0.14 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.06 (0.08)
161	-24.80 (8.68)	0.58 (1.15)	15.81 (8.58)	-10.68 (9.63)	-4.75 (2.15)	-38.73 (20.82)	8.59 (4.40)		0.11 (0.05)	-0.02 (0.01)	0.15 (0.09)
162	-23.55 (8.52)	0.67 (1.15)	20.75 (8.01)	-16.01 (8.96)	-5.04 (2.24)	-53.27 (21.66)			0.11 (0.05)	-0.03 (0.01)	0.13 (0.09)
163	-24.06 (8.41)	2.00 (1.03)	15.36 (8.46)	-8.34 (9.52)		-49.57 (21.57)	8.53 (4.44)	0.13 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.10 (0.09)
164	-9.13 (6.46)	2.05 (1.09)	12.82 (7.16)	-7.29 (8.04)	-6.51 (2.59)	-53.65 (21.95)		0.15 (0.06)			0.09 (0.09)
165	-10.15 (6.38)	1.72 (1.09)	10.00 (7.29)	-3.60 (8.37)	-6.31 (2.54)		8.07 (4.17)	0.13 (0.06)			0.10 (0.09)
166	-23.23 (8.41)	0.52 (1.14)	14.52 (8.48)	-9.26 (9.52)	-4.81 (2.13)		10.49 (4.24)		0.10 (0.05)	-0.02 (0.01)	0.14 (0.09)
167	-22.53 (8.28)	1.02 (1.06)	15.51 (8.53)	-9.19 (9.64)	-4.19 (2.02)		12.13 (4.34)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
168	-23.98 (8.01)	1.20 (1.03)	23.43 (8.00)	-18.35 (8.91)	-4.06 (2.05)	-59.45 (21.97)		0.12 (0.06)	0.12 (0.05)	-0.03 (0.01)	0.08 (0.09)
169	-28.07 (8.45)	1.03 (1.05)	24.23 (7.74)	-18.50 (8.81)	-4.37 (2.09)	-50.84 (20.71)			0.12 (0.05)	-0.03 (0.01)	0.15 (0.09)
170	-12.81 (6.03)	2.54 (0.94)	12.76 (7.23)	-4.57 (8.32)	-4.26 (2.23)	-48.41 (21.49)	9.81 (4.04)	0.13 (0.06)			0.10 (0.08)
171	-12.92 (6.69)	1.22 (1.04)	10.07 (7.05)	-3.95 (8.03)	-5.16 (2.33)	-59.05 (21.93)					0.14 (0.09)
172	-12 (7.02)	1.64 (1.15)	9.11 (7.41)	-2.49 (8.55)	-6.06 (2.57)	-46.33 (21.61)	4.95 (4.60)	0.15 (0.06)			0.12 (0.09)
173	-26.49 (8.43)	0.69 (1.06)	20.02 (8.19)	-14.85 (9.13)	-3.81 (2.02)	-58.64 (21.92)			0.12 (0.05)	-0.03 (0.01)	0.13 (0.09)
174	-11.11 (5.74)	2.52 (0.93)	12.05 (7.17)	-4.52 (8.28)	-4.23 (2.20)	-51.56 (22.00)	9.73 (4.04)	0.13 (0.06)			0.09 (0.08)
175	-26.88 (8.31)	0.99 (1.01)	25.07 (7.88)	-19.28 (8.94)	-4.10 (2.04)	-57.13 (20.79)		0.12 (0.06)	0.13 (0.05)	-0.03 (0.01)	0.11 (0.09)
176	-26.98 (8.81)	0.76 (1.08)	16.59 (8.57)	-10.68 (9.68)	-4.15 (2.02)	-41.95 (21.17)	8.59 (4.45)		0.11 (0.05)	-0.03 (0.01)	0.15 (0.09)
177	-23.85 (8.93)	1.06 (1.29)	18.64 (8.33)	-14.01 (9.34)	-5.62 (2.39)	-42.40 (20.94)			0.10 (0.05)	-0.02 (0.01)	0.15 (0.09)
178	-23.23 (8.36)	1.66 (1.22)	14.63 (8.60)	-8.13 (9.77)	-4.64 (2.14)		10.82 (4.13)		0.09 (0.05)	-0.02 (0.01)	0.13 (0.09)
179	-11.23 (6.59)	1.05 (1.04)	10.37 (7.25)	-4.87 (8.13)	-5.06 (2.33)	-64.28 (22.31)		0.13 (0.06)			0.11 (0.09)
180	-24.41 (8.01)	1.86 (1.00)	20.00 (7.85)	-13.07 (8.88)		-65.72 (22.22)		0.12 (0.06)	0.11 (0.05)	-0.02 (0.01)	0.08 (0.09)
181	-25.99 (8.19)	1.17 (1.05)	23.76 (7.82)	-17.94 (8.91)	-4.33 (2.10)	-53.39 (21.53)			0.13 (0.05)	-0.03 (0.01)	0.12 (0.09)
182	-22.57 (8.08)	1.01 (1.04)	15.25 (8.48)	-9.43 (9.57)	-4.32 (2.02)		11.48 (4.14)		0.11 (0.05)	-0.02 (0.01)	0.11 (0.08)
183	-19.17 (8.54)	1.52 (1.30)	11.97 (8.76)	-6.69 (9.84)	-5.41 (2.35)		8.99 (4.33)		0.08 (0.05)	-0.02 (0.01)	0.11 (0.09)
184	-11.60 (6.56)	1.67 (1.02)	10.59 (7.39)	-3.97 (8.27)	-5.25 (2.35)	-47.56 (21.66)	7.76 (4.17)	0.14 (0.06)			0.11 (0.09)
185	-12.52 (6.40)	1.58 (1.00)	8.20 (7.11)	-2.24 (8.14)	-5.35 (2.31)	-40.78 (20.75)	8.18 (4.05)				0.15 (0.09)
186	-20.01 (7.94)	1.22 (1.04)	14.34 (8.66)	-8.76 (9.64)	-4.12 (2.02)		11.71 (4.22)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.07 (0.08)
187	-12.03 (6.78)	1.59 (1.13)	8.33 (7.18)	-2.33 (8.27)	-6.10 (2.55)	-51.42 (21.76)					0.14 (0.09)
188	-14.38 (7.04)	1.42 (1.12)	9.67 (7.05)	-3.72 (8.13)	-6.29 (2.51)	-46.66 (20.72)					0.17 (0.09)
189	-9.53 (6.27)	1.67 (1.01)	9.52 (7.31)	-3.64 (8.23)	-5.22 (2.34)	-50.65 (22.12)	7.64 (4.18)	0.14 (0.06)			0.09 (0.08)
190	-10.52 (6.46)	1.76 (1.01)	13.28 (7.05)	-6.91 (8.01)	-5.56 (2.36)	-58.47 (21.87)		0.14 (0.06)			0.10 (0.09)
191	-20.90 (8.05)	1.07 (1.06)	14.97 (8.53)	-8.77 (9.63)	-4.13 (2.03)		11.33 (4.38)	0.10 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.08 (0.09)
192	-23.73 (8.71)	0.37 (1.14)	21.27 (8.29)	-16.83 (9.08)	-4.92 (2.22)	-54.74 (21.29)		0.13 (0.06)	0.11 (0.05)	-0.02 (0.01)	0.12 (0.09)
193	-21.66 (8.20)	1.20 (1.05)	15.04 (8.75)	-8.74 (9.73)	-4.23 (2.07)		11.70 (4.22)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.09 (0.09)
194	-11.28 (5.79)	2.63 (0.94)	12.79 (7.22)	-4.87 (8.32)	-4.27 (2.24)	-51.52 (22.24)	9.22 (4.08)	0.13 (0.06)			0.08 (0.08)
195	-20.87 (8.17)	1.86 (1.24)	14.17 (8.59)	-7.86 (9.74)	-4.68 (2.16)		10.43 (4.16)		0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
196	-12.48 (6.72)	1.60 (1.00)	13.76 (7.04)	-7.21 (8.00)	-5.59 (2.35)	-54.76 (21.14)		0.14 (0.06)			0.12 (0.09)
197	-9.13 (6.42)	2.05 (1.09)	10.35 (7.40)	-4.26 (8.36)	-6.08 (2.57)	-48.04 (22.17)	6.04 (4.31)	0.15 (0.06)			0.09 (0.09)
198	-25.85 (8.76)	0.48 (1.15)	21.39 (8.01)	-16.50 (8.97)	-5.07 (2.23)	-49.29 (20.81)			0.11 (0.05)	-0.03 (0.01)	0.15 (0.09)

TABLE 7.12. Extended

SOLAR^{2c}	WELL$_{1km}$	POWER$_{1km}$	CONTAG$_{5km}$	SALT$_{18km}$	RDdens$_{18km}$	MjRD$_{1km}$	AG$_{1km}$	LL	K	AIC$_c$	ΔAIC$_c$	Σw_i
0.05 (0.03)						-0.55 (0.58)		-172.69	11	369.06	4.90	0.728
0.03 (0.03)	-1.27 (0.89)					-0.58 (0.58)		-170.37	13	369.07	4.91	0.731
0.06 (0.03)				-2.30 (2.69)		-0.52 (0.58)		-170.37	13	369.07	4.91	0.734
0.05 (0.03)	-1.48 (0.93)	0.80 (0.60)		-3.40 (2.72)				-170.38	13	369.10	4.93	0.737
0.04 (0.03)					0.43 (0.49)			-171.56	12	369.12	4.95	0.740
0.04 (0.03)	-1.33 (0.92)		-0.02 (0.01)	-8.20 (2.91)			0.02 (0.86)	-170.40	13	369.13	4.97	0.743
0.04 (0.03)			-0.02 (0.01)	-7.50 (3.00)				-172.73	11	369.14	4.98	0.747
0.06 (0.03)				-2.33 (2.68)				-172.74	11	369.17	5.01	0.750
0.04 (0.03)					0.08 (0.48)			-171.59	12	369.17	5.01	0.753
0.04 (0.03)	-1.54 (0.94)						0.35 (0.88)	-170.42	13	369.18	5.01	0.756
0.06 (0.03)		0.85 (0.58)						-172.75	11	369.18	5.01	0.759
0.04 (0.03)		0.87 (0.59)						-172.76	11	369.20	5.03	0.762
0.06 (0.03)	-1.79 (0.94)	0.84 (0.59)		-5.84 (2.47)	0.90 (0.47)			-171.60	12	369.20	5.04	0.765
0.05 (0.03)			-0.02 (0.01)	-7.53 (2.97)	0.53 (0.50)	-0.57 (0.58)		-169.25	14	369.20	5.04	0.768
0.05 (0.03)	-1.91 (0.96)				0.88 (0.48)		0.35 (0.87)	-170.44	13	369.22	5.05	0.771
0.04 (0.03)	-1.25 (0.90)							-172.78	11	369.24	5.07	0.774
0.05 (0.03)						-0.44 (0.58)		-171.63	12	369.25	5.08	0.777
0.06 (0.03)					0.38 (0.49)	-0.50 (0.58)		-170.46	13	369.26	5.09	0.780
0.06 (0.03)			-0.01 (0.01)	-5.04 (2.99)				-171.64	12	369.27	5.11	0.783
0.05 (0.03)		0.71 (0.59)	-0.01 (0.01)					-171.64	12	369.28	5.11	0.787
0.05 (0.03)	-1.78 (0.95)			-6.33 (2.49)	0.88 (0.47)		0.34 (0.83)	-170.48	13	369.28	5.12	0.790
0.04 (0.03)	-1.84 (0.95)	0.80 (0.61)			0.90 (0.48)			-170.48	13	369.29	5.12	0.793
0.05 (0.03)	-1.53 (0.92)	1.06 (0.62)				-0.74 (0.61)		-170.50	13	369.33	5.16	0.796
0.05 (0.03)	-1.21 (0.88)					-0.57 (0.58)		-171.67	12	369.33	5.17	0.799
0.05 (0.03)	-1.20 (0.89)		-0.02 (0.01)	-3.53 (2.99)				-170.50	13	369.33	5.17	0.802
0.05 (0.03)		0.84 (0.60)		-5.15 (2.63)			0.01 (0.84)	-170.52	13	369.38	5.21	0.805
0.06 (0.03)				-4.85 (2.53)				-174.00	10	369.39	5.22	0.807
0.03 (0.03)	-1.22 (0.90)						0.46 (0.86)	-170.53	13	369.39	5.23	0.810
0.06 (0.03)	-1.78 (0.93)		-0.02 (0.01)	-7.80 (2.74)	1.00 (0.47)	-0.48 (0.58)		-170.53	13	369.39	5.23	0.813
0.07 (0.03)			-0.02 (0.01)	-8.16 (2.78)	0.80 (0.46)			-172.87	11	369.42	5.25	0.816
0.04 (0.03)	-1.22 (0.91)			-5.13 (2.60)			0.13 (0.84)	-170.54	13	369.42	5.25	0.819
0.04 (0.03)	-1.36 (0.91)	1.13 (0.63)		-5.81 (2.54)		-0.67 (0.61)		-170.54	13	369.42	5.25	0.822
0.04 (0.03)	-1.27 (0.91)				0.24 (0.49)			-170.55	13	369.44	5.27	0.825
0.05 (0.03)				-4.15 (2.71)			0.25 (0.87)	-170.55	13	369.44	5.28	0.828
0.04 (0.03)		0.83 (0.60)					0.33 (0.86)	-170.57	13	369.47	5.31	0.831
0.04 (0.03)	-1.24 (0.90)	0.86 (0.59)						-171.74	12	369.47	5.31	0.834
0.05 (0.03)	-1.25 (0.89)	0.71 (0.59)	-0.01 (0.01)					-170.58	13	369.49	5.33	0.837
0.05 (0.03)		1.14 (0.62)		-6.02 (2.53)		-0.65 (0.61)		-171.75	12	369.49	5.33	0.839
0.04 (0.03)	-1.19 (0.91)		-0.01 (0.01)	-6.92 (2.99)			-0.11 (0.86)	-169.40	14	369.50	5.34	0.842
0.06 (0.03)		0.80 (0.59)		-3.65 (2.74)				-171.76	12	369.50	5.34	0.845

TABLE 7.12. Continued

Rank	Intercept	ALLSAGE$_{3km}$	NDVI$_{5km}$	NDVI$_{5km}$[b]	GRASS$_{540}$	MIX$_{18km}$	RIP$_{5km}$	CTI	ELEV[c]	ELEV^{2}[d]	SOLAR
199	-29.39 (8.82)	0.68 (1.07)	22.35 (7.95)	-16.25 (9.07)	-4.11 (2.07)	-53.63 (20.73)			0.12 (0.05)	-0.03 (0.01)	0.16 (0.10)
200	-19.27 (8.83)	1.34 (1.30)	17.48 (8.50)	-12.30 (9.55)	-6.17 (2.50)			0.13 (0.06)	0.07 (0.05)	-0.01 (0.01)	0.10 (0.09)
201	-21.61 (8.44)	0.55 (1.15)	14.74 (8.62)	-8.99 (9.69)	-4.70 (2.15)		11.29 (4.33)	0.12 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
202	-23.81 (8.46)	1.68 (1.23)	14.76 (8.72)	-7.86 (9.92)	-4.58 (2.15)		11.07 (4.15)		0.09 (0.05)	-0.02 (0.01)	0.13 (0.09)
203	-12.77 (6.13)	2.57 (0.93)	11.94 (7.29)	-3.33 (8.42)	-4.25 (2.25)	-46.26 (21.37)	10.35 (4.09)	0.14 (0.06)			0.10 (0.08)
204	-10.63 (6.25)	1.73 (1.00)	8.19 (7.12)	-2.42 (8.14)	-5.33 (2.32)	-44.49 (21.58)	7.63 (4.08)				0.12 (0.08)
205	-10.83 (6.52)	1.30 (1.06)	8.72 (7.32)	-2.39 (8.37)	-5.02 (2.33)	-55.66 (22.78)	6.03 (4.48)	0.13 (0.06)			0.10 (0.09)
206	-25.07 (8.15)	1.65 (1.23)	22.46 (7.81)	-17.06 (8.94)	-4.47 (2.12)	-50.31 (21.72)			0.12 (0.05)	-0.03 (0.01)	0.12 (0.09)
207	-22.08 (8.32)	1.15 (1.08)	15.64 (8.59)	-8.95 (9.70)	-4.29 (2.08)		11.72 (4.37)	0.11 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
208	-21.29 (8.24)	0.68 (1.15)	14.14 (8.48)	-9.01 (9.51)	-4.78 (2.14)		10.22 (4.27)		0.10 (0.05)	-0.02 (0.01)	0.11 (0.09)
209	-24.05 (8.39)	1.62 (1.21)	14.48 (8.65)	-8.08 (9.84)	-4.55 (2.10)		11.35 (4.12)		0.10 (0.05)	-0.02 (0.01)	0.13 (0.09)
210	-12.77 (6.51)	1.71 (1.01)	9.06 (7.17)	-2.68 (8.18)	-5.32 (2.32)	-40.87 (21)	7.69 (4.08)				0.15 (0.09)
211	-12.56 (6.92)	1.47 (1.08)	9.63 (7.36)	-2.48 (8.41)	-5.12 (2.36)	-48.30 (21.80)	7.20 (4.44)	0.14 (0.06)			0.12 (0.09)
212	-11.72 (6.69)	1.63 (1.13)	7.81 (7.27)	-1.84 (8.37)	-5.85 (2.52)	-48.93 (22.41)	3.07 (4.60)				0.14 (0.09)
213	-17.44 (8.65)	1.56 (1.31)	16.94 (8.48)	-11.85 (9.52)	-6.12 (2.51)			0.13 (0.06)	0.07 (0.05)	-0.01 (0.01)	0.08 (0.09)
214	-26.56 (8.11)	1.61 (0.99)	18.86 (7.75)	-12.56 (8.78)		-61.49 (21.68)			0.12 (0.05)	-0.03 (0.01)	0.12 (0.08)
215	-12.01 (6.53)	1.28 (1.05)	7.59 (7.18)	-1.66 (8.21)	-5.06 (2.31)	-51.73 (22.46)	5.24 (4.38)				0.14 (0.09)
216	-21.79 (8.14)	2.98 (1.18)	14.72 (8.57)	-7.21 (9.69)		-42.24 (21.57)	9.34 (4.26)	0.15 (0.06)	0.09 (0.05)	-0.02 (0.01)	0.08 (0.09)
217	-21.62 (8.20)	1.82 (1.23)	14.00 (8.65)	-7.80 (9.82)	-4.57 (2.12)		10.98 (4.16)		0.09 (0.05)	-0.02 (0.01)	0.10 (0.09)
218	-22.27 (8.21)	2.20 (1.02)	15.00 (8.48)	-8.34 (9.47)		-46.31 (21.24)	9.34 (4.39)	0.14 (0.06)	0.10 (0.05)	-0.02 (0.01)	0.09 (0.08)

[a] Variable definitions provided in Table 4.2
[b] values are multiplied by 10^2
[c] values are multiplied by 10
[d] values are multiplied by 10^4

The composite model of white-tailed jackrabbit occurrence had good accuracy (ROC AUC = 0.70) when predicting presence and improved the prediction over the AIC$_c$-selected top model (ROC AUC = 0.68). The optimal cutoff probability for predicting white-tailed jackrabbit occurrence, based on sensitivity and specificity equality threshold, was 0.25 and resulted in an overall percent correctly classified accuracy of 64.9%.

White-tailed jackrabbit occurrence was highest in the Worland Basin and in areas throughout the southern portion of Wyoming of the WBEA area (Fig. 7.13). Based on our optimal cutoff point and a binary presence-absence prediction, 63,890 km^2 (22.1%) of white-tailed jackrabbit habitat was predicted for the Wyoming Basins (Fig. 7.14). White-tailed jackrabbits were likely to occupy areas with >82% big sagebrush land cover within 0.27 km (Fig. 7.15).

Cottontail rabbits

Two predictor variables, coniferous forest (0.27 and 0.54 km), were excluded because they were present on <20 survey blocks in the least frequent abundance category (present). Coniferous forest (3, 5, and 18 km), salt desert shrubland (0.27 km), all sagebrush mean patch size (1, 3, and 5 km), and all sagebrush contagion (5 km), were removed from consideration because of correlation. Our exploratory data analysis suggested a non-linear relationship between sagebrush and cottontail

TABLE 7.12. Extended

$SOLAR^{2c}$	$WELL_{1km}$	$POWER_{1km}$	$CONTAG_{5km}$	$SALT_{18km}$	$RDdens_{18km}$	$MjRD_{1km}$	AG_{1km}	LL	K	AIC_c	ΔAIC_c	Σw_i
0.07 (0.03)		0.80 (0.59)			0.65 (0.47)			-171.77	12	369.53	5.36	0.848
0.05 (0.03)			-0.02 (0.01)	-6.60 (3.11)				-171.77	12	369.53	5.36	0.851
0.05 (0.03)				-2.62 (2.65)		-0.58 (0.58)		-170.60	13	369.53	5.37	0.854
0.05 (0.03)		0.97 (0.62)	-0.01 (0.01)			-0.88 (0.62)		-170.61	13	369.55	5.38	0.857
0.04 (0.03)		1.13 (0.63)				-0.84 (0.62)		-171.78	12	369.55	5.39	0.859
0.05 (0.03)	-1.25 (0.89)			-4.74 (2.54)				-172.94	11	369.57	5.40	0.862
0.05 (0.03)	-1.51 (0.94)			-5.29 (2.53)	0.62 (0.51)	-0.44 (0.57)		-169.44	14	369.58	5.41	0.865
0.05 (0.03)	-1.53 (0.92)		-0.01 (0.01)					-171.79	12	369.58	5.42	0.868
0.04 (0.03)		0.83 (0.60)			0.06 (0.48)			-170.64	13	369.61	5.44	0.871
0.05 (0.03)	-1.17 (0.88)			-2.15 (2.66)				-171.81	12	369.61	5.44	0.874
0.05 (0.03)			-0.01 (0.01)			-0.60 (0.59)		-171.81	12	369.62	5.45	0.876
0.06 (0.03)		0.84 (0.59)		-4.86 (2.56)				-172.97	11	369.63	5.46	0.879
0.05 (0.03)		1.05 (0.63)		-5.12 (2.57)	0.34 (0.49)	-0.74 (0.61)		-169.47	14	369.64	5.47	0.882
0.06 (0.03)	-1.66 (0.95)		-0.01 (0.01)	-7.11 (2.92)	0.85 (0.51)			-170.67	13	369.67	5.50	0.885
0.04 (0.03)	-1.28 (0.91)		-0.02 (0.01)	-6.23 (3.07)				-170.68	13	369.70	5.54	0.887
0.05 (0.03)	-1.92 (0.94)				0.99 (0.47)			-173.01	11	369.70	5.54	0.890
0.06 (0.03)	-1.60 (0.93)			-5.18 (2.52)	0.72 (0.50)			-171.87	12	369.74	5.58	0.893
0.04 (0.03)		0.71 (0.61)	-0.01 (0.01)					-170.71	13	369.75	5.58	0.896
0.05 (0.03)	-1.26 (0.88)		-0.01 (0.01)			-0.62 (0.59)		-170.71	13	369.76	5.59	0.898
0.04 (0.03)				-0.95 (2.60)				-171.88	12	369.76	5.60	0.901

occurrence, so we assessed sagebrush variables in both linear and quadratic form. There was no evidence of non-linear relationships with NDVI or interactions between the sagebrush and NDVI variables.

Based on logistic regression analyses, the AIC_c-selected top sagebrush/NDVI model included all sagebrush within 5-km in quadratic form ($ALLSAGE_{5km}$) and NDVI within 5 km ($NDVI_{5km}$) (Table 7.21). Within 5-km there was 1.6% more all sagebrush at presence sites (70.6%, SE = 1.3) than at absent sites (69.0%, SE = 1.7) (Appendix 7.5).

After assessing individual multi-scale covariates (Table 7.22) and developing submodels, the top vegetation submodel for cottontail consisted of coniferous forest within 1 km ($CFRST_{1km}$), grassland within 18 km ($GRASS_{18km}$), mixed shrubland within 0.54 km (MIX_{540}), riparian within 0.27 km (RIP_{270}), and all sagebrush edge density within 5 km ($EDGE_{5km}$) in addition to the sagebrush/NDVI base model (Table 7.23). Topographic ruggedness within 0.27 km (TRI_{270}), elevation (ELEV), and 0.25-km distance decay from intermittent water ($iH2Od_{250}$), were important abiotic predictors of cottontail occurrence (Table 7.23). Only one disturbance factor, 1-km distance decay from power lines ($POWER_{1km}$), was included in the top disturbance submodel (Table 7.23).

The AIC_c-selected top cottontail model was a combination of vegetation, abiotic, and disturbance factors. Cottontails were

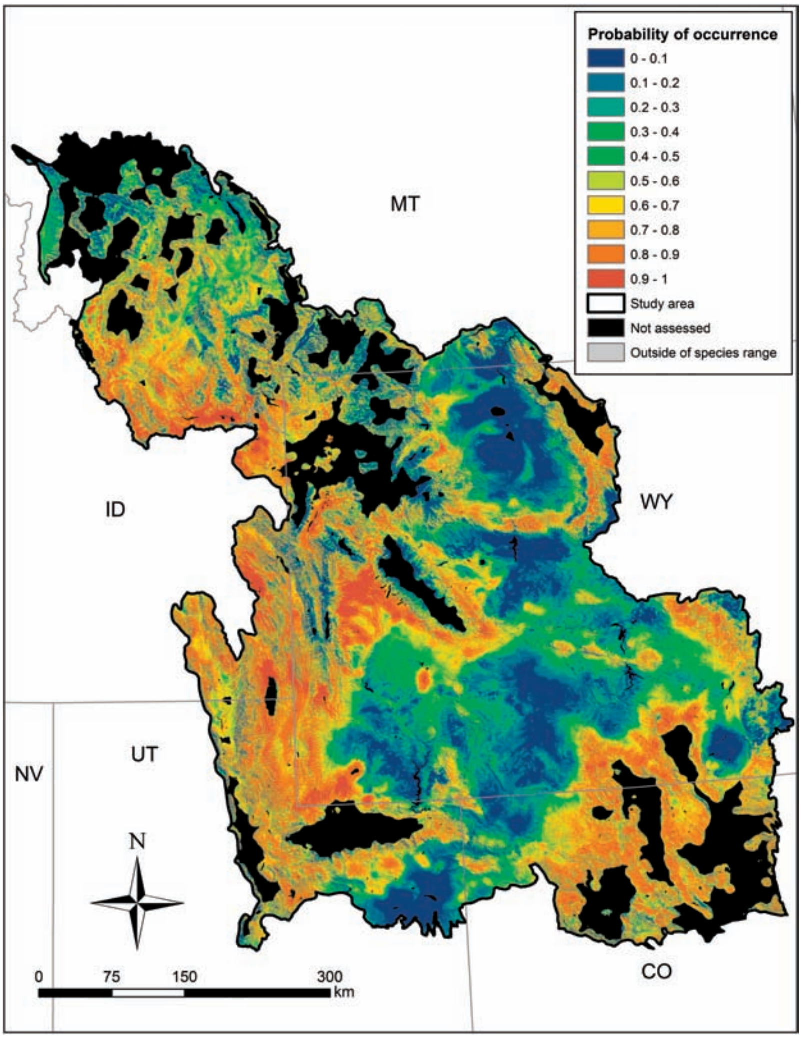

FIG. 7.7. Thatch ant probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Thatch ants are likely to occur in areas with probability > 0.38.

positively associated with moderate levels of all sagebrush, large expanses of coniferous forest, grassland, and mixed shrubland land cover, rugged topography, and proximity to power lines and negatively associated with high productivity and increased elevation (Table 7.24). The weight of evidence for the top model was low ($w_i = 0.06$) indicating other candidate models were suitable. Variables in the other 62 candidate models with cumulative Akaike weights of just ≥ 0.9 showed that cottontail probability of occurrence also was positively associated with increased all sagebrush edge density, riparian land cover, and proximity to intermittent water (Table 7.24). The final composite probability of occurrence model is below.

$$\text{Prob} = 1 / (1 + (\exp(-(7.56 + 1.33 * \text{ALLSAGE}_{5km} - 1.46 * \text{ALLSAGE}_{5km}^2 - 12.07 * \text{NDVI}_{5km} + 4.92 * \text{CFRST}_{1km} + 6.98 * \tag{7.6}$$

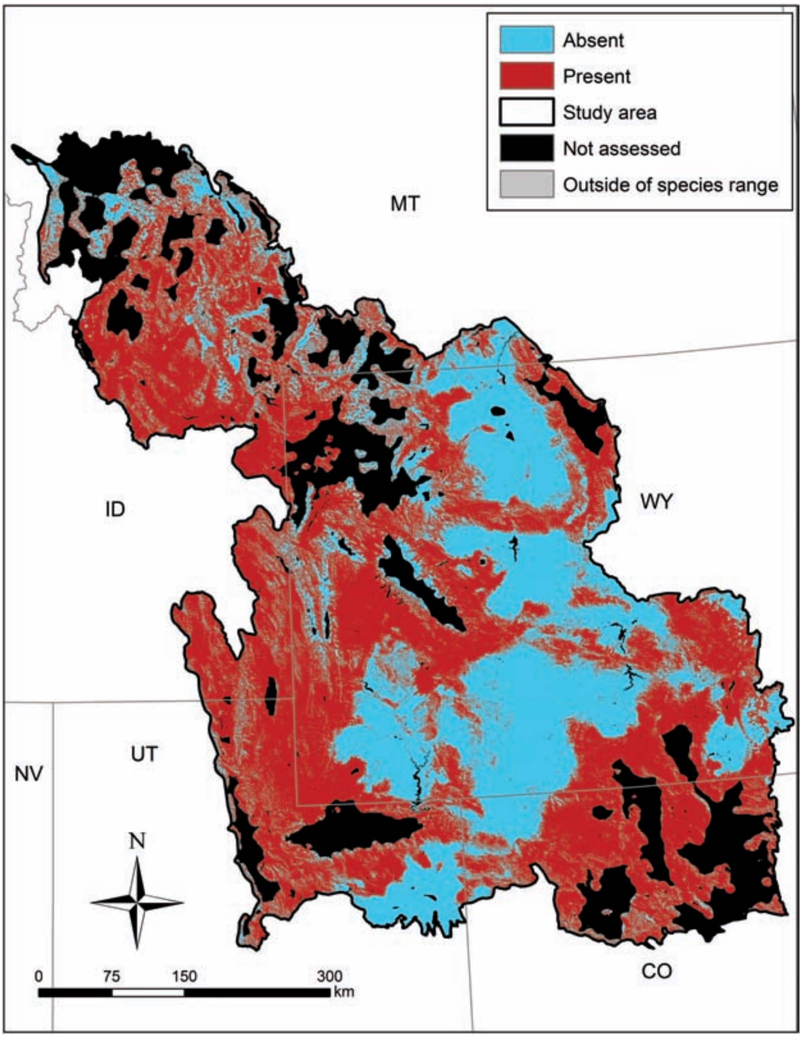

FIG. 7.8. Distribution of thatch ants estimated from ant mound abundance in the Wyoming Basins Ecoregional Assessment area and based on optimum probability cutoff threshold of 0.41. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

$GRASS_{18km} + 7.18 * MIX_{540} - 0.003 * ELEV + 0.03 * TRI_{270} + 1.52 * POWER_{1km} + 0.284 * iH2Od_{250} + 1.08 * RIP_{270} + 0.0009 * EDGE_{5km}))))$

Both the composite model and AIC_c-selected top model of cottontail occurrence had excellent accuracy (ROC AUC = 0.84) when predicting cottontail presence. The optimal cutoff probability for predicting cottontail occurrence based on the sensitivity-specificity equality threshold was 0.47 resulting in an overall percent correctly classified accuracy of 76.6%.

Cottontail probability of occurrence was highest near Green River, Wyoming; Vernal, Utah; and throughout the Worland Basin in the WBEA area (Fig. 7.16). Based on our optimal cutoff point and a binary presence-absence prediction, 121,131 km^2

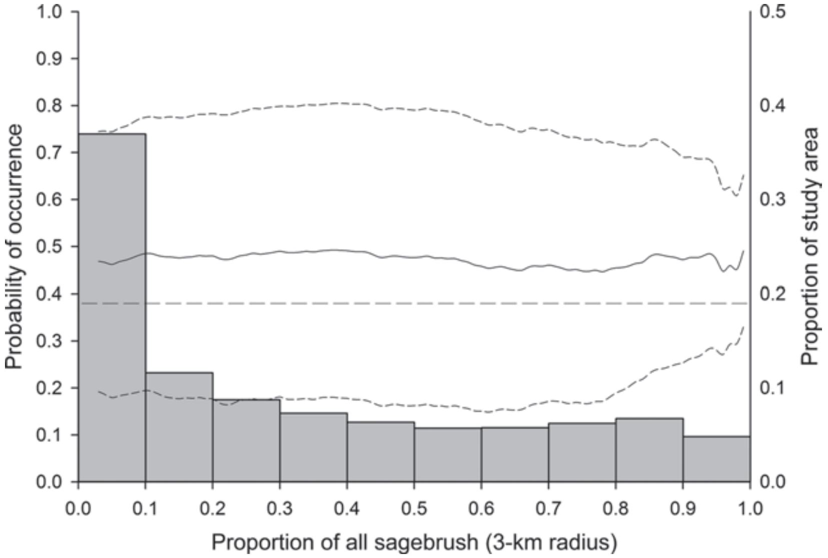

FIG. 7.9. The distribution of thatch ant probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all sagebrush (*Artemesia* spp.) within a 18-km radius. Mean probability of occurrence (black line, ± 1SD [dashed lines]) values were calculated in each one percent increment of all sagebrush within an 18-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.41), above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all sagebrush within 18 km.

TABLE 7.13. Results of AIC_c-based model selection for short-horned lizard occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{5km} + NDVI_{18km}$	-147.23	3	300.54	0.00	0.09
2	$ABIGSAGE_{1km} + NDVI_{18km}$	-147.30	3	300.67	0.14	0.08
3	$ABIGSAGE_{540} + NDVI_{18km}$	-147.39	3	300.85	0.31	0.07
4	$ABIGSAGE_{3km} + NDVI_{18km}$	-147.40	3	300.87	0.33	0.07
5	$ALLSAGE_{1km} + NDVI_{18km}$	-147.57	3	301.21	0.67	0.06
6	$ALLSAGE_{5km} + NDVI_{18km}$	-147.78	3	301.63	1.09	0.05
7	$ALLSAGE_{540} + NDVI_{18km}$	-147.78	3	301.63	1.09	0.05
8	$ALLSAGE_{3km} + NDVI_{18km}$	-147.92	3	301.92	1.38	0.04
9	$ABIGSAGE_{18km} + NDVI_{18km}$	-147.96	3	302.00	1.46	0.04
10	$ALLSAGE_{18km} + NDVI_{18km}$	-147.97	3	302.01	1.48	0.04

[a] Variable definitions provided in Table 4.2

TABLE 7.14. Evaluation statistics from AIC_c-based univariate model selection for short-horned lizard occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran logistic regression models with the all big sagebrush (5-km radius) and NDVI (18-km radius) variables as a base model for all variables tested. We used AIC_c to identify the scale at which short-horned lizards respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$GRASS_{1km}$	-146.95	4	301.98	0.00	0.20
	$GRASS_{5km}$	-147.15	4	302.38	0.40	0.17
	$GRASS_{270}$	-147.19	4	302.46	0.48	0.16
	$GRASS_{3km}$	-147.20	4	302.47	0.49	0.16
	$GRASS_{540}$	-147.20	4	302.48	0.50	0.16
	$GRASS_{18km}$	-147.23	4	302.53	0.55	0.15
	MIX_{5km}	-146.53	4	301.14	0.00	0.36
	MIX_{3km}	-146.93	4	301.93	0.80	0.24
	MIX_{18km}	-147.08	4	302.24	1.11	0.21
	MIX_{1km}	-147.17	4	302.42	1.28	0.19
	RIP_{5km}	-146.81	4	301.70	0.00	0.27
	RIP_{1km}	-147.19	4	302.45	0.75	0.19
	RIP_{540}	-147.22	4	302.52	0.82	0.18
	RIP_{3km}	-147.23	4	302.54	0.84	0.18
	RIP_{18km}	-147.23	4	302.54	0.84	0.18
	$SALT_{540}$	-146.82	4	301.72	0.00	0.41
	$SALT_{1km}$	-147.06	4	302.19	0.48	0.32
	$SALT_{270}$	-147.21	4	302.49	0.78	0.27
	$CONTAG_{5km}$	-146.12	4	300.32	0.00	0.31
	$EDGE_{5km}$	-146.44	4	300.96	0.65	0.23
	$CONTAG_{1km}$	-147.03	4	302.13	1.81	0.13
	$EDGE_{1km}$	-147.14	4	302.35	2.03	0.11
	$EDGE_{3km}$	-147.15	4	302.37	2.05	0.11
	$CONTAG_{3km}$	-147.16	4	302.40	2.08	0.11
Abiotic	CLAY	-147.21	4	302.50	0.00	1.00
	CTI	-145.62	4	299.32	0.00	0.71
	CTI^{2c}	-145.49	5	301.11	1.79	0.29
	ELEV	-146.35	4	300.78	0.00	0.54
	$ELEV^{2c}$	-145.48	5	301.09	0.31	0.46
	$iH2Od_{1km}{}^{b}$	-147.04	4	302.15	0.00	0.34
	$iH2Od_{500}{}^{b}$	-147.05	4	302.17	0.02	0.33
	$iH2Od_{250}{}^{b}$	-147.06	4	302.19	0.05	0.33

TABLE 7.14. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$pH2Od_{250}$[b]	-147.06	4	302.19	0.00	0.37
	$pH2Od_{1km}$[b]	-147.17	4	302.42	0.23	0.33
	$pH2Od_{500}$[b]	-147.23	4	302.53	0.34	0.31
	$SOIL_{cm}$	-147.23	4	302.53	0.00	1.00
	SAND	-147.16	4	302.39	0.00	1.00
	SOLAR	-147.14	4	302.35	0.00	0.65
	$SOLAR^{2c}$	-146.73	5	303.59	1.23	0.35
	Tmin	-146.57	4	301.22	0.00	0.73
	$Tmin^{2c}$	-146.54	5	303.20	1.98	0.27
	TRI_{5km}	-145.67	4	299.42	0.00	0.22
	TRI_{1km}	-145.82	4	299.72	0.30	0.19
	TRI_{18km}	-146.10	4	300.27	0.85	0.14
	TRI_{540}	-146.10	4	300.28	0.86	0.14
	TRI_{3km}	-146.10	4	300.28	0.86	0.14
	TRI_{270}	-146.47	4	301.02	1.60	0.10
	TRI	-146.97	4	302.01	2.59	0.06
Disturbance	AG_{250}[b]	-146.61	4	301.30	0.00	0.43
	AG_{500}[b]	-146.96	4	302.00	0.70	0.30
	AG_{1km}[b]	-147.10	4	302.28	0.98	0.26
	$MjRD_{250}$[b]	-146.63	4	301.34	0.00	0.44
	$MjRD_{500}$[b]	-147.02	4	302.11	0.77	0.30
	$MjRD_{1km}$[b]	-147.18	4	302.44	1.11	0.26
	$PIPE_{1km}$[b]	-146.96	4	301.99	0.00	0.35
	$PIPE_{500}$[b]	-146.99	4	302.05	0.06	0.34
	$PIPE_{250}$[b]	-147.07	4	302.21	0.22	0.31
	$POWER_{500}$[b]	-146.86	4	301.79	0.00	0.35
	$POWER_{1km}$[b]	-146.91	4	301.89	0.11	0.33
	$POWER_{250}$[b]	-146.92	4	301.91	0.12	0.33
	$RDdens_{18km}$	-146.27	4	300.61	0.00	0.17
	$RDdens_{1km}$	-146.57	4	301.22	0.61	0.13
	$2RD_{500}$[b]	-146.64	4	301.36	0.75	0.12
	$2RD_{1km}$[b]	-146.65	4	301.38	0.77	0.12
	$2RD_{250}$[b]	-146.73	4	301.54	0.93	0.11
	$RDdens_{3km}$	-146.85	4	301.78	1.17	0.10
	$RDdens_{5km}$	-146.90	4	301.88	1.27	0.09
	$RDdens_{270}$	-147.02	4	302.12	1.51	0.08

TABLE 7.14. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	RDdens$_{540}$	-147.04	4	302.16	1.55	0.08
	WELL$_{250}$^{b}	-147.07	4	302.21	0.00	0.35
	WELL$_{1km}$^{b}	-147.10	4	302.27	0.06	0.34
	WELL$_{500}$^{b}	-147.22	4	302.52	0.30	0.30

[a] Variable definitions provided in Table 4.2

[b] Distance decay function ($e^{(\text{Euclidean distance from feature /-distance parameter})}$)

[c] Quadratic function (variable + variable^2)

(41.9%) of cottontail habitat was predicted for the Wyoming Basins (Fig. 7.17). Cottontails were likely to occupy areas with sagebrush land cover >60% and <75% within 5 km (Fig. 7.18).

Least chipmunk

Seven predictor variables were excluded because they contained values >0 on <20 survey blocks in the least frequent abundance category (present). These variables included proportion of coniferous forest (0.27 and 0.54 km), grassland (0.27 km), mixed shrubland (0.27, 0.5, 1 km), and riparian (0.27 km). Slope, mean annual maximum temperature, precipitation, and soil bulk density were correlated with other variables and excluded. There was no evidence of non-linear relationships between sagebrush or NDVI and least chipmunk occurrence or sagebrush/NDVI interactions.

Based on logistic regression analyses, the AIC$_c$-selected top sagebrush/NDVI

TABLE 7.15. Results of AIC$_c$-based submodel selection for short-horned lizard occurrence in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC$_c$), change in AIC$_c$ value from the top model (ΔAIC$_c$), and Akaike weight (w_i). Only models with ΔAIC$_c$ ≤ 2 are shown.

Category	Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	1	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CONTAG$_{5km}$	-146.12	4	300.37	0.00	0.08
	2	ABIGSAGE$_{5km}$ + NDVI$_{18km}$	-147.23	3	300.54	0.17	0.07
	3	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + SALT$_{5km}$	-146.42	4	300.96	0.59	0.06
	4	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CONTAG$_{5km}$ + SALT$_{5km}$	-145.47	5	301.13	0.77	0.05
	5	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CONTAG$_{5km}$ + RIP$_{5km}$	-145.50	5	301.19	0.82	0.05
	6	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + MIX$_{5km}$	-146.53	4	301.19	0.82	0.05
	7	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CONTAG$_{5km}$ + MIX$_{5km}$	-145.55	5	301.28	0.92	0.05
	8	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + SALT$_{5km}$ + GRASS$_{1km}$	-145.58	5	301.35	0.98	0.05
	9	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RIP$_{5km}$	-146.81	4	301.75	1.38	0.04
	10	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + SALT$_{5km}$ + MIX$_{5km}$	-145.82	5	301.83	1.46	0.04
	11	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CONTAG$_{5km}$ + SALT$_{5km}$ + GRASS$_{1km}$	-144.83	6	301.94	1.57	0.04
	12	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + GRASS$_{1km}$	-146.95	4	302.03	1.66	0.03
	13	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CONTAG$_{5km}$ + GRASS$_{1km}$	-145.93	5	302.06	1.69	0.03
	14	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CONTAG$_{5km}$ + SALT$_{5km}$ + MIX$_{5km}$	-144.97	6	302.20	1.83	0.03

TABLE 7.15. Continued

Category	Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Abiotic	1	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CTI + TRI$_{5km}$	-142.80	5	295.80	0.00	0.06
	2	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CTI + TRI$_{5km}$ + ELEV	-141.79	6	295.85	0.05	0.06
	3	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CTI + TRI$_{5km}$ + pH2Od$_{250}$	-142.32	6	296.91	1.11	0.03
	4	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CTI + TRI$_{5km}$ + ELEV + pH2Od$_{250}$	-141.45	7	297.25	1.45	0.03
	5	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CTI + TRI$_{5km}$ + Tmin	-142.66	6	297.58	1.78	0.02
	6	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + CTI + TRI$_{5km}$ + iH2Od$_{1km}$	-142.70	6	297.66	1.86	0.02
Disturbance	1	ABIGSAGE$_{5km}$ + NDVI$_{18km}$	-147.23	3	300.54	0.00	0.06
	2	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$	-146.27	4	300.66	0.13	0.05
	3	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$ + AG$_{250}$	-145.56	5	301.30	0.77	0.04
	4	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$ + MjRD$_{250}$	-145.57	5	301.33	0.79	0.04
	5	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + AG$_{250}$	-146.61	4	301.35	0.81	0.04
	6	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + MjRD$_{250}$	-146.63	4	301.39	0.85	0.04
	7	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + POWER$_{500}$	-146.86	4	301.84	1.30	0.03
	8	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$ + POWER$_{500}$	-145.85	5	301.90	1.36	0.03
	9	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$ + WELL$_{250}$	-145.91	5	302.01	1.47	0.03
	10	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + PIPE$_{1km}$	-146.96	4	302.04	1.50	0.03
	11	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + WELL$_{250}$	-147.07	4	302.26	1.73	0.02
	12	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$ + AG$_{250}$ + MjRD$_{250}$	-145.00	6	302.27	1.73	0.02
	13	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$ + MjRD$_{250}$ + POWER$_{500}$	-145.08	6	302.42	1.88	0.02
	14	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + RDdens$_{18km}$ + PIPE$_{1km}$	-146.12	5	302.42	1.88	0.02
	15	ABIGSAGE$_{5km}$ + NDVI$_{18km}$ + AG$_{250}$ + MjRD$_{250}$	-146.15	5	302.49	1.96	0.02

[a] Variable definitions provided in Table 4.2

model consisted of big sagebrush (5-km, BIGSAGE$_{5km}$) (Table 7.25). Within 5-km there was 9.7% less big sagebrush at presence sites (46.9%, SE = 4.1) than at absence sites (56.5%, SE = 1.6; Appendix 7.6).

After assessing individual multi-scale covariates (Table 7.27) and developing submodels, the top vegetation submodel for least chipmunk use consisted of grassland within 3 km (GRASS$_{3km}$), mixed shrubland within 18 km (MIX$_{18km}$), and all sagebrush edge density within 3 km (EDGE$_{3km}$), in addition to the sagebrush/NDVI base model (Table 7.28). Mean minimum temperature (Tmin), topographic ruggedness within 18 km (TRI$_{18km}$), solar radiation (SOLAR), and percent soil sand content (SAND) were important abiotic predictors (Table 7.28). Four disturbance factors, 1-km distance decay from power lines (POWER$_{1km}$), 0.25-km distance decay from pipelines (PIPE$_{250}$), 1-km distance decay from interstates/major highways (MjRD$_{1km}$), and 0.5-km distance decay from oil/gas wells (WELL$_{500}$), were included in the top disturbance submodel (Table 7.28).

The AIC$_c$-selected top least chipmunk model was a combination of vegetation, abiotic, and disturbance factors. Least chipmunks were negatively associated with large expanses of big sagebrush

TABLE 7.16. Results of AIC_c-based model selection for the combined short-horned lizard occurrence model[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Intercept	$ABIGSAGE_{5km}$	$NDVI_{18km}$	$CONTAG_{5km}$	CTI	TRI_{5km}	LL	K	AIC_c	ΔAIC_c	Σw_i
1	2.00 (1.70)	0.11 (1.54)	-4.50 (2.36)	0.02 (0.01)	-0.21 (0.09)	-0.04 (0.02)	-141.35	6	294.97	0.00	0.441
2	0.39 (1.45)	2.39 (1.17)	-3.09 (2.15)		-0.19 (0.09)	-0.04 (0.02)	-142.80	5	295.80	0.83	0.731
3	0.62 (1.50)	1.28 (1.34)	-6.98 (2.30)	0.02 (0.01)	-0.14 (0.08)		-144.17	5	298.52	3.55	0.806
4	-0.78 (1.34)	3.21 (1.14)	-5.54 (2.05)		-0.13 (0.08)		-145.62	4	299.37	4.40	0.855
5	-1.65 (1.09)	2.40 (1.12)	-2.77 (2.15)			-0.03 (0.02)	-145.67	4	299.47	4.50	0.901

[a] Variable definitions provided in Table 4.2

land cover, increased all sagebrush edge density, increased mean minimum temperature, and proximity to pipelines, but positively associated with proximity to power lines (Table 7.29). The weight of evidence for the top model was low (w_i = 0.04) with 136 models with a cumulative Akaike weight of just ≥ 0.9. Variables in these other candidate models showed that least chipmunk locations also were positively associated with increased solar radiation, and proximity to highways and oil/gas wells, but negatively associated with topographic ruggedness, proportion of mixed shrubland and grassland land cover, and percent soil sand content (Table 7.29). The final composite probability of occurrence model is below.

$$\text{Prob} = 1 / (1 + (\exp(-(-1.26 - 0.92 * BIGSAGE_{5km} - 0.02 * EDGE_{3km} - 0.25 * Tmin - 0.46 * PIPE_{250} + 0.51 * POWER_{1km} + 0.002 * SOLAR - 0.01 * TRI_{18km} - 0.003 * SAND + 0.15 * MjRD_{1km} - 2.57 * MIX_{18km} + 0.37 * WELL_{500} + -0.41 * GRASS_{3km})))) \tag{7.7}$$

The composite model of least chipmunk occurrence had good model accuracy (ROC AUC = 0.75). The model accuracy of the composite was a slight improvement over the AIC_c-selected top model (ROC AUC = 0.74). The optimal cutoff probability for predicting least chipmunk occurrence based on sensitivity and specificity equality threshold was 0.18 resulting in an overall percent correctly classified accuracy of 69.4%.

Least chipmunk occurrence was predicted to be highest in high-elevation shrubland areas of the south east and western portions of the Wyoming Basins Ecoregional Assessment area (Fig. 7.19). Within the Wyoming Basins, 44.4% of the area (153,437 km^2) was predicted to be suitable least chipmunk habitat (Fig. 7.20) using our optimal cutoff point and a binary presence/absence classification. Least

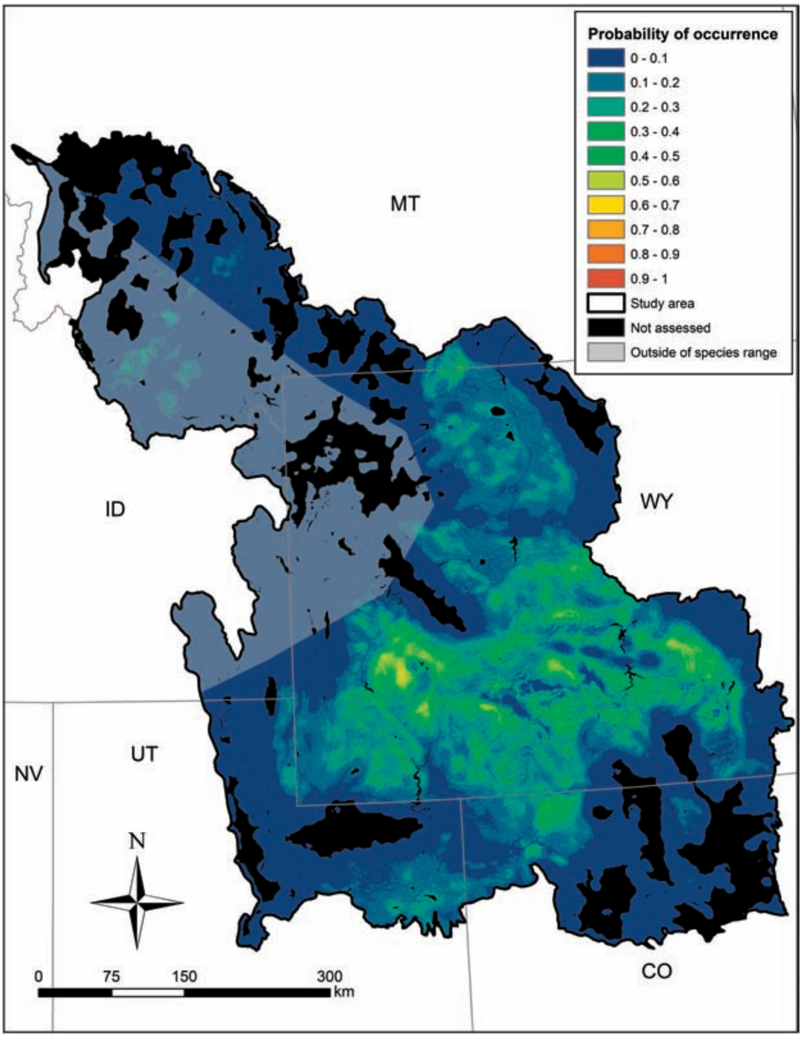

FIG. 7.10. Short-horned lizard probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the range of the short-horned lizard; black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Short-horned lizards are likely to occur in areas with probability > 0.22.

chipmunks were more likely to occur in areas with <6 or >91% big sagebrush within 5-km (Fig. 7.21).

Model Evaluation

Short-horned lizards were the only species for which we had sufficient data to evaluate models. Our model of short-horned lizard occurrence validated well (Fig. 7.22) with slope of observed versus expected values being close to 1.0 and the intercept close to zero (slope = 0.89, 95% CI = -0.15–1.92; intercept = -0.014, 95% CI = -0.16–0.19, R^2 = 0.426), although fit was only moderate suggesting variation among binned occurrence classes.

DISCUSSION

Understanding the distribution of wildlife species, both common and rare, is important to assessing the integrity of the

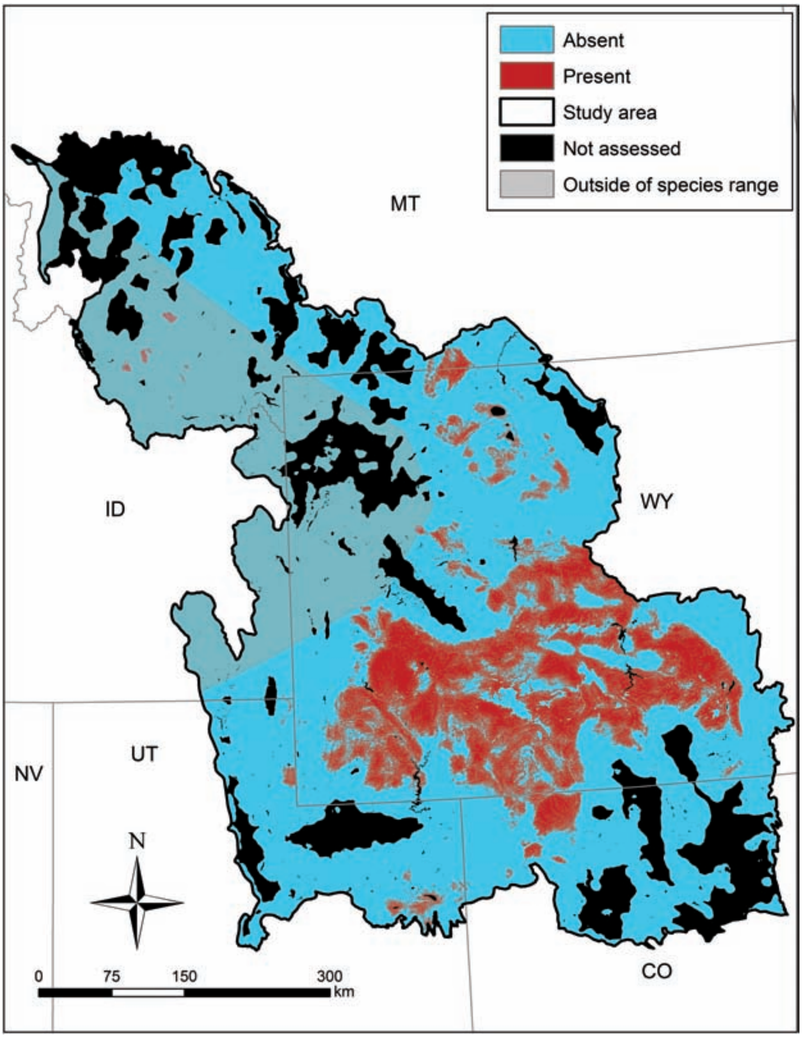

FIG. 7.11. Distribution of short-horned lizards in the Wyoming Basins Ecoregional Assessment area based on optimum probability cutoff threshold of 0.22. Semi-transparent grey shaded areas are outside the range of the short-horned lizard, black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

wildlife community of a region. Knowing how sagebrush-associated wildlife species respond to habitat and disturbance characteristics and the spatial distribution of these species provides information useful for resource managers when planning treatments or mitigation efforts. For example, information on the distribution of seed predators may help when planning seed mixes or the timing of the seeding itself, and the distribution of potential prey species can help guide management of predator species of conservation concern, such as the ferruginous hawk. Below, we discuss the key factors influencing abundance or occurrence of each species assessed across the WBEA.

Harvester Ant

Harvester ants were negatively associated with high productivity and large expanses of sagebrush. Areas of high productivity generally have increased soil

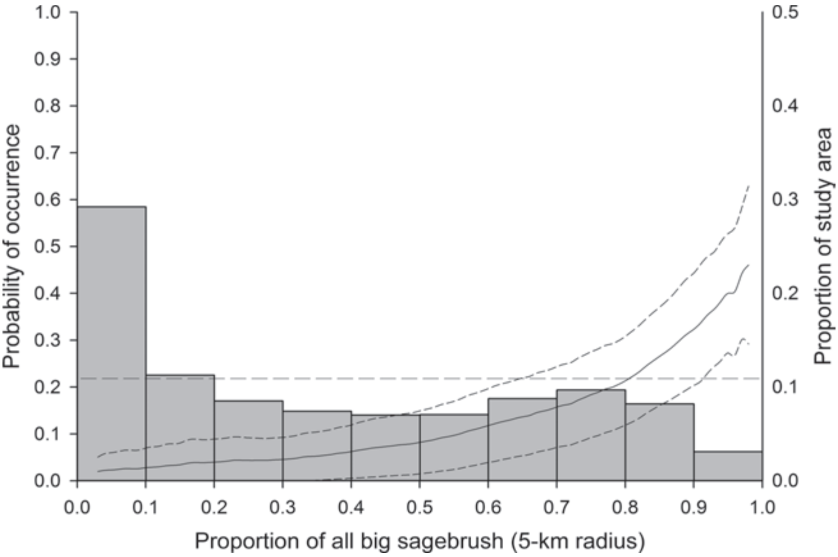

FIG. 7.12. Distribution of short-horned lizard probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemesia tridentata*) within a 5-km radius. Mean probability of occurrence (black line, ±1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 5-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.22), above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 5 km.

moisture which can be problematic for harvester ants because high levels of moisture in the nest can lead to germination of cached seed (Cole 1932a). Increases in harvester ant mound abundance has been associated with a reduction in cover of sagebrush (Sneva 1979) and other perennial shrubs (Sharp and Barr 1960). In Oregon, the number of mounds more than doubled following a 95% reduction in sagebrush cover (Sneva 1979). However, harvester ants in Idaho had their highest densities in sagebrush communities (Blom et al. 1991), although there was a high degree of variability in densities that was attributable to differences in soil characteristics.

Several soil characteristics were important predictors of harvester ant occurrence

TABLE 7.17. Results of AIC$_c$-based model selection for white-tailed jackrabbit occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC$_c$), change in AIC$_c$ value from the top model (ΔAIC$_c$), and Akaike weight (w_i). Only models with Δ AIC$_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
1	BIGSAGE$_{270}$	-165.48	2	335.01	0.00	0.11
2	BIGSAGE$_{270}$ + NDVI	-165.22	3	336.51	1.51	0.05
3	BIGSAGE$_{270}$ + NDVI$_{270}$	-165.28	3	336.64	1.64	0.05
4	BIGSAGE$_{270}$ + NDVI$_{540}$	-165.41	3	336.90	1.90	0.04
5	BIGSAGE$_{270}$ + NDVI$_{18km}$	-165.45	3	336.97	1.96	0.04
6	BIGSAGE$_{270}$ + NDVI$_{3km}$	-165.45	3	336.97	1.97	0.04

[a] Variable definitions provided in Table 4.2

TABLE 7.18. Evaluation statistics from AIC_c-based univariate model selection for white-tailed jackrabbit occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran generalized ordered logistic models with the big sagebrush (0.27-km radius) variable as a base model for all variables tested. We used AIC_c to identify the scale at which white-tailed jackrabbits respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{18km}$	-165.34	3	336.72	0.00	0.34
	$CFRST_{5km}$	-165.35	3	336.74	0.02	0.34
	$CFRST_{3km}$	-165.43	3	336.90	0.18	0.31
	$GRASS_{540}$	-163.52	3	333.07	0.00	0.32
	$GRASS_{1km}$	-163.86	3	333.75	0.68	0.22
	$GRASS_{270}$	-163.93	3	333.89	0.82	0.21
	$GRASS_{3km}$	-164.38	3	334.80	1.73	0.13
	$GRASS_{5km}$	-165.13	3	336.30	3.23	0.06
	$GRASS_{18km}$	-165.32	3	336.67	3.60	0.05
	MIX_{5km}	-165.40	3	336.84	0.00	0.21
	MIX_{3km}	-165.44	3	336.92	0.08	0.20
	MIX_{1km}	-165.47	3	336.98	0.14	0.20
	MIX_{18km}	-165.47	3	336.99	0.14	0.20
	MIX_{540}	-165.48	3	336.99	0.15	0.20
	RIP_{1km}	-165.33	3	336.69	0.00	0.18
	RIP_{540}	-165.41	3	336.85	0.16	0.17
	RIP_{18km}	-165.42	3	336.88	0.19	0.17
	RIP_{270}	-165.43	3	336.91	0.22	0.17
	RIP_{3km}	-165.48	3	337.00	0.31	0.16
	RIP_{5km}	-165.48	3	337.00	0.32	0.16
	$SALT_{3km}$	-162.78	3	331.60	0.00	0.40
	$SALT_{5km}$	-163.08	3	332.20	0.59	0.30
	$SALT_{18km}$	-163.87	3	333.78	2.18	0.13
	$SALT_{1km}$	-164.23	3	334.49	2.88	0.09
	$SALT_{540}$	-164.92	3	335.87	4.27	0.05
	$SALT_{270}$	-165.41	3	336.86	5.25	0.03
	$PATCH_{1km}$	-164.11	3	334.25	0.00	0.24
	$EDGE_{3km}$	-164.50	3	335.03	0.78	0.16
	$CONTAG_{5km}$	-164.68	3	335.40	1.16	0.13
	$PATCH_{3km}$	-164.92	3	335.87	1.62	0.10
	$PATCH_{5km}$	-165.01	3	336.05	1.80	0.10
	$EDGE_{5km}$	-165.28	3	336.59	2.34	0.07
	$CONTAG_{1km}$	-165.34	3	336.73	2.48	0.07

TABLE 7.18. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$CONTAG_{3km}$	-165.36	3	336.76	2.51	0.07
	$EDGE_{1km}$	-165.40	3	336.83	2.59	0.06
Abiotic	CTI^{2b}	-164.15	4	336.38	0.00	0.58
	CTI	-165.48	3	337.00	0.62	0.42
	ELEV	-165.33	3	336.69	0.00	0.71
	$ELEV^{2b}$	-165.21	4	338.50	1.81	0.29
	$iH2Od_{1km}^{c}$	-165.32	3	336.68	0.00	0.35
	$iH2Od_{500}^{c}$	-165.34	3	336.71	0.03	0.34
	$iH2Od_{250}^{c}$	-165.42	3	336.89	0.20	0.31
	$pH2Od_{500}^{c}$	-164.31	3	334.65	0.00	0.37
	$pH2Od_{1km}^{c}$	-164.45	3	334.93	0.29	0.32
	$pH2Od_{250}^{c}$	-164.50	3	335.04	0.39	0.31
	$SOLAR^{2b}$	-163.88	4	335.83	0.00	0.56
	SOLAR	-165.13	3	336.29	0.46	0.44
	Tmin	-165.42	3	336.89	0.00	0.71
	$Tmin^{2b}$	-165.31	4	338.69	1.81	0.29
	TRI_{540}	-163.32	3	332.68	0.00	0.33
	TRI_{270}	-163.50	3	333.04	0.36	0.28
	TRI_{1km}	-164.34	3	334.72	2.04	0.12
	TRI	-164.49	3	335.01	2.33	0.10
	TRI_{18km}	-164.89	3	335.82	3.13	0.07
	TRI_{5km}	-165.23	3	336.49	3.81	0.05
	TRI_{3km}	-165.36	3	336.76	4.07	0.04
Disturbance	AG_{250}^{c}	-165.00	3	336.04	0.00	0.38
	AG_{500}^{c}	-165.13	3	336.29	0.25	0.33
	AG_{1km}^{c}	-165.27	3	336.57	0.53	0.29
	$MjRD_{1km}^{c}$	-162.73	3	331.49	0.00	0.41
	$MjRD_{500}^{c}$	-162.79	3	331.62	0.13	0.38
	$MjRD_{250}^{c}$	-163.36	3	332.77	1.27	0.21
	$PIPE_{500}^{c}$	-165.30	3	336.64	0.00	0.35
	$PIPE_{1km}^{c}$	-165.34	3	336.73	0.08	0.33
	$PIPE_{250}^{c}$	-165.40	3	336.84	0.19	0.32
	$POWER_{500}^{c}$	-163.83	3	333.70	0.00	0.37
	$POWER_{1km}^{c}$	-163.94	3	333.92	0.22	0.33
	$POWER_{250}^{c}$	-164.05	3	334.13	0.44	0.30
	$RDdens_{3km}$	-163.86	3	333.76	0.00	0.33

TABLE 7.18. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{5km}$	-164.62	3	335.29	1.52	0.15
	$RDdens_{18km}$	-165.18	3	336.39	2.63	0.09
	$2RD_{500}{}^{c}$	-165.24	3	336.51	2.75	0.08
	$2RD_{1km}{}^{c}$	-165.24	3	336.52	2.76	0.08
	$2RD_{250}{}^{c}$	-165.33	3	336.69	2.93	0.08
	$RDdens_{1km}$	-165.44	3	336.91	3.15	0.07
	$RDdens_{540}$	-165.48	3	337.00	3.24	0.06
	$RDdens_{270}$	-165.48	3	337.00	3.24	0.06
	$WELL_{500}{}^{c}$	-164.93	3	335.90	0.00	0.35
	$WELL_{1km}{}^{c}$	-164.96	3	335.96	0.06	0.34
	$WELL_{250}{}^{c}$	-165.09	3	336.22	0.31	0.30

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + $variable^2$)

[c] Distance decay function ($e^{(\text{Euclidean distance from feature/-distance parameter})}$)

within the Wyoming Basins. Soil sand content and soil depth were positively associated, and soil clay content was negatively associated, with harvester ant occurrence. In Idaho, high harvester ant densities were also associated with increased sand content (Blom et al. 1991). Sand content may improve the ability of harvester ants to build nests and increase availability of pebbles for making nest mounds (Cole 1932a). Harvester ant (*P. occidentalis*) locations in North Dakota, at the eastern edge of the species range, all contained high percent sand content, and no sites were found in clay or silty clay loam soils (DeMers 1993). Increased soil depth may be necessary for proper nest construction because harvester ants use relatively deep reaches of the soil profile (Lavigne 1969, Fitzner et al. 1979, MacKay 1981). In central Oregon, the highest colony densities were found on deep soils with low densities occurring on rocky, shallow soils (Willard and Crowell 1965). Overwintering workers have been found as deep as 2.7 m in Wyoming (Lavigne 1969) and Washington (Fitzner et al. 1979).

Grassland and salt desert shrubland were both negatively associated with harvester ant occurrence, whereas sagebrush edge density was positively associated with harvester ants. Mounds were scarce in shadscale saltbush (*Atriplex confertifolia*) habitats in Idaho and western Wyoming (Cole 1932a, Sharp and Barr 1960, Blom et al. 1991), and densities were lower in crested wheatgrass (*Agropyron cristatum*), Indian ricegrass (*Achnatherum hymenoides*), and basin wildrye (*Leymus cinerus*) communities (Blom et al. 1991). An increase in sagebrush patch edges may provide increased proximity to a variety of food sources, enhancing ant density.

The only other abiotic factor in addition to soil characteristics was a positive association with increased minimum temperatures when predicting harvester ant occurrence. Harvester ants are temperature sensitive and limit daily and seasonal foraging to specific temperature ranges with activity occurring between 25 to 55 C and maximum foraging between 40 to 45 C (Crist and MacMahon 1991). At a grassland site in northeastern Colorado,

TABLE 7.19. Results of AIC_c -based submodel selection for white-tailed jackrabbit occurrence in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$BIGSAGE_{270}$ + $GRASS_{540}$ + $SALT_{3km}$	-160.35	4	328.77	0.00	0.18
	2	$BIGSAGE_{270}$ + $CFRST_{18km}$ + $GRASS_{540}$ + $SALT_{3km}$	-160.22	5	330.57	1.80	0.08
	3	$BIGSAGE_{270}$ + $GRASS_{540}$ + RIP_{1km} + $SALT_{3km}$	-160.31	5	330.74	1.97	0.07
Abiotic	1	$BIGSAGE_{270}$ + TRI_{540}	-163.32	3	332.68	0.00	0.07
	2	$BIGSAGE_{270}$ + $pH2Od_{500}$ + TRI_{540}	-162.81	4	333.69	1.01	0.04
	3	$BIGSAGE_{270}$ + SOLAR + SOLAR2 + TRI_{540}	-161.82	5	333.76	1.08	0.04
	4	$BIGSAGE_{270}$ + ELEV + TRI_{540}	-163.08	4	334.23	1.55	0.03
	5	$BIGSAGE_{270}$ + Tmin + TRI_{540}	-163.16	4	334.39	1.71	0.03
	6	$BIGSAGE_{270}$ + $iH2Od_{1km}$ + TRI_{540}	-163.20	4	334.48	1.80	0.03
	7	$BIGSAGE_{270}$ + ELEV + Tmin + TRI_{540}	-162.21	5	334.54	1.86	0.03
	8	$BIGSAGE_{270}$ + $pH2Od_{500}$	-164.31	3	334.65	1.97	0.03
Disturbance	1	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $PIPE_{500}$ + $POWER_{500}$	-158.79	6	329.78	0.00	0.05
	2	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $PIPE_{500}$ + $POWER_{500}$ + AG_{250}	-157.84	7	329.94	0.16	0.04
	3	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $WELL_{500}$	-159.93	5	329.99	0.21	0.04
	4	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $PIPE_{500}$ + $POWER_{500}$ + $WELL_{500}$	-157.85	7	329.96	0.19	0.04
	5	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + AG_{250} + $WELL_{500}$	-158.90	6	329.99	0.22	0.04
	6	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $PIPE_{500}$ + $POWER_{500}$	-159.96	5	330.05	0.27	0.04
	7	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $PIPE_{500}$ + $POWER_{500}$ + AG_{250} + $WELL_{500}$	-156.88	8	330.11	0.33	0.04
	8	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $PIPE_{500}$ + $POWER_{500}$+ AG_{250}	-159.06	6	330.31	0.53	0.04
	9	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $PIPE_{500}$ + AG_{250} + $WELL_{500}$	-158.04	7	330.34	0.56	0.04
	10	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $PIPE_{500}$ + $RDdens_{3km}$ + $WELL_{500}$	-159.17	6	330.53	0.75	0.03
	11	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $PIPE_{500}$ + AG_{250}	-159.17	6	330.53	0.76	0.03
	12	$BIGSAGE_{270}$ + $MjRD_{1km}$ + $RDdens_{3km}$ + $POWER_{500}$ + $WELL_{500}$	-159.22	6	330.64	0.86	0.03

harvester ants opened mound entrances when soil surface temperatures reached 24 C, but little activity took place until temperatures reached 28 C (Rogers 1974). Mean minimum temperatures may be low enough within the areas of the WBEA that they limit harvester ant foraging activity, therefore reducing their probability of occurrence and abundance.

Ants were positively associated with two disturbance factors: proximity to agricultural land and pipelines. Soil disturbances associated with these areas may lead to increased seed production by exotic invasive species, leading to increased food resources. In areas with high cover of cheatgrass, harvester ants harvested large quantities of cheatgrass seed (Cole 1932a).

Proximity to oil/gas development was negatively associated with harvester ant occurrence. Disturbance of the soil surface and crested wheatgrass seedings were negatively associated with nest densities in Idaho (Blom et al. 1991). Both are characteristics of active oil and gas fields with crested wheatgrass commonly used in well pad reclamation efforts and subsequently associated with oil/gas well locations (Ch. 10). Also, drilling rigs, pump stations, or condensation tanks at active well pads can cause shadowing which can induce emigration in actively foraging colonies of *P. occidentalis* (Coffin and Lauenroth 1990).

Abundance of harvester ants on survey blocks in the WBEA were similar to previous studies (3-80 mounds/ha; Soule and Knapp 1996). Although we were unable to conduct a formal analysis of detection probability, this comparison is evidence that our abundance estimates were comparable with previous research. This is not a substitute for a detection analysis, and we encourage future efforts account for detectability when possible.

Thatch Ant

Thatch ants were positively associated with large expanses of sagebrush land cover. Thatch ants were most abundant

TABLE 7.19. Continued

Category	Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	13	$BIGSAGE_{270} + MjRD_{1km} + RDdens_{3km} + PIPE_{500}$	-160.29	5	330.71	0.94	0.03
	14	$BIGSAGE_{270} + AG_{250} + MjRD_{1km} + RDdens_{3km} + POWER_{500} + WELL_{500}$	-158.34	7	330.94	1.16	0.03
	15	$BIGSAGE_{270} + MjRD_{1km} + RDdens_{3km}$	-161.51	4	331.09	1.31	0.02
	16	$BIGSAGE_{270} + AG_{250} + MjRD_{1km} + PIPE_{500}$	-160.51	5	331.15	1.38	0.02
	17	$BIGSAGE_{270} + AG_{250} + RDdens_{3km} + MjRD_{1km}$	-160.54	5	331.20	1.42	0.02
	18	$BIGSAGE_{270} + MjRD_{1km} + PIPE_{500}$	-161.59	4	331.25	1.47	0.02
	19	$BIGSAGE_{270} + RDdens_{3km} + POWER_{500} + WELL_{500}$	-160.61	5	331.35	1.57	0.02
	20	$BIGSAGE_{270} + MjRD_{1km}$	-162.73	3	331.49	1.72	0.02
	21	$BIGSAGE_{270} + MjRD_{1km} + RDdens_{3km} + POWER_{500}$	-160.74	5	331.60	1.83	0.02
	22	$BIGSAGE_{270} + MjRD_{1km} + AG_{250}$	-161.79	4	331.66	1.89	0.02
	23	$BIGSAGE_{270} + MjRD_{1km} + POWER_{500}$	-161.81	4	331.70	1.93	0.02

[a] Variable definitions provided in Table 4.2

TABLE 7.20. Results of AIC$_c$-based model selection for the combined white-tailed jackrabbit occurrence models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Intercept	BIGSAGE$_{270}$	GRASS$_{540}$	SALT$_{3km}$	TRI$_{540}$	MjRD$_{1km}$
1	-1.66 (0.59)	1.12 (0.55)	3.29 (1.34)	2.82 (1.43)	-0.02 (0.01)	-1.82 (0.78)
2	-1.61 (0.59)	1.11 (0.55)	3.21 (1.34)	2.85 (1.43)	-0.02 (0.01)	-1.58 (0.78)
3	-1.57 (0.59)	1.02 (0.55)	2.97 (1.36)	2.60 (1.45)	-0.02 (0.01)	-1.88 (0.83)
4	-1.34 (0.66)	1.15 (0.56)	3.11 (1.35)	2.67 (1.43)	-0.02 (0.01)	-1.73 (0.78)
5	-1.32 (0.66)	1.14 (0.55)	3.04 (1.35)	2.72 (1.44)	-0.02 (0.01)	-1.51 (0.78)
6	-1.64 (0.59)	1.06 (0.55)	3.15 (1.36)	2.62 (1.45)	-0.02 (0.01)	-2.06 (0.84)
7	-1.21 (0.53)	0.87 (0.52)	3.02 (1.33)		-0.03 (0.01)	-1.90 (0.78)
8	-1.17 (0.53)	0.78 (0.52)	2.69 (1.34)		-0.03 (0.01)	-2.02 (0.83)
9	-1.15 (0.53)	0.86 (0.52)	2.95 (1.33)		-0.03 (0.01)	-1.67 (0.78)
10	-2.51 (0.43)	1.64 (0.50)	3.16 (1.33)	3.53 (1.39)		-1.61 (0.77)
11	-0.86 (0.60)	0.91 (0.53)	2.81 (1.33)		-0.03 (0.01)	-1.79 (0.77)
12	-1.30 (0.66)	1.08 (0.56)	2.95 (1.36)	2.45 (1.46)	-0.02 (0.01)	-1.98 (0.84)
13	-2.47 (0.43)	1.64 (0.50)	3.08 (1.33)	3.59 (1.39)		-1.39 (0.77)
14	-0.83 (0.60)	0.82 (0.53)	2.48 (1.35)		-0.03 (0.01)	-1.94 (0.82)
15	-1.23 (0.53)	0.82 (0.52)	2.85 (1.34)		-0.03 (0.01)	-2.21 (0.84)
16	-2.40 (0.43)	1.52 (0.50)	2.84 (1.34)	3.30 (1.42)		-1.71 (0.82)
17	-0.83 (0.60)	0.90 (0.53)	2.76 (1.33)		-0.03 (0.01)	-1.59 (0.78)
18	-0.87 (0.60)	0.85 (0.53)	2.63 (1.34)		-0.03 (0.01)	-2.12 (0.83)
19	-2.20 (0.51)	1.68 (0.50)	2.98 (1.34)	3.38 (1.39)		-1.52 (0.76)
20	-1.88 (0.58)	1.18 (0.55)	3.01 (1.33)	3.10 (1.42)	-0.02 (0.01)	
21	-1.24 (0.54)	0.70 (0.51)		2.23 (1.42)	-0.02 (0.01)	-1.80 (0.81)
22	-2.18 (0.51)	1.68 (0.50)	2.92 (1.34)	3.46 (1.39)		-1.32 (0.76)
23	-2.48 (0.43)	1.56 (0.51)	3.02 (1.34)	3.30 (1.42)		-1.87 (0.83)
24	-2.09 (0.51)	1.56 (0.50)	2.64 (1.35)	3.13 (1.42)		-1.64 (0.81)
25	-0.55 (0.56)	0.59 (0.50)			-0.03 (0.01)	-1.85 (0.80)
26	-1.26 (0.54)	0.79 (0.51)		2.53 (1.40)	-0.02 (0.01)	-1.47 (0.77)
27	-1.30 (0.54)	0.79 (0.51)		2.47 (1.39)	-0.02 (0.01)	-1.72 (0.77)
28	-0.87 (0.61)	0.75 (0.52)		2.07 (1.42)	-0.02 (0.01)	-1.72 (0.80)
29	-0.92 (0.49)	0.53 (0.49)			-0.03 (0.01)	-1.93 (0.81)
30	-1.51 (0.66)	1.21 (0.55)	2.81 (1.34)	2.95 (1.43)	-0.02 (0.01)	
31	-0.92 (0.61)	0.83 (0.51)		2.30 (1.40)	-0.02 (0.01)	-1.61 (0.76)
32	-0.91 (0.61)	0.83 (0.51)		2.38 (1.40)	-0.02 (0.01)	-1.38 (0.76)
33	-2.15 (0.51)	1.60 (0.51)	2.81 (1.35)	3.12 (1.42)		-1.79 (0.82)
34	-2.60 (0.42)	1.64 (0.49)	2.97 (1.32)	3.71 (1.39)		

TABLE 7.20. Extended

POWER$_{500}$	PIPE$_{500}$	RDdens$_{3km}$	LL	K	AIC$_c$	ΔAIC$_c$	$\sum w_i$
			-155.53	6	323.32	0.00	0.069
-1.37 (1.11)			-154.59	7	323.53	0.21	0.132
-1.66 (1.12)	0.83 (0.66)		-153.82	8	324.10	0.78	0.179
		-0.23 (0.22)	-154.94	7	324.24	0.91	0.223
-1.32 (1.12)		-0.22 (0.22)	-154.09	8	324.64	1.32	0.259
	0.53 (0.63)		-155.18	7	324.72	1.40	0.294
			-157.42	5	325.02	1.70	0.323
-1.67 (1.12)	1.00 (0.65)		-155.38	7	325.11	1.79	0.352
-1.35 (1.12)			-156.52	6	325.32	1.99	0.377
			-157.61	5	325.42	2.09	0.402
		-0.27 (0.22)	-156.62	6	325.51	2.19	0.425
	0.58 (0.63)	-0.25 (0.22)	-154.53	8	325.51	2.19	0.448
-1.34 (1.08)			-156.67	6	325.61	2.29	0.470
-1.65 (1.14)	1.04 (0.65)	-0.27 (0.22)	-154.60	8	325.65	2.33	0.492
	0.73 (0.62)		-156.76	6	325.78	2.46	0.513
-1.66 (1.10)	0.88 (0.66)		-155.80	7	325.95	2.63	0.531
-1.28 (1.13)		-0.25 (0.22)	-155.84	7	326.03	2.71	0.549
	0.77 (0.62)	-0.28 (0.22)	-155.89	7	326.14	2.82	0.566
		-0.23 (0.22)	-157.01	6	326.28	2.96	0.582
-1.87 (1.13)			-157.07	6	326.40	3.08	0.597
-1.81 (1.13)	1.00 (0.65)		-156.12	7	326.60	3.28	0.610
-1.28 (1.09)		-0.22 (0.22)	-156.16	7	326.68	3.36	0.623
	0.57 (0.63)		-157.21	6	326.69	3.37	0.636
-1.65 (1.11)	0.93 (0.66)	-0.24 (0.22)	-155.18	8	326.82	3.50	0.648
-1.78 (1.15)	1.18 (0.64)	-0.31 (0.22)	-156.24	7	326.83	3.51	0.660
-1.45 (1.13)			-157.29	6	326.84	3.52	0.672
			-158.34	5	326.87	3.55	0.684
-1.80 (1.15)	1.05 (0.65)	-0.29 (0.22)	-155.21	8	326.88	3.55	0.696
-1.80 (1.13)	1.15 (0.64)		-157.33	6	326.93	3.61	0.707
-1.79 (1.13)		-0.26 (0.22)	-156.35	7	327.06	3.74	0.718
		-0.29 (0.22)	-157.41	6	327.08	3.76	0.728
-1.39 (1.13)		-0.27 (0.22)	-156.48	7	327.31	3.98	0.738
	0.62 (0.63)	-0.25 (0.22)	-156.53	7	327.42	4.10	0.747
-1.76 (1.10)			-158.62	5	327.44	4.12	0.756

TABLE 7.20. Continued

Rank	Intercept	$BIGSAGE_{270}$	$GRASS_{540}$	$SALT_{3km}$	TRI_{540}	$MjRD_{1km}$
35	-0.54 (0.56)	0.66 (0.49)			-0.03 (0.01)	-1.67 (0.76)
36	-0.58 (0.56)	0.61 (0.50)			-0.03 (0.01)	-2.03 (0.82)
37	-1.29 (0.54)	0.73 (0.51)		2.22 (1.41)	-0.02 (0.01)	-2.01 (0.83)
38	-0.90 (0.61)	0.77 (0.52)		2.03 (1.42)	-0.02 (0.01)	-1.91 (0.82)
39	-0.94 (0.49)	0.61 (0.49)			-0.03 (0.01)	-1.80 (0.77)
40	-0.88 (0.49)	0.60 (0.49)			-0.03 (0.01)	-1.56 (0.77)
41	-0.52 (0.56)	0.65 (0.49)			-0.03 (0.01)	-1.46 (0.76)
42	-2.01 (0.36)	1.17 (0.45)		2.88 (1.38)		-1.67 (0.80)
43	-0.97 (0.49)	0.55 (0.49)			-0.03 (0.01)	-2.14 (0.82)
44	-2.03 (0.57)	1.23 (0.55)	3.09 (1.33)	3.08 (1.42)	-0.02 (0.01)	
45	-2.25 (0.51)	1.68 (0.50)	2.78 (1.33)	3.56 (1.39)		
46	-1.88 (0.57)	1.15 (0.55)	2.90 (1.36)	3.03 (1.43)	-0.02 (0.01)	
47	-1.66 (0.44)	1.23 (0.45)		2.72 (1.38)		-1.59 (0.80)
48	-1.60 (0.65)	1.25 (0.55)	2.86 (1.34)	2.90 (1.43)	-0.02 (0.01)	
49	-2.05 (0.36)	1.28 (0.45)		3.21 (1.35)		-1.33 (0.76)
50	-2.09 (0.36)	1.27 (0.45)		3.13 (1.35)		-1.56 (0.76)
51	-1.73 (0.45)	1.33 (0.45)		2.97 (1.36)		-1.45 (0.76)
52	-1.50 (0.65)	1.17 (0.55)	2.66 (1.37)	2.85 (1.44)	-0.02 (0.01)	
53	-2.69 (0.43)	1.64 (0.50)	3.06 (1.32)	3.63 (1.39)		
54	-1.42 (0.52)	0.94 (0.52)	2.72 (1.31)		-0.03 (0.01)	
55	-1.72 (0.44)	1.34 (0.45)		3.06 (1.36)		-1.24 (0.76)
56	-2.10 (0.39)	1.36 (0.48)	2.42 (1.31)			-1.84 (0.82)
57	-2.29 (0.52)	1.68 (0.50)	2.84 (1.33)	3.45 (1.39)		
58	-1.02 (0.60)	0.97 (0.53)	2.50 (1.32)		-0.03 (0.01)	
59	-1.10 (0.60)	0.91 (0.51)		2.60 (1.40)	-0.02 (0.01)	
60	-1.52 (0.53)	0.87 (0.50)		2.78 (1.39)	-0.02 (0.01)	

[a] Variable definitions provided in Table 4.2

in semi-arid habitats, including sagebrush. Mounds were typically centered on a sagebrush shrub (Cole 1932b); thatch ants fulfilled most of their dietary needs by tending aphids on sagebrush (Weber 1935, McIver and Yandell 1998) and were abundant at high elevation sites with increased shrub cover (Mont-Blanc et al. 2007). In our study, thatch ant occurrence was associated with areas of moderate to high productivity. These ants are commonly found on the margin of deciduous woodlands and in river valleys (Weber 1935), which typically have increased productivity. Similarly, thatch ant occurrence in the WBEA area increased with increasing proportions of riparian land cover and topographic moisture; both factors increase vegetation cover.

TABLE 7.20. Extended

$POWER_{500}$	$PIPE_{500}$	$RDdens_{3km}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
		-0.31 (0.21)	-158.72	5	327.63	4.31	0.764
	0.88 (0.62)	-0.32 (0.21)	-157.74	6	327.74	4.42	0.771
	0.68 (0.62)		-157.75	6	327.77	4.45	0.779
	0.73 (0.62)	-0.30 (0.22)	-156.74	7	327.85	4.52	0.786
			-159.87	4	327.87	4.55	0.793
-1.42 (1.14)			-158.89	5	327.96	4.64	0.800
-1.34 (1.14)		-0.30 (0.21)	-157.87	6	328.01	4.69	0.807
-1.80 (1.11)	1.03 (0.65)		-157.90	6	328.06	4.73	0.813
	0.85 (0.61)		-158.95	5	328.08	4.76	0.820
			-158.96	5	328.10	4.78	0.826
-1.68 (1.10)		-0.26 (0.22)	-157.92	6	328.11	4.79	0.833
-2.01 (1.17)	0.29 (0.61)		-156.96	7	328.27	4.95	0.838
-1.79 (1.13)	1.08 (0.65)	-0.29 (0.22)	-156.97	7	328.30	4.98	0.844
		-0.30 (0.22)	-158.02	6	328.31	4.99	0.850
-1.42 (1.10)			-159.13	5	328.46	5.13	0.855
			-160.18	4	328.49	5.16	0.860
		-0.29 (0.22)	-159.25	5	328.69	5.37	0.865
-1.98 (1.17)	0.37 (0.61)	-0.27 (0.22)	-156.18	8	328.81	5.49	0.870
			-160.35	4	328.82	5.50	0.874
-1.88 (1.15)			-159.35	5	328.89	5.57	0.878
-1.35 (1.11)		-0.27 (0.22)	-158.33	6	328.92	5.60	0.883
-1.64 (1.09)	1.13 (0.64)		-158.35	6	328.96	5.64	0.887
		-0.29 (0.22)	-159.44	5	329.06	5.74	0.891
-1.78 (1.15)		-0.29 (0.22)	-158.40	6	329.07	5.74	0.895
-1.83 (1.14)		-0.31 (0.22)	-158.43	6	329.13	5.80	0.898
-1.93 (1.14)			-159.47	5	329.14	5.81	0.902

Thatch ant occurrence decreased with increasing abundance of grassland and mixed shrubland land cover. These habitat types may support populations of thatch ants, but the lack of vegetation (sagebrush) that support food sources (aphids) may limit population size. Sagebrush contagion and salt desert shrubland both had negative associations with thatch ant occurrence. The high elevation habitats that these ants inhabit generally have inclusions of coniferous forest, aspen woodlands, and other montane shrub communities that decrease the contagion of sagebrush patches within the area occupied. Also, salt desert shrubland is generally found at low elevations, whereas thatch ants are part of the high elevation ant community (MontBlanc 2007).

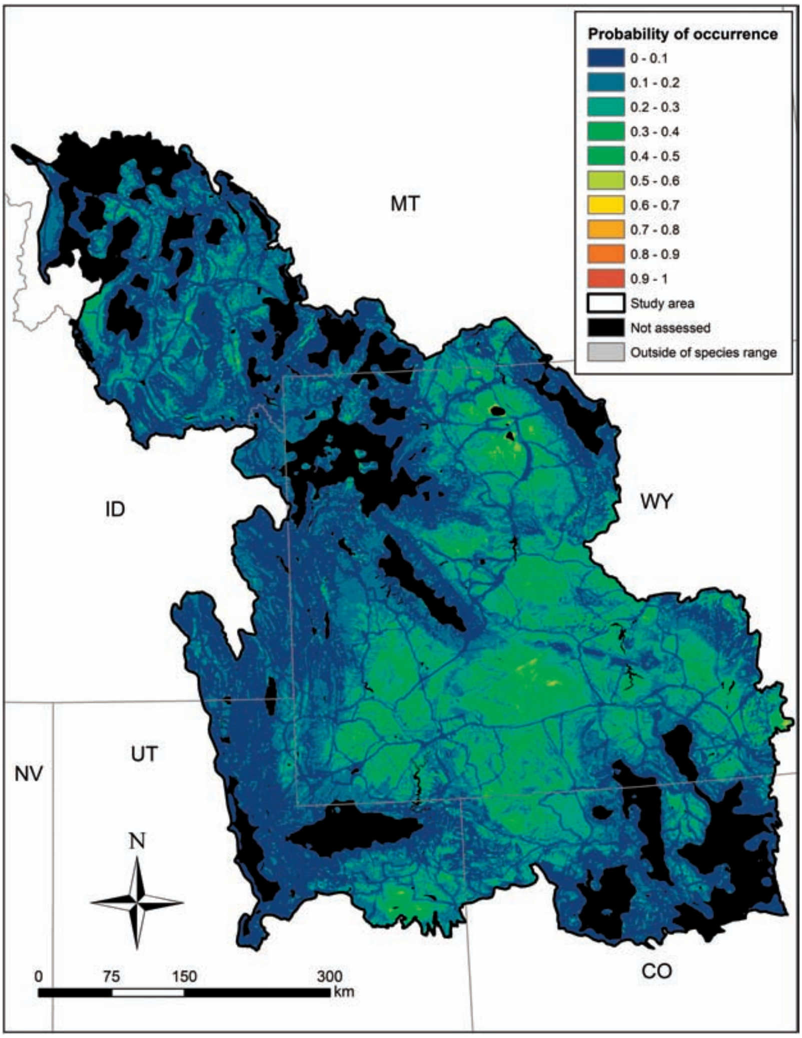

FIG. 7.13. White-tailed jackrabbit probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). White-tail jackrabbits are likely to occur in areas with probability > 0.25.

Thatch ants in the WBEA area had an affinity for moderate to high elevation habitats and areas with increased solar radiation. Thatch ants are common between 1,524 to 2,438 m elevation (Cole 1932b, Risch et al. 2008). The most productive thatch ant habitats had increased exposure to sunlight (Weber 1935) and mounds were found predominately on warmer east, south-east and south exposed sites (Risch et al. 2008).

Disturbance factors were additions to the AIC$_c$-selected top model although the strength of these relationships is questionable given the large error estimates surrounding their coefficients. Raptors use power lines as perches for prey searching, and thereby may indirectly enhance habitat for thatch ants through increased predation on avian, mammalian, and reptilian species which, in turn, prey on thatch ants (Engel et al. 1992, Knight and Kawashima 1993, Steenhof et al. 1993). Proximity to agriculture was also positively associated with thatch ant occurrence in the WBEA.

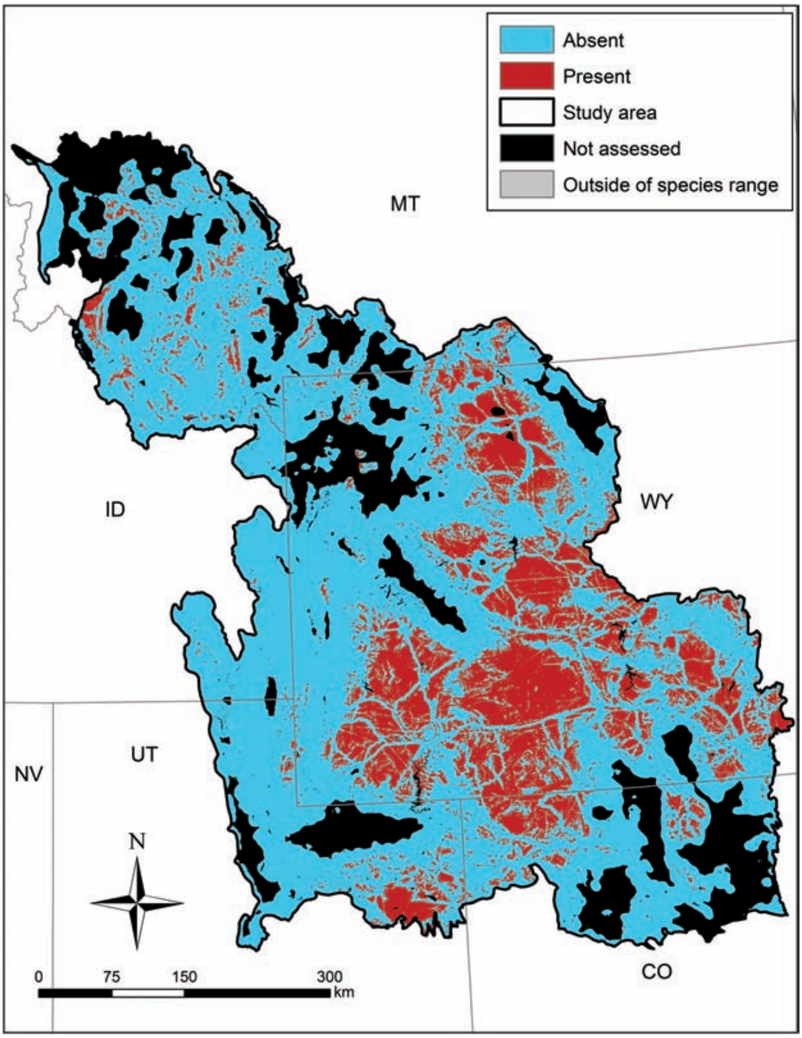

FIG. 7.14. Distribution of white-tailed jackrabbits in the Wyoming Basins Ecoregional Assessment area based on optimum probability cutoff threshold of 0.25. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

Cultivation attracts insects (Benton et al. 2002) which are the primary prey of thatch ants (Weber 1935). Correlative abiotic factors, such as soil depth and productivity, which make land suitable for agricultural purposes, may also be beneficial for thatch ants.

Thatch ants were negatively associated with proximity to oil/gas wells and highways but positively associated with road density. However, the direct link between these disturbance factors and thatch ant occurrence was not readily apparent, although oil/gas development and highways both influence the distribution of exotic vegetation (Ch. 10) which may alter food availability for thatch ants in the WBEA area.

The influences of thatch ants on ecosystems include a reduction in the likelihood of pest insect outbreak (McIver et al. 1997), increased plant diversity (Beattie and Culver 1977), and reduced insect diversity and abundance (Hiekkenen 1999). Our thatch ant model for the WBEA improves

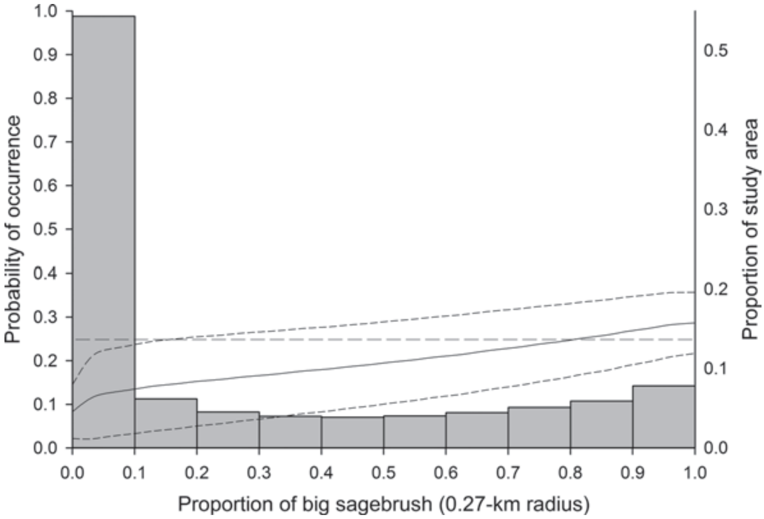

FIG. 7.15. Distribution of white-tailed jackrabbit probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of big sagebrush (*Artemisia tridentata* ssp. *tridentata*, *A. t.* ssp. *wyomingensis*) within a 0.27-km radius. Mean probability of occurrence (black line, ± 1SD [dashed lines]) values were calculated in each one percent increment of big sagebrush within a 0.27-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.25), above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of big sagebrush within 0.27 km.

our understanding of the factors influencing the spatial distribution of thatch ants across the WBEA area and may further work on the distribution of insects, plant diversity, and pest insects in the sagebrush ecosystem.

Abundance of thatch ants on survey blocks in the WBEA was higher than the 0.11–0.17 mound/ha reported in Yellowstone National Park (Risch et al. 2008) but lower than the 73.3 mounds/ha at a super colony site in Oregon (McIver et al. 1997). Although we were unable to conduct a formal analysis of detection probability, this comparison is evidence that our abundance estimates were comparable with previous research. Future data collection and analysis efforts should account for detectability when possible.

Short-horned Lizard

Research on short-horned lizard habitat relationships has been limited (Pianka and Parker 1975; Powell and Russell 1998a, 1998b, James 2004), partly because of their cryptic nature. Short-horned lizard occur-

TABLE 7.21. Results of AIC$_c$-based model selection for cottontail occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC$_c$), change in AIC$_c$ value from the top model (ΔAIC$_c$), and Akaike weight (w_i). Only models with ΔAIC$_c$ ≤ 2 are shown.

Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
1	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km}$	-186.94	4	382.01	0.00	0.23
2	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{3km}$	-187.66	4	383.45	1.43	0.15
3	$ALLSAGE_{540} + ALLSAGE_{540}^2 + NDVI_{3km}$	-187.91	4	383.95	1.94	0.14

[a] Variable definitions provided in Table 4.2

TABLE 7.22. Evaluation statistics from AIC_c-based univariate model selection for cottontail occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran logistic models with all sagebrush (5 km, quadratic) and NDVI (5-km) variables as a base model for all variables tested. We used AIC_c to identify the scale at which cottontails respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-184.66	5	379.52	0.00	1.00
	$GRASS_{18km}$	-184.13	5	378.45	0.00	0.86
	$GRASS_{540}$	-184.78	5	379.75	1.30	0.45
	$GRASS_{1km}$	-185.32	5	380.83	2.38	0.26
	$GRASS_{270}$	-186.02	5	382.22	3.77	0.13
	$GRASS_{3km}$	-186.27	5	382.74	4.29	0.10
	$GRASS_{5km}$	-186.72	5	383.64	5.19	0.06
	MIX_{540}	-184.39	5	378.97	0.00	0.56
	MIX_{1km}	-185.35	5	380.88	1.91	0.21
	MIX_{3km}	-185.95	5	382.10	3.13	0.12
	MIX_{5km}	-186.45	5	383.10	4.13	0.07
	MIX_{18km}	-186.94	5	384.07	5.09	0.04
	RIP_{270}	-185.81	5	381.81	0.00	0.25
	RIP_{5km}	-185.96	5	382.10	0.29	0.21
	RIP_{18km}	-186.08	5	382.36	0.55	0.19
	RIP_{3km}	-186.40	5	382.98	1.17	0.14
	RIP_{540}	-186.43	5	383.05	1.24	0.13
	RIP_{1km}	-186.91	5	384.00	2.19	0.08
	$EDGE_{5km}$	-183.44	5	377.07	0.00	0.68
	$EDGE_{3km}$	-184.70	5	379.60	2.53	0.19
	$CONTAG_{1km}$	-185.93	5	382.06	4.99	0.06
	$EDGE_{1km}$	-185.95	5	382.09	5.02	0.05
	$CONTAG_{3km}$	-186.83	5	383.85	6.78	0.02
	$SALT_{270}$	-186.38	5	382.94	0.00	0.35
	$SALT_{540}$	-186.78	5	383.76	0.82	0.24
	$SALT_{18km}$	-186.90	5	384.00	1.06	0.21
	$SALT_{1km}$	-186.94	5	384.08	1.14	0.20
Abiotic	CTI	-186.92	5	384.03	0.00	1.00
	ELEV	-177.38	5	364.95	0.00	1.00
	$iH2Od_{250}$[b]	-184.61	5	379.41	0.00	0.43
	$iH2Od_{1km}$[b]	-184.99	5	380.17	0.76	0.29
	$iH2Od_{500}$[b]	-185.02	5	380.24	0.83	0.28
	$pH2Od_{500}$[b]	-186.65	5	383.48	0.00	0.35

TABLE 7.22. Continued

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
	pH2Od$_{250}$[b]	-186.69	5	383.57	0.08	0.33
	pH2Od$_{1km}$[b]	-186.73	5	383.66	0.18	0.32
	SOLAR	-185.30	5	380.79	0.00	1.00
	Tmin	-179.50	5	369.20	0.00	1.00
	TRI$_{270}$	-181.47	5	373.13	0.00	0.47
	TRI$_{540}$	-181.91	5	374.01	0.87	0.30
	TRI$_{1km}$	-182.90	5	376.00	2.87	0.11
	TRI	-183.23	5	376.66	3.52	0.08
	TRI$_{3km}$	-184.43	5	379.06	5.93	0.02
	TRI$_{5km}$	-185.71	5	381.61	8.48	0.01
	TRI$_{18km}$	-186.24	5	382.66	9.53	0.00
Disturbance	AG$_{1km}$[b]	-186.46	5	383.11	0.00	0.43
	AG$_{500}$[b]	-186.83	5	383.85	0.74	0.30
	AG$_{250}$[b]	-186.94	5	384.07	0.96	0.27
	MjRD$_{500}$[b]	-186.23	5	382.65	0.00	0.35
	MjRD$_{1km}$[b]	-186.27	5	382.73	0.07	0.33
	MjRD$_{250}$[b]	-186.30	5	382.80	0.14	0.32
	PIPE$_{1km}$[b]	-186.58	5	383.36	0.00	0.37
	PIPE$_{500}$[b]	-186.72	5	383.63	0.27	0.32
	PIPE$_{250}$[b]	-186.75	5	383.69	0.34	0.31
	POWER$_{1km}$[b]	-185.10	5	380.40	0.00	0.58
	POWER$_{500}$[b]	-185.82	5	381.83	1.43	0.28
	POWER$_{250}$[b]	-186.52	5	383.23	2.83	0.14
	2RD$_{1km}$[b]	-186.32	5	382.82	0.00	0.16
	RDdens$_{18km}$	-186.49	5	383.17	0.35	0.13
	2RD$_{500}$[b]	-186.53	5	383.25	0.43	0.13
	RDdens$_{540}$	-186.55	5	383.30	0.47	0.12
	2RD$_{250}$[b]	-186.72	5	383.63	0.80	0.10
	RDdens$_{1km}$	-186.79	5	383.76	0.94	0.10
	RDdens$_{270}$	-186.88	5	383.95	1.12	0.09
	RDdens$_{3km}$	-186.93	5	384.05	1.23	0.08
	RDdens$_{5km}$	-186.93	5	384.06	1.23	0.08
	WELL$_{250}$[b]	-186.93	5	384.04	0.00	0.34
	WELL$_{500}$[b]	-186.93	5	384.06	0.01	0.33
	WELL$_{1km}$[b]	-186.94	5	384.07	0.03	0.33

[a] Variable definitions provided in Table 4.2

[b] Distance decay function ($e^{(\text{Euclidean distance from feature/-distance parameter})}$)

rence in the WBEA was positively associated with big sagebrush and aggregation of sagebrush habitats, which corroborates previous research (Pianka and Parker 1975; Reynolds 1979; Montanucci 1981; Werschkul 1982; Powell and Russell 1985, 1998b; Powell et al. 1998; James 2004). Short-horned lizards move through vegetation and forage in more open habitats. Thus, short-horned lizards are found in semi-open, more thinly vegetated habitats. Short-horned lizards rarely occur in thick, grass-dominated habitats, such as crested wheatgrass fields or native grasslands, except when grass patches have been grazed heavily or are interspersed with sagebrush (Reynolds 1979, Werschkul 1982, James 2004). Within the WBEA, short-horned lizards were more likely to occur in low productivity areas, relatively flat habitats, and sites with decreased topographic moisture. These habitat associations fit with the life history and habitat associations of this desert dwelling species (Pianka and Parker 1975, Powell and Russell 1998b, Powell et al. 1998, Sherbrooke 2003). Short-horned lizards were found in all habitat types but riparian near Vernal, Utah (Grant 1986) and typically inhabited upland habitat in areas bisected by riparian vegetation, swales and other topographically moist areas (Pianka and Parker 1975).

Pygmy Rabbit

We were unable to model the distribution of pygmy rabbits in the WBEA area because of a limited number of observations (Ch. 4). Pygmy rabbits often occur in disjunct and isolated populations throughout their range (Green and Flinders 1980, Dobler and Dixon 1990), which may be due to the distribution of suitable habitat. In Idaho, only 17% of the potential habitat for pygmy rabbits was highly suitable (priority rank 1 [Rachlow and Svancara 2003]), and at the Idaho National Laboratory, only 23% of the 1,999-km^2 site was estimated to be suitable for pygmy rabbits (Gabler et al. 2000). Given this distribution pattern, a species-specific sampling scheme stratified by characteristics important for pygmy rabbit occurrence (Rachlow and Svancara 2006) is likely required to assess habitat needs and disturbance responses for pygmy rabbits within the WBEA area.

The known range of pygmy rabbits in Wyoming (Purcell 2006) was recently expanded by >100 km after survey efforts were extended beyond the previously delineated range of the species. Our sampling suggests that potential pygmy rabbit habitat within the WBEA area occurs outside of this updated range, and includes the Worland Basin and the areas east of Riverton, Wyoming. Furthermore, a pygmy rabbit was seen at one survey block within the Worland Basin. To verify these findings, the Worland Basin should be surveyed more intensely.

White-tailed Jackrabbit

Our model predicted white-tailed jackrabbit to be rare throughout the non-mountainous areas of the Wyoming Basins. White-tailed jackrabbits were positively associated with the proportion of big sagebrush within a small radius (0.27 km), which is an area much smaller than the typical home range (2–3 km^2, Jackson 1961). During the day, white-tailed jackrabbits hide at the base of bushes or beside rocks (Dalquest 1948, Rogowitz 1997), while at night they feed in areas with high herbaceous cover, often moving to these areas from adjacent upland habitat (McAdoo et al. 1986). Therefore, our diurnal surveys sampled roosting habitat consisting of small patches of sagebrush in proximity to small-scale grassland land cover (0.54 km) potentially used as foraging habitat. White-tailed jackrabbits in Colorado were most common in crested wheatgrass and alfalfa (*Medicago sativa*) habitats in between areas of four-wing saltbush (*Atriplex canescens*) and prairie sagewort (*Artemisia frigida*) (Flinders and Hansen 1973). Salt desert shrubland (3 km) was the only important large-scale habitat variable, which may be an indica-

TABLE 7.23. Results of AIC_c-based submodel selection for cottontail occurrence in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta\text{AIC}_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{GRASS}_{18km} + \text{RIP}_{270} + \text{EDGE}_{5km}$	-176.52	9	371.63	0.00	0.09
	2	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{GRASS}_{18km} + \text{EDGE}_{5km}$	-177.76	8	371.98	0.35	0.08
	3	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{RIP}_{270} + \text{EDGE}_{5km}$	-177.91	8	372.28	0.66	0.07
	4	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{EDGE}_{5km}$	-179.10	7	372.55	0.93	0.06
	5	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{GRASS}_{18km} + \text{MIX}_{540} + \text{RIP}_{270} + \text{EDGE}_{5km}$	-178.45	8	373.35	1.73	0.04
	6	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{EDGE}_{5km} + \text{SALT}_{270}$	-178.46	8	373.38	1.75	0.04
	7	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{RIP}_{270} + \text{EDGE}_{5km} + \text{SALT}_{270}$	-177.42	9	373.42	1.80	0.04
	8	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{GRASS}_{18km} + \text{RIP}_{270} + \text{EDGE}_{5km} + \text{SALT}_{270}$	-176.39	10	373.48	1.86	0.04
	9	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{CFRST}_{1km} + \text{MIX}_{540} + \text{GRASS}_{18km} + \text{RIP}_{270}$	-178.55	8	373.57	1.94	0.03
Abiotic	1	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250}$	-168.83	7	352.02	0.00	0.07
	2	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250} + \text{SOLAR}$	-167.85	8	352.16	0.14	0.06
	3	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250} + \text{SOLAR} + \text{pH2Od}_{500}$	-166.94	9	352.46	0.44	0.05
	4	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250} + \text{Tmin}$	-168.09	8	352.64	0.62	0.05
	5	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250} + \text{SOLAR} + \text{pH2Od}_{500} + \text{Tmin}$	-165.99	10	352.68	0.66	0.05
	6	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{SOLAR}$	-169.18	7	352.71	0.69	0.05
	7	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250} + \text{SOLAR} + \text{Tmin}$	-167.07	9	352.71	0.70	0.05
	8	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270}$	-170.27	6	352.80	0.79	0.05
	9	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250} + \text{pH2Od}_{500}$	-168.22	8	352.89	0.88	0.04
	10	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250} + \text{pH2Od}_{500} + \text{Tmin}$	-167.34	9	353.27	1.25	0.04
	11	$\text{ALLSAGE}_{5km} + \text{ALLSAGE}_{5km}{}^2 + \text{NDVI}_{5km} + \text{ELEV} + \text{TRI}_{270} + \text{iH2Od}_{250\,+}\text{CTI}$	-168.49	8	353.44	1.42	0.03

TABLE 7.23. Continued

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
	12	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + ELEV + TRI_{270} + SOLAR + pH2Od_{500}$	-168.52	8	353.51	1.49	0.03
	13	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + ELEV + TRI_{270} + CTI$	-169.61	7	353.58	1.57	0.03
	14	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + ELEV + TRI_{270} + SOLAR + CTI$	-168.60	8	353.66	1.64	0.03
	15	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + ELEV + TRI_{270} + iH2Od_{250} + SOLAR + CTI$	-167.55	9	353.68	1.67	0.03
	16	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + ELEV + TRI_{270} + SOLAR + Tmin$	-168.62	8	353.71	1.69	0.03
	17	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + ELEV + TRI_{270} + Tmin$	-169.76	7	353.89	1.87	0.03
Disturbance	1	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + POWER_{1km}$	-185.10	5	380.40	0.00	0.09
	2	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + POWER_{1km} + 2RD_{1km}$	-184.51	6	381.29	0.90	0.06
	3	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + POWER_{1km} + AG_{1km}$	-184.63	6	381.52	1.13	0.05
	4	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + POWER_{1km} + MjRD_{500}$	-184.72	6	381.71	1.31	0.05
	5	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km}$	-186.94	4	382.01	1.62	0.04
	6	$ALLSAGE_{5km} + ALLSAGE_{5km}^2 + NDVI_{5km} + POWER_{1km} + PIPE_{1km}$	-185.04	6	382.35	1.95	0.03

[a] Variable definitions provided in Table 4.2

TABLE 7.24. Results of AIC_c-based model selection for the combined cottontail occurrence models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Model	Constant	$ALLSAGE_{5km}$	$ALLSAGE_{5km}^2$	$NDVI_{5km}$	$CFRST_{1km}$	$GRASS_{18km}$	MIX_{540}	ELEV[b]
1	7.24 (2.17)	2.53 (4.82)	-2.14 (3.76)	-12.18 (2.35)	6.03 (2.59)	9.61 (5.04)	11.91 (8.59)	-0.27 (0.06)
2	7.47 (2.19)	1.81 (4.85)	-1.61 (3.80)	-12.59 (2.39)	6.05 (2.61)	9.83 (5.04)	12.06 (8.58)	-0.27 (0.06)
3	6.98 (2.16)	2.13 (4.80)	-1.99 (3.75)	-11.95 (2.34)	5.67 (2.60)	9.25 (5.08)	11.76 (8.49)	-0.26 (0.06)
4	7.54 (2.17)	2.30 (4.82)	-1.78 (3.75)	-12.27 (2.35)	6.28 (2.59)	10.12 (5.01)		-0.28 (0.06)
5	7.78 (2.19)	1.59 (4.86)	-1.24 (3.79)	-12.66 (2.39)	6.31 (2.62)	10.37 (5.01)		-0.28 (0.06)
6	7.29 (2.16)	1.91 (4.80)	-1.63 (3.74)	-12.03 (2.34)	5.92 (2.60)	9.81 (5.04)		-0.27 (0.06)
7	7.22 (2.19)	1.65 (4.83)	-1.59 (3.78)	-12.30 (2.40)	5.77 (2.62)	9.46 (5.07)	11.97 (8.52)	-0.26 (0.06)
8	7.34 (2.18)	3.27 (4.82)	-3.46 (3.70)	-12.39 (2.39)	5.58 (2.58)		12.63 (8.43)	-0.25 (0.06)
9	7.64 (2.19)	3.76 (4.85)	-3.70 (3.71)	-12.65 (2.40)	5.94 (2.57)		12.70 (8.51)	-0.27 (0.06)
10	7.53 (2.19)	1.43 (4.84)	-1.23 (3.78)	-12.37 (2.39)	6.02 (2.62)	10.03 (5.04)		-0.27 (0.06)
11	7.84 (2.21)	3.17 (4.89)	-3.27 (3.75)	-13.04 (2.45)	6.01 (2.60)		12.92 (8.52)	-0.27 (0.06)
12	7.14 (2.27)	1.95 (6.05)	-1.56 (5.27)	-12.01 (2.58)	6.02 (2.59)	9.46 (5.13)	11.87 (8.59)	-0.27 (0.06)
13	7.36 (2.30)	1.21 (6.10)	-1.00 (5.32)	-12.41 (2.63)	6.05 (2.61)	9.67 (5.14)	12.04 (8.57)	-0.27 (0.06)
14	7.69 (2.18)	3.13 (4.84)	-3.17 (3.70)	-12.50 (2.39)	5.85 (2.58)			-0.27 (0.06)
15	7.99 (2.19)	3.60 (4.86)	-3.40 (3.71)	-12.76 (2.40)	6.21 (2.57)			-0.28 (0.06)
16	7.00 (2.26)	2.24 (6.03)	-2.11 (5.27)	-11.98 (2.59)	5.67 (2.60)	9.27 (5.16)	11.76 (8.49)	-0.26 (0.06)
17	7.42 (2.27)	1.65 (6.05)	-1.12 (5.26)	-12.07 (2.58)	6.27 (2.59)	9.95 (5.10)		-0.28 (0.06)
18	7.54 (2.21)	2.90 (4.86)	-3.16 (3.73)	-12.71 (2.44)	5.69 (2.60)		12.87 (8.47)	-0.26 (0.06)
19	7.82 (2.12)	-2.63 (4.28)	1.04 (3.48)	-10.44 (2.10)		8.90 (4.94)	12.63 (8.60)	-0.23 (0.06)
20	7.66 (2.29)	0.92 (6.10)	-0.56 (5.31)	-12.46 (2.62)	6.30 (2.61)	10.19 (5.11)		-0.28 (0.06)
21	8.20 (2.22)	3.02 (4.91)	-2.97 (3.75)	-13.14 (2.45)	6.28 (2.60)			-0.28 (0.06)
22	7.29 (2.26)	1.95 (6.04)	-1.67 (5.27)	-12.04 (2.58)	5.92 (2.60)	9.82 (5.13)		-0.27 (0.06)
23	8.20 (2.13)	-2.55 (4.32)	1.11 (3.50)	-10.59 (2.10)		9.27 (4.90)	12.86 (8.72)	-0.24 (0.06)
24	8.39 (2.16)	-3.22 (4.37)	1.62 (3.54)	-10.97 (2.15)		9.55 (4.91)	13.01 (8.71)	-0.24 (0.06)
25	7.20 (2.29)	1.56 (6.09)	-1.50 (5.33)	-12.27 (2.63)	5.77 (2.62)	9.44 (5.16)	11.97 (8.53)	-0.26 (0.06)
26	8.19 (2.12)	-3.09 (4.28)	1.57 (3.47)	-10.47 (2.10)		9.49 (4.90)		-0.24 (0.06)
27	7.25 (2.30)	1.83 (6.10)	-1.74 (5.28)	-12.04 (2.64)	5.91 (2.56)		12.55 (8.48)	-0.26 (0.06)
28	8.03 (2.15)	-3.13 (4.33)	1.45 (3.52)	-10.73 (2.14)		9.14 (4.94)	12.85 (8.63)	-0.23 (0.06)
29	7.90 (2.21)	2.76 (4.88)	-2.87 (3.73)	-12.81 (2.44)	5.97 (2.61)			-0.27 (0.06)
30	7.11 (2.29)	2.10 (6.07)	-2.27 (5.28)	-12.02 (2.65)	5.56 (2.57)		12.55 (8.42)	-0.25 (0.06)
31	7.43 (2.33)	1.12 (6.15)	-1.19 (5.33)	-12.39 (2.69)	5.97 (2.59)		12.78 (8.49)	-0.26 (0.06)
32	8.57 (2.13)	-3.01 (4.33)	1.64 (3.49)	-10.63 (2.10)		9.80 (4.87)		-0.26 (0.06)
33	8.77 (2.16)	-3.69 (4.37)	2.16 (3.53)	-11.00 (2.14)		10.11 (4.87)		-0.26 (0.06)
34	7.50 (2.28)	1.28 (6.09)	-1.07 (5.32)	-12.33 (2.62)	6.02 (2.62)	9.99 (5.13)		-0.27 (0.06)
35	8.18 (2.16)	-1.57 (4.33)	-0.39 (3.43)	-10.76 (2.13)			13.53 (8.55)	-0.23 (0.06)
36	7.57 (2.30)	1.49 (6.11)	-1.27 (5.27)	-12.09 (2.64)	6.17 (2.57)			-0.28 (0.06)

TABLE 7.24. Extended

TRI_{270}	$POWER_{1km}$	RIP_{270}	$iH2Od_{250}$	$EDGE_{5km}{}^{c}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
0.03 (0.01)	1.63 (0.66)				-161.08	10	342.87	0.00	0.060
0.03 (0.01)	1.60 (0.66)	2.78 (2.09)			-160.04	11	342.94	0.06	0.118
0.03 (0.01)	1.61 (0.66)		0.67 (0.50)		-160.17	11	343.20	0.32	0.168
0.03 (0.01)	1.61 (0.66)				-162.34	9	343.27	0.39	0.218
0.03 (0.01)	1.58 (0.66)	2.73 (2.09)			-161.35	10	343.41	0.54	0.263
0.03 (0.01)	1.59 (0.66)		0.66 (0.50)		-161.44	10	343.58	0.71	0.305
0.03 (0.01)	1.59 (0.66)	2.21 (2.10)	0.52 (0.52)		-159.53	12	344.07	1.20	0.338
0.03 (0.01)	1.63 (0.66)		0.71 (0.49)		-161.87	10	344.44	1.56	0.365
0.03 (0.01)	1.65 (0.66)				-162.94	9	344.46	1.59	0.392
0.03 (0.01)	1.57 (0.66)	2.15 (2.11)	0.52 (0.51)		-160.84	11	344.53	1.66	0.418
0.03 (0.01)	1.62 (0.66)	2.60 (2.04)			-161.99	10	344.69	1.82	0.442
0.03 (0.01)	1.62 (0.67)			0.03 (0.02)	-161.07	11	344.99	2.12	0.463
0.03 (0.01)	1.59 (0.66)	2.78 (2.08)		0.03 (0.02)	-160.03	12	345.07	2.20	0.483
0.03 (0.01)	1.61 (0.66)		0.70 (0.49)		-163.38	9	345.33	2.46	0.501
0.03 (0.01)	1.63 (0.66)				-164.44	8	345.34	2.46	0.518
0.03 (0.01)	1.61 (0.66)		0.67 (0.50)	-0.01 (0.02)	-160.17	12	345.35	2.48	0.535
0.03 (0.01)	1.60 (0.66)			0.03 (0.02)	-162.33	10	345.36	2.49	0.552
0.03 (0.01)	1.60 (0.66)	2.01 (2.03)	0.59 (0.51)		-161.31	11	345.47	2.60	0.569
0.03 (0.01)	1.55 (0.65)		0.75 (0.49)		-162.39	10	345.49	2.62	0.585
0.03 (0.01)	1.57 (0.66)	2.73 (2.09)		0.03 (0.02)	-161.33	11	345.52	2.65	0.601
0.03 (0.01)	1.59 (0.66)	2.53 (2.04)			-163.55	9	345.68	2.80	0.615
0.03 (0.01)	1.59 (0.66)		0.66 (0.50)	0.01 (019)	-161.44	11	345.73	2.85	0.630
0.03 (0.01)	1.57 (0.65)				-163.59	9	345.76	2.89	0.644
0.03 (0.01)	1.54 (0.65)	2.76 (2.05)			-162.54	10	345.79	2.91	0.658
0.03 (0.01)	1.59 (0.66)	2.21 (2.10)	0.52 (0.52)	0.01 (0.19)	-159.53	13	346.24	3.37	0.669
0.03 (0.01)	1.52 (0.65)		0.75 (0.49)		-163.85	9	346.27	3.40	0.680
0.03 (0.01)	1.61 (0.67)			0.09 (0.18)	-162.80	10	346.32	3.44	0.691
0.03 (0.01)	1.53 (0.65)	2.10 (2.06)	0.62 (0.51)		-161.80	11	346.45	3.57	0.701
0.03 (0.01)	1.58 (0.66)	1.92 (2.03)	0.58 (0.50)		-162.87	10	346.45	3.58	0.711
0.03 (0.01)	1.60 (0.67)		0.69 (0.50)	0.06 (0.18)	-161.81	11	346.48	3.61	0.720
0.03 (0.01)	1.57 (0.67)	2.61 (2.03)		0.01 (0.18)	-161.84	11	346.53	3.66	0.730
0.03 (0.01)	1.54 (0.65)				-165.05	8	346.56	3.68	0.739
0.03 (0.01)	1.51 (0.65)	2.70 (2.06)			-164.05	9	346.67	3.80	0.748
0.03 (0.01)	1.57 (0.66)	2.15 (2.11)	0.51 (0.52)	0.01 (0.19)	-160.84	12	346.69	3.81	0.757
0.04 (0.01)	1.56 (0.65)		0.79 (0.49)		-164.06	9	346.69	3.81	0.766
0.03 (0.01)	1.58 (0.67)			0.01 (0.18)	-164.28	9	347.13	4.25	0.773

TABLE 7.24. Continued

Model	Constant	ALLSAGE$_{5km}$	ALLSAGE$_{5km}^{2}$	NDVI$_{5km}$	CFRST$_{1km}$	GRASS$_{18km}$	MIX$_{540}$	ELEV[b]
37	8.40 (2.15)	-3.59 (4.33)	1.98 (3.51)	-10.75 (2.14)		9.74 (4.90)		-0.25 (0.06)
38	7.17 (2.16)	3.01 (4.82)	-2.66 (3.76)	-12.67 (2.35)	5.78 (2.59)	9.83 (4.96)	12.08 (8.86)	-0.26 (0.06)
39	8.60 (2.17)	-1.41 (4.39)	-0.42 (3.47)	-10.91 (2.14)			13.67 (8.66)	-0.24 (0.06)
40	7.43 (2.29)	1.78 (6.09)	-1.80 (5.28)	-12.07 (2.65)	5.84 (2.58)			-0.26 (0.06)
41	7.76 (2.33)	0.79 (6.17)	-0.71 (5.33)	-12.44 (2.69)	6.24 (2.59)			-0.28 (0.06)
42	7.26 (2.32)	1.47 (6.14)	-1.70 (5.34)	-12.27 (2.69)	5.68 (2.60)		12.78 (8.45)	-0.25 (0.06)
43	6.91 (2.13)	3.75 (4.77)	-3.21 (3.72)	-12.24 (2.30)	5.74 (2.56)	9.64 (4.97)	11.96 (8.87)	-0.26 (0.06)
44	8.78 (2.20)	-1.99 (4.44)	0.00 (3.50)	-11.26 (2.18)			13.90 (8.66)	-0.24 (0.06)
45	7.85 (2.22)	-2.48 (5.61)	0.89 (5.05)	-10.49 (2.35)		8.95 (5.04)	12.64 (8.60)	-0.23 (0.06)
46	7.49 (2.15)	2.77 (4.83)	-2.30 (3.76)	-12.73 (2.35)	6.01 (2.59)	10.31 (4.93)		-0.27 (0.06)
47	6.69 (2.12)	3.30 (4.76)	-3.04 (3.71)	-12.00 (2.29)	5.36 (2.57)	9.27 (5.01)	11.80 (8.81)	-0.24 (0.06)
48	7.22 (2.13)	3.52 (4.78)	-2.86 (3.72)	-12.30 (2.30)	5.97 (2.56)	10.09 (4.94)		-0.27 (0.06)
49	8.37 (2.19)	-1.98 (4.38)	-0.08 (3.47)	-11.01 (2.17)			13.78 (8.59)	-0.23 (0.06)
50	8.09 (2.23)	-3.16 (5.63)	1.73 (5.04)	-10.42 (2.33)		9.10 (5.01)	12.82 (8.71)	-0.24 (0.06)
51	8.28 (2.26)	-3.81 (5.69)	2.21 (5.10)	-10.81 (2.38)		9.39 (5.02)	12.98 (8.70)	-0.24 (0.06)
52	6.99 (2.12)	3.08 (4.76)	-2.68 (3.70)	-12.06 (2.29)	5.59 (2.57)	9.78 (4.97)		-0.26 (0.06)
53	8.62 (2.16)	-2.00 (4.36)	0.09 (3.44)	-10.80 (2.13)				-0.24 (0.06)
54	6.94 (2.15)	2.81 (4.80)	-2.63 (3.75)	-12.37 (2.35)	5.48 (2.60)	9.47 (4.99)	12.00 (8.83)	-0.25 (0.06)
55	8.21 (2.22)	-3 .00(5.62)	1.48 (5.04)	-10.50 (2.34)		9.52 (5)		-0.24 (0.06)
56	7.59 (2.32)	1.16 (6.15)	-1.24 (5.34)	-12.31 (2.68)	5.95 (2.60)			-0.27 (0.06)
57	8.03 (2.25)	-3.13 (5.68)	1.45 (5.11)	-10.73 (2.38)		9.14 (5.04)	12.85 (8.63)	-0.23 (0.06)
58	9.04 (2.18)	-1.85 (4.42)	0.07 (3.47)	-10.96 (2.14)				-0.26 (0.06)
59	8.44 (2.23)	-3.70 (5.64)	2.33 (5.04)	-10.44 (2.32)		9.61 (4.98)		-0.26 (0.06)
60	7.26 (2.15)	2.58 (4.81)	-2.27 (3.74)	-12.43 (2.35)	5.71 (2.60)	9.99 (4.96)		-0.26 (0.06)
61	7.95 (2.27)	-2.78 (5.66)	0.84 (5.06)	-10.39 (2.38)			13.45 (8.54)	-0.23 (0.06)
62	8.65 (2.25)	-4.34 (5.70)	2.81 (5.09)	-10.82 (2.37)		9.92 (4.98)		-0.25 (0.06)
63	9.23 (2.21)	-2.43 (4.47)	0.50 (3.51)	-11.30 (2.18)				-0.26 (0.06)

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^2
[c] Coefficients and standard errors multiplied by 10

tor of the regional context or conditions for white-tailed jackrabbit occurrence. White-tailed jackrabbit occurrence was associated with less rugged terrain, the only abiotic influence. Habitats of white-tailed jackrabbits are generally flat or gently sloping shrub and grassland habitats (Svihla 1931, Kim 1987), which are typically less rugged.

Several disturbance factors influenced the distribution of white-tailed jackrabbits in the Wyoming Basins. Rabbit occurrence was positively associated with proximity to pipelines which may be a function of revegetation efforts on pipeline rights-of-way, ultimately leading to short-term grassland habitat (Booth and

TABLE 7.24. Extended

TRI_{270}	$POWER_{1km}$	RIP_{270}	$iH2Od_{250}$	$EDGE_{5km}$[c]	LL	K	AIC_c	ΔAIC_c	Σw_i
0.03 (0.01)	1.50 (0.65)	2.03 (2.06)	0.61 (0.51)		-163.30	10	347.30	4.43	0.780
0.03 (0.01)		2.95 (2.11)			-163.30	10	347.30	4.43	0.786
0.04 (0.01)	1.58 (0.65)				-165.42	8	347.31	4.43	0.793
0.03 (0.01)	1.58 (0.66)		0.68 (0.49)	0.07 (0.18)	-163.31	10	347.33	4.45	0.799
0.03 (0.01)	1.54 (0.66)	2.53 (2.03)		0.11 (0.18)	-163.37	10	347.45	4.58	0.805
0.03 (0.01)	1.57 (0.66)	2.04 (2.03)	0.56 (0.51)	0.07 (0.18)	-161.24	12	347.48	4.61	0.811
0.03 (0.01)					-164.45	9	347.48	4.61	0.817
0.04 (0.01)	1.55 (0.65)	2.55 (2.01)			-164.49	9	347.55	4.68	0.823
0.03 (0.01)	1.55 (0.65)		0.76 (0.50)	-0.01 (0.18)	-162.39	11	347.64	4.76	0.828
0.03 (0.01)		2.92 (2.11)			-164.53	9	347.64	4.77	0.834
0.03 (0.01)			0.68 (0.50)		-163.49	10	347.68	4.80	0.839
0.03 (0.01)					-165.65	8	347.76	4.89	0.845
0.04 (0.01)	1.54 (0.65)	1.88 (1.99)	0.68 (0.50)		-163.55	10	347.81	4.94	0.850
0.03 (0.01)	1.55 (0.65)			0.03 (0.02)	-163.58	10	347.86	4.99	0.855
0.03 (0.01)	1.52 (0.65)	2.75 (2.05)		0.03 (0.02)	-162.53	11	347.90	5.03	0.859
0.03 (0.01)			0.68 (0.49)		-164.68	9	347.93	5.06	0.864
0.04 (0.01)	1.53 (0.65)		0.78 (0.48)		-165.77	8	348.01	5.14	0.869
0.03 (0.01)		2.37 (2.11)	0.53 (0.51)		-162.75	11	348.36	5.48	0.873
0.03 (0.01)	1.52 (0.65)		0.75 (0.49)	0.01 (0.18)	-163.85	10	348.40	5.53	0.876
0.03 (0.01)	1.55 (0.66)	1.96 (2.03)	0.55 (0.51)	0.08 (0.18)	-162.78	11	348.41	5.54	0.880
0.03 (0.01)	1.53 (0.65)	2.10 (2.06)	0.62 (0.51)	0.01 (0.18)	-161.80	12	348.60	5.73	0.884
0.04 (0.01)	1.55 (0.65)				-167.13	7	348.62	5.75	0.887
0.03 (0.01)	1.53 (0.65)			0.03 (0.02)	-165.03	9	348.64	5.76	0.890
0.03 (0.01)		2.32 (2.12)	0.53 (0.51)		-163.98	10	348.67	5.80	0.894
0.04 (0.01)	1.53 (0.65)		0.77 (0.49)	0.06 (0.18)	-164.00	10	348.71	5.83	0.897
0.03 (0.01)	1.50 (0.65)	2.70 (2.06)		0.03 (0.02)	-164.03	10	348.77	5.89	0.900
0.04 (0.01)	1.51 (0.65)	2.47 (2.01)			-166.27	8	348.99	6.12	0.903

Cox 2009). Grasslands were a preferred foraging habitat for white-tailed jackrabbits (Flinders and Hansen 1973). Proximity to interstates and major highways and power lines in the WBEA area had a negative influence on white-tailed jackrabbit occurrence. Power lines can increase raptor populations by increasing local availability of nesting and perching platforms (Knight and Kawashima 1993, Steenhof et al. 1993). White-tailed jackrabbits are common prey (McGahan 1967) of raptors, such as golden eagles, that may forage long distances (>3 km) from nest sites in search of prey (Marzluff et al. 1997). The negative association between jackrabbit occurrence

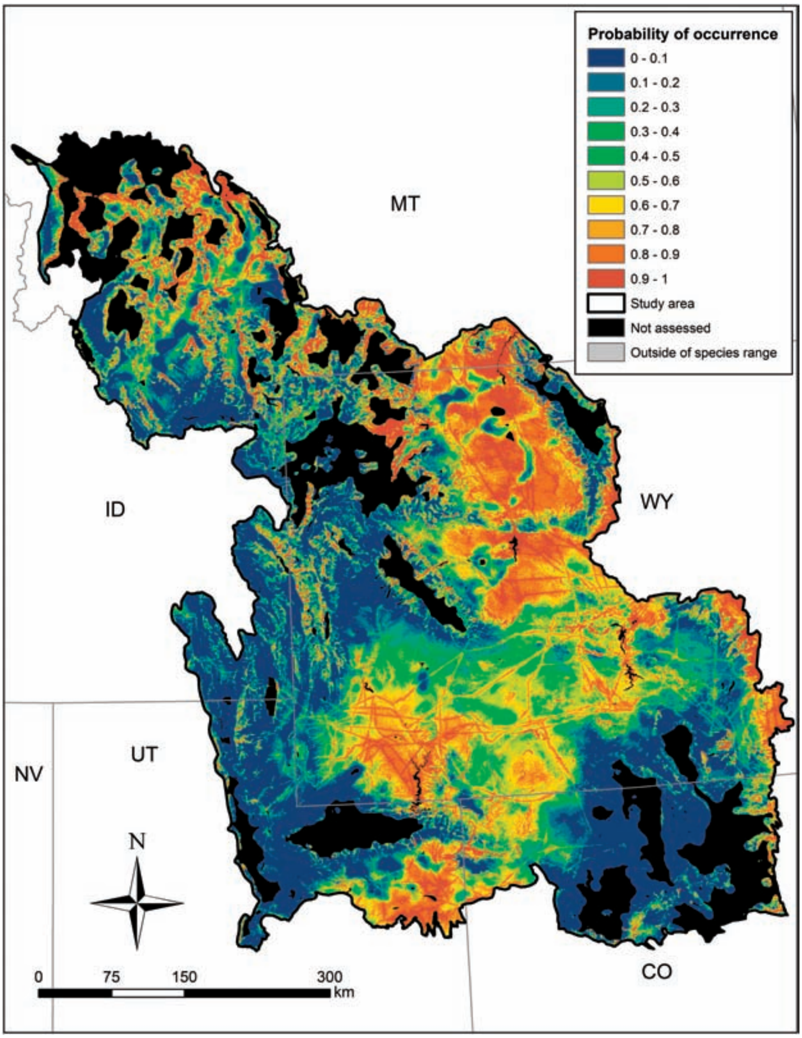

FIG. 7.16. Cottontail probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Cottontails are likely to occur in areas with probability > 0.47.

and interstates and major highways may be due to direct mortality or increased abundance of synanthropic predators (Johnston 2001, Leu et al. 2008).

Our model did not perform well using internal validation tests and we were unable to obtain independent data in order to validate this model. Therefore, caution should be taken when using our white-tailed jackrabbit model. Clearly further research is needed to fully understand how vegetation, abiotic, and disturbance factors influence the distribution of white-tailed jackrabbits.

Cottontail

Cottontails were associated with moderate levels of sagebrush but were predicted to occur over the entire range of sagebrush, indicating that other factors were important in determining their distribution. Cotton-

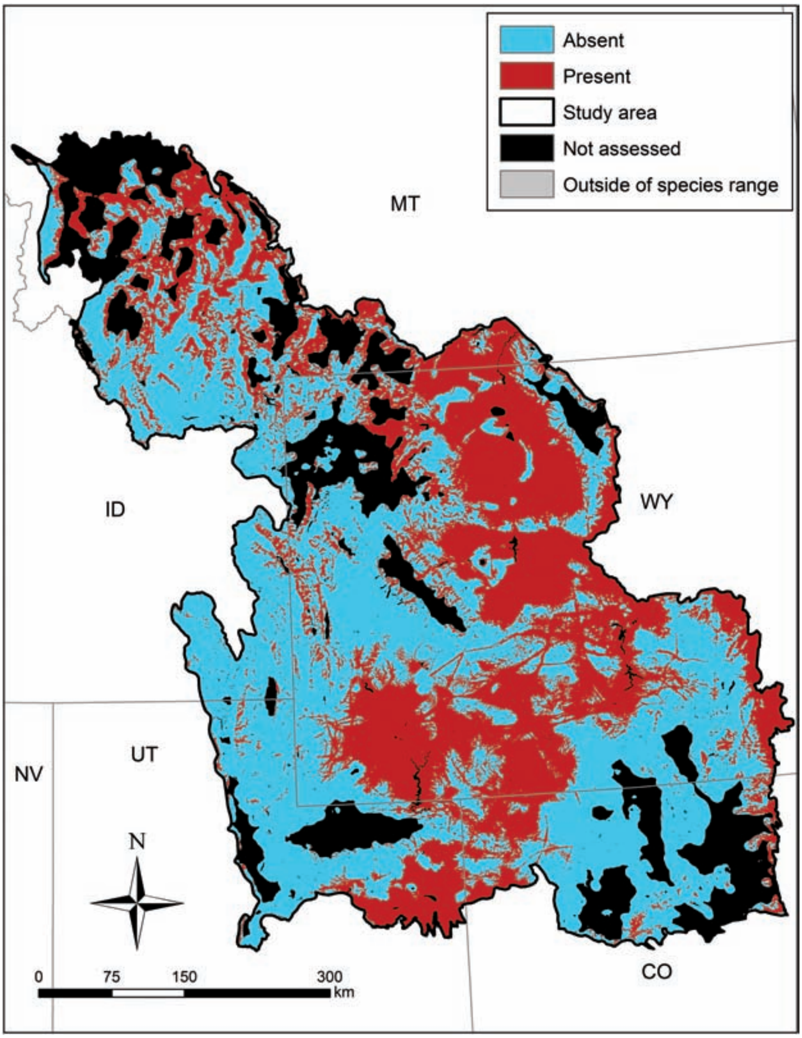

FIG. 7.17. Distribution of cottontail rabbits in the Wyoming Basins Ecoregional Assessment area based on optimum probability cutoff threshold of 0.47. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

tails are found in a variety of habitats and this was apparent from the large number of land cover types positively associated with cottontail occurrence in the WBEA, including coniferous forest, grassland, mixed shrubland, and riparian, as well as sagebrush edge. In a large-scale context, shrub and grassland habitats commonly associated with cottontails have low productivity. The generalist tendency of cottontails also is illustrated by the wide variety of plants they consume (Turkowski 1975, Hansen and Gold 1977, DeCalesta 1979).

Abiotic factors associated with cottontail occurrence included proximity to intermittent water and increased topographic ruggedness, while increased elevation had a negative influence. Areas of intermittent water may increase cover of forbs, which are a primary food source

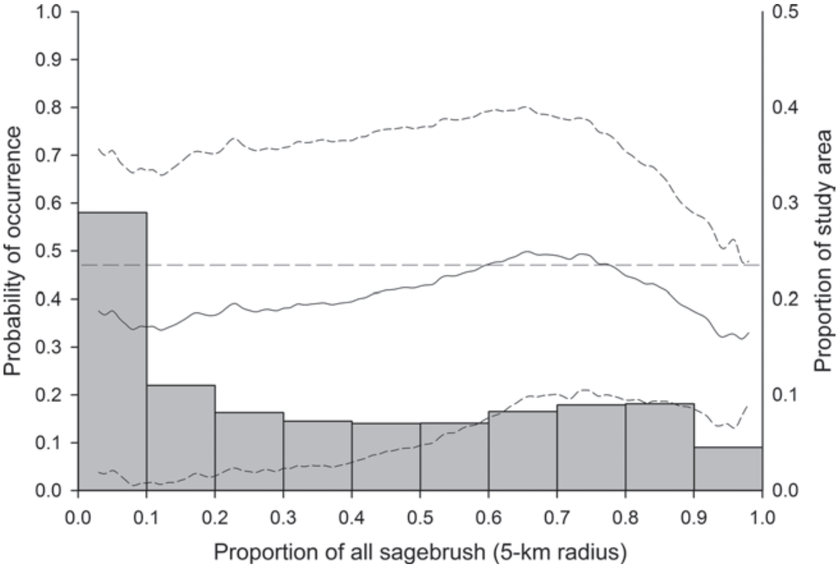

FIG. 7.18. Distribution of cottontail probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata*) within a 5-km radius. Mean probability of occurrence (black line, ±1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 5-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.47), above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 5 km.

during the growing season (MacCracken and Hansen 1984).

Cottontails had a non-intuitive positive association with distance to power lines. We expected that cottontails would have a negative association because of the potential for increased predation due to the increased raptor densities (Steenhof et al. 1993). Food resources or other environmental conditions may increase the likeli-

TABLE 7.25. Results of AIC_c-based model selection for least chipmunk occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_cvalue from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$BIGSAGE_{5km}$	-143.05	2	290.14	0.00	0.04
2	$BIGSAGE_{18km}$	-143.42	2	290.88	0.75	0.03
3	$BIGSAGE_{3km}$	-143.68	2	291.40	1.26	0.02
4	$NDVI_{5km}$	-143.92	2	291.89	1.75	0.02
5	$NDVI_{3km}$	-143.94	2	291.92	1.79	0.02
6	$BIGSAGE_{1km}$	-143.97	2	291.98	1.85	0.01
7	$BIGSAGE_{5km}$ + NDVI	-143.00	3	292.08	1.95	0.01
8	$BIGSAGE_{5km} + NDVI_{5km}$	-143.01	3	292.09	1.96	0.01
9	$BIGSAGE_{5km} + NDVI_{3km}$	-143.01	3	292.10	1.96	0.01

[a] Variable definitions provided in Table 4.2.

TABLE 7.26. Evaluation statistics from AIC$_c$-based univariate model selection for least chipmunk occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and Akaike weight [w_i]). We ran logistic models with big sagebrush (5-km radius) as a base model for all variables tested. We used AIC$_c$ to identify the scale at which least chipmunks respond to individual variables.

Category	Variable[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	CFRST$_{5km}$	-142.88	3	291.84	0.00	0.26
	CFRST$_{1km}$	-142.93	3	291.94	0.10	0.25
	CFRST$_{18km}$	-142.94	3	291.95	0.11	0.25
	CFRST$_{3km}$	-142.97	3	292.01	0.17	0.24
	GRASS$_{3km}$	-141.47	3	289.01	0.00	0.32
	GRASS$_{540}$	-141.77	3	289.61	0.60	0.24
	GRASS$_{5km}$	-142.00	3	290.08	1.07	0.19
	GRASS$_{1km}$	-142.03	3	290.13	1.13	0.18
	GRASS$_{18km}$	-143.01	3	292.10	3.10	0.07
	MIX$_{18km}$	-141.10	3	288.28	0.00	0.75
	MIX$_{5km}$	-142.79	3	291.66	3.38	0.14
	MIX$_{3km}$	-143.03	3	292.13	3.85	0.11
	RIP$_{18km}$	-142.67	3	291.42	0.00	0.25
	RIP$_{1km}$	-142.81	3	291.70	0.29	0.21
	RIP$_{540}$	-142.87	3	291.82	0.40	0.20
	RIP$_{5km}$	-143.02	3	292.13	0.71	0.17
	RIP$_{3km}$	-143.05	3	292.17	0.76	0.17
	EDGE$_{3km}$	-136.05	3	278.17	0.00	0.95
	CONTAG$_{3km}$	-139.18	3	284.43	6.26	0.04
	EDGE$_{1km}$	-142.74	3	291.55	13.38	0.00
	CONTAG$_{5km}$	-142.81	3	291.70	13.53	0.00
	PATCH$_{3km}$	-142.88	3	291.83	13.65	0.00
	CONTAG$_{1km}$	-142.98	3	292.03	13.86	0.00
	PATCH$_{1km}$	-143.00	3	292.07	13.90	0.00
	PATCH$_{5km}$	-143.02	3	292.12	13.95	0.00
	EDGE$_{5km}$	-143.04	3	292.15	13.97	0.00
	SALT$_{18km}$	-142.75	3	291.58	0.00	0.22
	SALT$_{3km}$	-142.83	3	291.74	0.16	0.21
	SALT$_{540}$	-142.86	3	291.79	0.21	0.20
	SALT$_{1km}$	-142.94	3	291.95	0.37	0.19
	SALT$_{5km}$	-142.95	3	291.97	0.39	0.18
Abiotic	CLAY	-142.28	3	290.64	0.00	1.00
	CTI	-142.65	3	291.37	0.00	1.00
	ELEV	-141.95	3	289.97	0.00	1.00
	iH2Od$_{1km}$[b]	-142.89	3	291.86	0.00	0.36
	iH2Od$_{250}$[b]	-143.00	3	292.09	0.23	0.32
	iH2Od$_{500}$[b]	-143.02	3	292.12	0.27	0.32

TABLE 7.26. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$pH2Od_{250}{}^b$	-142.70	3	291.47	0.00	0.41
	$pH2Od_{500}{}^b$	-142.98	3	292.04	0.56	0.31
	$pH2Od_{1km}{}^b$	-143.05	3	292.17	0.70	0.29
	$SOIL_{cm}$	-142.54	3	291.16	0.00	1.00
	SAND	-142.84	3	291.75	0.00	1.00
	SOLAR	-142.24	3	290.55	0.00	1.00
	Tmin	-134.98	3	276.04	0.00	1.00
	TRI_{18km}	-141.26	3	288.60	0.00	0.39
	TRI_{3km}	-142.32	3	290.71	2.10	0.14
	TRI	-142.39	3	290.85	2.24	0.13
	TRI_{5km}	-142.68	3	291.43	2.83	0.10
	TRI_{270}	-142.75	3	291.58	2.98	0.09
	TRI_{540}	-142.84	3	291.75	3.15	0.08
	TRI_{1km}	-142.92	3	291.92	3.31	0.08
Disturbance	$AG_{250}{}^b$	-142.68	3	291.44	0.00	0.40
	$AG_{500}{}^b$	-142.95	3	291.99	0.54	0.31
	$AG_{1km}{}^b$	-143.01	3	292.10	0.66	0.29
	$MjRD_{1km}{}^b$	-142.31	3	290.70	0.00	0.49
	$MjRD_{250}{}^b$	-142.87	3	291.82	1.12	0.28
	$MjRD_{500}{}^b$	-143.04	3	292.16	1.46	0.23
	$PIPE_{250}{}^b$	-141.69	3	289.46	0.00	0.60
	$PIPE_{500}{}^b$	-142.60	3	291.27	1.80	0.24
	$PIPE_{1km}{}^b$	-143.02	3	292.11	2.64	0.16
	$POWER_{1km}{}^b$	-141.72	3	289.52	0.00	0.59
	$POWER_{500}{}^b$	-142.62	3	291.32	1.80	0.24
	$POWER_{250}{}^b$	-142.98	3	292.03	2.51	0.17
	$RDdens_{3km}$	-140.86	3	287.79	0.00	0.37
	$RDdens_{18km}$	-141.60	3	289.27	1.48	0.18
	$RDdens_{5km}$	-142.27	3	290.61	2.82	0.09
	$2RD_{250}{}^b$	-142.28	3	290.63	2.84	0.09
	$2RD_{500}{}^b$	-142.65	3	291.37	3.58	0.06
	$RDdens_{1km}$	-142.67	3	291.42	3.62	0.06
	$2RD_{1km}{}^b$	-142.72	3	291.51	3.72	0.06
	$RDdens_{270}$	-143.03	3	292.13	4.34	0.04
	$RDdens_{540}$	-143.03	3	292.14	4.35	0.04
	$WELL_{500}{}^b$	-141.56	3	289.20	0.00	0.45
	$WELL_{1km}{}^b$	-141.97	3	290.01	0.81	0.30
	$WELL_{250}{}^b$	-142.15	3	290.37	1.17	0.25

[a] Variable definitions provided in Table 4.2

[b] Distance decay function ($e^{(\text{Euclidean distance from feature/-distance parameter})}$)

TABLE 7.27. Results of AIC$_c$-based submodel selection for least chipmunk occurrence in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC$_c$), change in AIC$_c$ value from the top model (ΔAIC$_c$), and Akaike weight (w_i). Only models with ΔAIC$_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC$_c$	ΔAIC$_c$	w_i
Vegetation	1	BIGSAGE$_{5km}$ + EDGE$_{3km}$ + GRASS$_{3km}$ + MIX$_{18km}$	-133.69	5	277.57	0.00	0.12
	2	BIGSAGE$_{5km}$ + EDGE$_{3km}$ + GRASS$_{3km}$	-134.80	4	277.72	0.15	0.11
	3	BIGSAGE$_{5km}$ + EDGE$_{3km}$ + MIX$_{18km}$	-134.85	4	277.83	0.27	0.10
	4	BIGSAGE$_{5km}$ + EDGE$_{3km}$	-136.05	3	278.17	0.61	0.09
Abiotic	1	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOLAR + SAND	-131.17	6.00	274.61	0.00	0.03
	2	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOLAR	-132.30	5.00	274.80	0.18	0.03
	3	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOLAR + CTI	-131.31	6.00	274.89	0.28	0.03
	4	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOLAR + SOIL$_{cm}$	-131.43	6.00	275.13	0.52	0.03
	5	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SAND	-132.56	5.00	275.31	0.70	0.02
	6	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOLAR + CLAY	-131.57	6.00	275.41	0.80	0.02
	7	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + CTI	-132.63	5.00	275.44	0.83	0.02
	8	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$	-133.67	4.00	275.47	0.86	0.02
	9	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + CTI + SAND	-131.62	6.00	275.51	0.90	0.02
	10	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOIL$_{cm}$	-132.78	5.00	275.74	1.13	0.02
	11	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + CLAY	-132.79	5.00	275.78	1.16	0.02
	12	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + CTI + CLAY	-131.77	6.00	275.81	1.19	0.02
	13	BIGSAGE$_{5km}$ + Tmin	-134.98	3.00	276.04	1.42	0.02
	14	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + CTI + SOIL$_{cm}$	-131.98	6.00	276.23	1.61	0.02
	15	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SAND + CLAY	-132.00	6.00	276.28	1.66	0.01
	16	BIGSAGE$_{5km}$ + Tmin + SAND	-134.10	4.00	276.32	1.71	0.01
	17	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOLAR + iH2Od$_{1km}$	-132.06	6.00	276.39	1.78	0.01
	18	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SOLAR + pH2Od$_{250}$	-132.08	6.00	276.43	1.82	0.01
	19	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + CTI + pH2Od$_{250}$	-132.10	6.00	276.46	1.85	0.01
	20	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + SAND + pH2Od$_{250}$	-132.11	6.00	276.49	1.88	0.01
	21	BIGSAGE$_{5km}$ + Tmin + TRI$_{18km}$ + pH2Od$_{250}$	-133.21	5.00	276.60	1.99	0.01
Disturbance	1	BIGSAGE$_{5km}$ + PIPE$_{250}$ + POWER$_{1km}$ + WELL$_{500}$ + MjRD$_{1km}$	-135.35	6.00	282.97	0.00	0.16
	2	BIGSAGE$_{5km}$ + PIPE$_{250}$ + POWER$_{1km}$ + WELL$_{500}$	-136.76	5.00	283.72	0.75	0.11

[a] Variable definitions provided in Table 4.2

TABLE 7.28. Results of AIC_c-based model selection for the combined least chipmunk occurrence models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [$\sum w_i$]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Model	Constant	$BIGSAGE_{5km}$	$EDGE_{3km}$	Tmin	$POWER_{1km}$	$PIPE_{250}$	TRI_{18km}	SOLAR
1	-1.61 (0.68)	-0.48 (0.55)	-0.02 (0.01)	-0.27 (0.10)	1.61 (0.71)	-2.03 (1.50)		
2	-0.60 (0.97)	-1.41 (0.80)	-0.02 (0.01)	-0.28 (0.10)	1.10 (0.67)		-0.02 (0.01)	
3	-2.60 (1.78)	-1.47 (0.79)	-0.02 (0.01)	-0.26 (0.09)			-0.03 (0.01)	0.02 (0.01)
4	0.37 (1.02)	-1.38 (0.79)	-0.02 (0.01)	-0.28 (0.09)			-0.03 (0.01)	
5	-1.69 (0.67)	-0.51 (0.54)	-0.02 (0.01)	-0.29 (0.10)	1.26 (0.65)			
6	-1.51 (0.67)	-0.71 (0.57)	-0.02 (0.01)	-0.26 (0.10)	1.33 (0.65)			
7	-0.25 (0.94)	-1.48 (0.79)	-0.02 (0.01)	-0.26 (0.09)			-0.02 (0.01)	
8	0.00 (0.95)	-1.72 (0.81)	-0.02 (0.01)	-0.23 (0.10)			-0.02 (0.01)	
9	-1.26 (0.74)	-0.35 (0.56)	-0.02 (0.01)	-0.31 (0.09)	1.21 (0.65)			
10	-0.44 (0.95)	-1.47 (0.79)	-0.02 (0.01)	-0.27 (0.10)			-0.02 (0.01)	
11	-3.49 (1.69)	-0.34 (0.56)	-0.02 (0.01)	-0.29 (0.10)	1.29 (0.65)			0.01 (0.01)
12	-1.37 (0.73)	-0.75 (0.58)	-0.02 (0.01)	-0.28 (0.10)	1.24 (0.65)			
13	-0.08 (0.96)	-1.48 (0.79)	-0.02 (0.01)	-0.24 (0.10)		-1.46 (1.40)	-0.02 (0.01)	
14	-1.78 (0.68)	-0.49 (0.54)	-0.02 (0.01)	-0.30 (0.10)	1.10 (0.68)			
15	-1.59 (0.67)	-0.34 (0.54)	-0.02 (0.01)	-0.26 (0.09)		-1.98 (1.47)		
16	-1.50 (0.65)	-0.42 (0.53)	-0.02 (0.01)	-0.27 (0.09)				
17	-1.05 (0.72)	-0.25 (0.55)	-0.02 (0.01)	-0.29 (0.09)				
18	-0.03 (0.99)	-1.43 (0.79)	-0.02 (0.01)	-0.23 (0.10)			-0.03 (0.01)	
19	-1.66 (0.67)	-0.41 (0.54)	-0.02 (0.01)	-0.28 (0.09)				
20	-0.22 (0.94)	-1.50 (0.78)	-0.02 (0.01)	-0.25 (0.10)			-0.02 (0.01)	
21	-1.62 (0.69)	-0.45 (0.56)	-0.02 (0.01)	-0.28 (0.10)	1.24 (0.65)			
22	-1.49 (0.67)	-0.61 (0.56)	-0.02 (0.01)	-0.25 (0.10)				
23	-1.33 (0.66)	-0.60 (0.55)	-0.02 (0.01)	-0.25 (0.09)				
24	-1.17 (0.71)	-0.68 (0.58)	-0.02 (0.01)	-0.26 (0.09)				
25	-1.22 (0.74)	-0.24 (0.55)	-0.02 (0.01)	-0.30 (0.09)				
26	-0.70 (0.77)	-0.51 (0.59)	-0.02 (0.01)	-0.28 (0.09)				
27	-1.32 (0.72)	-0.68 (0.58)	-0.02 (0.01)	-0.27 (0.10)				
28	-3.18 (1.66)	-0.26 (0.56)	-0.02 (0.01)	-0.27 (0.09)				0.01 (0.01)
29	-1.41 (0.66)	-0.38 (0.54)	-0.02 (0.01)	-0.26 (0.09)		-1.26 (1.36)		
30	-2.74 (1.68)	-0.08 (0.57)	-0.02 (0.01)	-0.29 (0.09)				0.01 (0.01)
31	-0.97 (0.72)	-0.19 (0.56)	-0.02 (0.01)	-0.28 (0.09)		-1.29 (1.36)		
32	-0.94 (0.73)	-0.42 (0.58)	-0.02 (0.01)	-0.27 (0.10)				
33	-1.01 (0.71)	-0.85 (0.59)	-0.02 (0.01)	-0.24 (0.10)				
34	-1.22 (0.67)	-0.56 (0.55)	-0.02 (0.01)	-0.23 (0.10)		-1.46 (1.43)		
35	-0.11 (0.41)	-1.26 (0.53)	-0.03 (0.01)		1.75 (0.71)	-3.02 (1.69)		
36	-2.91 (1.64)	-0.44 (0.58)	-0.02 (0.01)	-0.25 (0.09)				0.01 (0.01)

TABLE 7.28. Extended

SAND	$WELL_{500}$	$MjRD_{1km}$	$GRASS_{3km}$	MIX_{18km}	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
					-128.55	6	269.37	0.00	0.040
					-128.64	6	269.55	0.18	0.076
					-128.69	6	269.64	0.27	0.111
-0.02 (0.01)					-128.72	6	269.70	0.34	0.145
					-129.80	5	269.80	0.43	0.177
	1.69 (1.20)				-128.87	6	270.01	0.64	0.206
					-129.92	5	270.02	0.66	0.235
	1.68 (1.20)				-129.01	6	270.29	0.92	0.260
-0.01 (0.01)					-129.03	6	270.32	0.96	0.284
		0.80 (0.60)			-129.08	6	270.44	1.07	0.308
					-129.11	6	270.49	1.12	0.331
			-3.40 (3.21)		-129.17	6	270.60	1.23	0.352
					-129.22	6	270.70	1.34	0.372
		0.55 (0.63)			-129.44	6	271.15	1.78	0.389
		1.15 (0.64)			-129.47	6	271.21	1.84	0.405
					-131.56	4	271.25	1.89	0.420
-0.02 (0.01)					-130.65	5	271.48	2.12	0.434
				-21.57 (30.66)	-129.64	6	271.56	2.19	0.447
		0.81 (0.60)			-130.68	5	271.56	2.19	0.461
			-1.93 (3.14)		-129.71	6	271.69	2.32	0.473
				-10.90 (30.16)	-129.73	6	271.74	2.37	0.485
	1.69 (1.20)	0.90 (0.60)			-129.76	6	271.79	2.42	0.497
	1.50 (1.19)				-130.82	5	271.83	2.46	0.509
			-3.57 (3.20)		-130.85	5	271.89	2.53	0.520
-0.01 (0.01)		0.77 (0.59)			-129.84	6	271.95	2.58	0.531
-0.02 (0.01)			-3.72 (3.22)		-129.87	6	272.01	2.65	0.542
		0.85 (0.60)	-3.80 (3.25)		-129.90	6	272.06	2.70	0.552
					-130.94	5	272.08	2.71	0.562
					-131.02	5	272.24	2.87	0.572
-0.02 (0.01)					-130.01	6	272.29	2.92	0.581
-0.02 (0.01)					-130.08	6	272.42	3.06	0.590
-0.01 (0.01)	1.31 (1.22)				-130.10	6	272.47	3.10	0.598
	1.46 (1.19)		-3.48 (3.18)		-130.14	6	272.55	3.18	0.606
	1.64 (1.19)				-130.15	6	272.56	3.19	0.615
	2.72 (1.16)				-130.21	6	272.69	3.33	0.622
	1.45 (1.20)				-130.25	6	272.76	3.40	0.629

TABLE 7.28. Continued

Model	Constant	$BIGSAGE_{5km}$	$EDGE_{3km}$	Tmin	$POWER_{1km}$	$PIPE_{250}$	TRI_{18km}	SOLAR
37	-3.07 (1.67)	-0.27 (0.56)	-0.02 (0.01)	-0.28 (0.09)				0.01 (0.01)
38	1.55 (0.76)	-2.37 (0.75)	-0.03 (0.01)			-2.37 (1.57)	-0.03 (0.01)	
39	-2.82 (1.69)	-0.53 (0.60)	-0.02 (0.01)	-0.26 (0.09)				0.01 (0.01)
40	-1.40 (0.67)	-0.35 (0.55)	-0.02 (0.01)	-0.26 (0.10)				
41	-3.09 (1.67)	-0.22 (0.56)	-0.02 (0.01)	-0.26 (0.09)		-1.23 (1.34)		0.01 (0.01)
42	-1.13 (0.71)	-0.62 (0.58)	-0.02 (0.01)	-0.25 (0.09)		-1.10 (1.34)		
43	1.50 (0.75)	-2.11 (0.77)	-0.03 (0.01)				-0.03 (0.01)	
44	-2.71 (0.53)	-0.32 (0.54)		-0.34 (0.09)	1.69 (0.70)	-2.16 (1.48)		
45	-1.57 (0.69)	-0.33 (0.55)	-0.02 (0.01)	-0.26 (0.10)				
46	-0.99 (0.74)	-0.19 (0.57)	-0.02 (0.01)	-0.28 (0.10)				
47	-0.99 (1.66)	-2.36 (0.76)	-0.03 (0.01)				-0.03 (0.01)	0.02 (0.01)
48	-2.83 (0.54)	-0.28 (0.55)		-0.34 (0.09)	1.52 (0.72)	-2.61 (1.56)		
49	-1.23 (0.68)	-0.52 (0.57)	-0.02 (0.01)	-0.23 (0.10)				
50	1.15 (0.76)	-2.10 (0.74)	-0.03 (0.01)		1.35 (0.72)	-2.69 (1.57)	-0.03 (0.01)	
51	-1.80 (0.86)	-1.10 (0.80)		-0.33 (0.09)	1.55 (0.71)	-2.17 (1.48)	-0.02 (0.01)	
52	-1.17 (1.69)	-1.85 (0.76)	-0.03 (0.01)				-0.04 (0.01)	0.02 (0.01)
53	-1.07 (0.73)	-0.61 (0.59)	-0.02 (0.01)	-0.24 (0.10)				
54	-4.66 (1.61)	-0.13 (0.57)		-0.34 (0.09)	1.73 (0.70)	-2.20 (1.46)		0.01 (0.01)
55	-2.28 (0.62)	-0.15 (0.56)		-0.36 (0.09)	1.64 (0.70)	-2.24 (1.47)		
56	-2.60 (0.53)	-0.50 (0.57)		-0.32 (0.09)	1.81 (0.71)	-2.46 (1.57)		
57	1.19 (0.76)	-2.38 (0.76)	-0.03 (0.01)		1.03 (0.66)		-0.03 (0.01)	
58	1.30 (0.76)	-2.15 (0.74)	-0.03 (0.01)			-2.80 (1.56)	-0.03 (0.01)	
59	-3.08 (1.67)	-0.19 (0.57)	-0.02 (0.01)	-0.25 (0.10)				0.01 (0.01)
60	-4.22 (1.68)	-1.18 (0.80)		-0.35 (0.09)	1.12 (0.64)		-0.02 (0.01)	0.02 (0.01)
61	1.40 (0.75)	-2.39 (0.76)	-0.03 (0.01)				-0.03 (0.01)	
62	-1.33 (0.68)	-0.31 (0.55)	-0.02 (0.01)	-0.24 (0.10)		-1.24 (1.36)		
63	1.51 (0.75)	-1.87 (0.75)	-0.03 (0.01)			-1.90 (1.44)	-0.03 (0.01)	
64	-1.08 (1.71)	-2.09 (0.74)	-0.03 (0.01)			-1.95 (1.41)	-0.03 (0.01)	0.02 (0.01)
65	-0.14 (0.41)	-1.09 (0.52)	-0.03 (0.01)			-2.90 (1.63)		
66	-2.81 (0.53)	-0.37 (0.54)		-0.37 (0.09)	1.26 (0.63)			
67	1.28 (0.76)	-2.42 (0.76)	-0.03 (0.01)				-0.03 (0.01)	
68	1.42 (0.75)	-1.89 (0.76)	-0.03 (0.01)				-0.03 (0.01)	
69	-2.47 (0.59)	-0.52 (0.58)		-0.33 (0.09)	1.64 (0.70)	-2.05 (1.47)		
70	-3.34 (1.69)	-1.14 (0.79)		-0.36 (0.09)			-0.03 (0.01)	0.02 (0.01)
71	-1.90 (0.85)	-1.16 (0.79)		-0.36 (0.09)	1.13 (0.64)		-0.02 (0.01)	
72	-1.57 (0.84)	-1.19 (0.79)		-0.32 (0.09)		-2.08 (1.44)	-0.02 (0.01)	
73	-3.92 (1.66)	-1.25 (0.78)		-0.34 (0.09)			-0.03 (0.01)	0.02 (0.01)
74	-4.64 (1.60)	-0.20 (0.56)		-0.37 (0.09)	1.28 (0.63)			0.01 (0.01)

TABLE 7.28. Extended

SAND	WELL$_{500}$	MjRD$_{1km}$	GRASS$_{3km}$	MIX$_{18km}$	LL	K	AIC$_c$	ΔAIC$_c$	$\sum w_i$
		0.73 (0.60)			-130.25	6	272.77	3.41	0.637
	2.53 (1.14)				-130.25	6	272.77	3.41	0.644
			-3.57 (3.25)		-130.26	6	272.78	3.42	0.651
				-14.25 (29.51)	-131.44	5	273.07	3.70	0.657
					-130.41	6	273.10	3.73	0.664
			-3.25 (3.21)		-130.44	6	273.15	3.79	0.670
	2.26 (1.15)			-46.87 (30.56)	-130.48	6	273.22	3.86	0.675
					-131.58	5	273.35	3.99	0.681
		0.82 (0.60)		-15.10 (29.90)	-130.55	6	273.36	4.00	0.686
-0.01 (0.01)				-11.50 (30.22)	-130.57	6	273.41	4.04	0.692
	2.31 (1.15)				-130.59	6	273.45	4.09	0.697
		0.94 (0.65)			-130.61	6	273.48	4.12	0.702
	1.52 (1.19)			-14.83 (28.89)	-130.68	6	273.63	4.26	0.707
					-130.69	6	273.64	4.28	0.711
					-130.70	6	273.66	4.29	0.716
				-51.62 (31.95)	-130.71	6	273.69	4.33	0.720
			-3.58 (3.20)	-14.41 (29.27)	-130.72	6	273.71	4.34	0.725
					-130.72	6	273.71	4.34	0.730
-0.01 (0.01)					-130.75	6	273.77	4.40	0.734
	1.57 (1.20)				-130.78	6	273.82	4.45	0.738
	2.53 (1.15)				-130.79	6	273.85	4.48	0.743
		1.15 (0.63)			-130.82	6	273.91	4.54	0.747
				-14.06 (29.43)	-130.82	6	273.91	4.54	0.751
					-130.89	6	274.04	4.68	0.755
	2.35 (1.14)				-131.94	5	274.06	4.70	0.758
				-13.27 (30.04)	-130.92	6	274.11	4.74	0.762
				-48.69 (31.96)	-130.99	6	274.25	4.88	0.766
					-131.02	6	274.31	4.94	0.769
	2.71 (1.15)	1.32 (0.63)			-131.03	6	274.32	4.95	0.772
					-133.11	4	274.34	4.97	0.776
	2.56 (1.15)	0.82 (0.60)			-131.06	6	274.39	5.02	0.779
				-51.24 (32.01)	-132.19	5	274.58	5.21	0.782
			-2.83 (3.25)		-131.16	6	274.59	5.22	0.785
-0.02 (0.01)					-131.17	6	274.61	5.25	0.788
					-132.22	5	274.62	5.26	0.791
		1.22 (0.64)			-131.26	6	274.79	5.42	0.793
					-132.30	5	274.80	5.43	0.796
					-132.34	5	274.86	5.50	0.798

TABLE 7.28. Continued

Model	Constant	$BIGSAGE_{5km}$	$EDGE_{3km}$	Tmin	$POWER_{1km}$	$PIPE_{250}$	TRI_{18km}	SOLAR
75	-1.24 (1.70)	-2.13 (0.75)	-0.03 (0.01)				-0.03 (0.01)	0.02 (0.01)
76	-1.35 (0.94)	-1.08 (0.80)		-0.37 (0.09)	1.05 (0.65)		-0.02 (0.01)	
77	1.44 (0.75)	-2.15 (0.74)	-0.03 (0.01)			-2.04 (1.44)	-0.03 (0.01)	
78	-2.41 (0.62)	-0.23 (0.55)		-0.38 (0.09)	1.20 (0.63)			
79	1.22 (0.76)	-1.86 (0.76)	-0.03 (0.01)		0.84 (0.66)		-0.03 (0.01)	
80	-1.45 (1.71)	-2.10 (0.75)	-0.03 (0.01)		0.91 (0.65)		-0.03 (0.01)	0.02 (0.01)
81	-2.52 (0.59)	-0.60 (0.58)		-0.35 (0.09)	1.24 (0.63)			
82	1.85 (0.89)	-2.34 (0.76)	-0.03 (0.01)				-0.03 (0.01)	
83	-0.99 (0.89)	-1.13 (0.79)		-0.36 (0.09)			-0.02 (0.01)	
84	1.30 (0.76)	-1.89 (0.76)	-0.03 (0.01)				-0.03 (0.01)	
85	-3.86 (1.67)	-1.20 (0.78)		-0.32 (0.09)		-1.42 (1.32)	-0.03 (0.01)	0.02 (0.01)
86	-2.67 (0.57)	-0.29 (0.56)		-0.33 (0.10)	1.68 (0.70)	-2.17 (1.48)		
87	1.41 (0.75)	-2.38 (0.75)	-0.03 (0.01)				-0.03 (0.01)	
88	-0.11 (0.40)	-1.07 (0.52)	-0.03 (0.01)		1.55 (0.70)	-2.60 (1.56)		
89	-2.73 (0.53)	-0.51 (0.56)		-0.35 (0.09)	1.30 (0.63)			
90	1.93 (0.89)	-1.83 (0.76)	-0.03 (0.01)				-0.03 (0.01)	
91	-1.57 (0.82)	-1.23 (0.78)		-0.34 (0.09)			-0.02 (0.01)	
92	-3.81 (1.68)	-1.25 (0.79)		-0.34 (0.09)			-0.03 (0.01)	0.02 (0.01)
93	0.22 (0.46)	-1.58 (0.56)	-0.03 (0.01)		1.19 (0.64)			
94	-4.21 (1.62)	-0.05 (0.58)		-0.38 (0.09)	1.22 (0.63)			0.01 (0.01)
95	-0.15 (0.41)	-0.74 (0.57)	-0.03 (0.01)		1.54 (0.71)	-2.53 (1.57)		
96	-1.78 (0.86)	-1.34 (0.81)		-0.34 (0.09)	1.18 (0.64)		-0.02 (0.01)	
97	-0.23 (0.41)	-1.04 (0.52)	-0.03 (0.01)		1.38 (0.72)	-3.12 (1.66)		
98	-2.90 (0.54)	-0.35 (0.54)		-0.37 (0.09)	1.10 (0.65)			
99	-0.08 (0.40)	-1.32 (0.53)	-0.03 (0.01)		1.20 (0.64)			
100	-1.71 (0.83)	-1.23 (0.79)		-0.35 (0.09)			-0.02 (0.01)	
101	-0.75 (1.75)	-2.07 (0.76)	-0.03 (0.01)				-0.03 (0.01)	0.02 (0.01)
102	-1.15 (0.91)	-1.15 (0.79)		-0.37 (0.09)			-0.02 (0.01)	
103	-2.72 (0.53)	-0.18 (0.54)		-0.33 (0.09)		-1.92 (1.41)		
104	1.33 (0.74)	-2.18 (0.74)	-0.03 (0.01)				-0.03 (0.01)	
105	-0.83 (0.90)	-1.08 (0.79)		-0.34 (0.09)		-1.52 (1.37)	-0.02 (0.01)	
106	-2.08 (0.68)	-0.46 (0.59)		-0.37 (0.09)	1.17 (0.63)			
107	1.97 (0.89)	-2.10 (0.75)	-0.03 (0.01)			-2.08 (1.46)	-0.03 (0.01)	
108	-1.96 (0.86)	-1.17 (0.80)		-0.36 (0.09)	0.95 (0.67)		-0.02 (0.01)	
109	-4.34 (1.62)	-0.43 (0.60)		-0.35 (0.09)	1.26 (0.63)			0.01 (0.01)
110	-0.11 (0.40)	-0.99 (0.58)	-0.03 (0.01)		1.16 (0.64)			
111	0.13 (0.45)	-1.30 (0.55)	-0.03 (0.01)		1.49 (0.70)	-2.29 (1.52)		
112	1.42 (0.75)	-1.90 (0.75)	-0.03 (0.01)				-0.03 (0.01)	

TABLE 7.28. Extended

SAND	$WELL_{500}$	$MjRD_{1km}$	$GRASS_{3km}$	MIX_{18km}	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
					-132.36	5	274.91	5.54	0.801
-0.02 (0.01)					-131.32	6	274.92	5.55	0.803
					-132.39	5	274.98	5.61	0.806
-0.01 (0.01)					-132.40	5	274.99	5.62	0.808
				-49.94 (32.42)	-131.42	6	275.11	5.75	0.810
					-131.44	6	275.15	5.78	0.813
			-3.31 (3.25)		-132.52	5	275.23	5.86	0.815
-0.01 (0.01)	2.26 (1.15)				-131.48	6	275.23	5.87	0.817
-0.02 (0.01)					-132.56	5	275.31	5.94	0.819
		0.71 (0.60)		-52.92 (32.35)	-131.53	6	275.32	5.95	0.821
					-131.55	6	275.36	5.99	0.823
				-7.30 (32.22)	-131.56	6	275.38	6.01	0.825
	2.28 (1.14)		-2.48 (3.04)		-131.56	6	275.39	6.02	0.827
					-132.60	5	275.39	6.03	0.829
	1.22 (1.19)				-132.61	5	275.41	6.04	0.831
-0.01 (0.01)				-53.07 (33.11)	-131.58	6	275.43	6.06	0.833
					-133.67	4	275.47	6.11	0.835
		0.72 (0.60)			-131.62	6	275.52	6.15	0.836
	2.33 (1.15)		-4.26 (3.18)		-131.63	6	275.54	6.17	0.838
-0.01 (0.01)					-131.64	6	275.55	6.18	0.840
				-41.44 (32.35)	-131.64	6	275.55	6.19	0.842
	1.31 (1.20)				-131.65	6	275.56	6.19	0.844
		0.91 (0.65)			-131.66	6	275.59	6.22	0.845
		0.57 (0.62)			-132.70	5	275.59	6.23	0.847
	2.43 (1.14)				-132.71	5	275.60	6.23	0.849
		0.85 (0.59)			-132.71	5	275.61	6.24	0.851
-0.01 (0.01)					-131.69	6	275.65	6.28	0.852
-0.02 (0.01)		0.81 (0.60)			-131.70	6	275.66	6.29	0.854
		1.17 (0.63)			-132.75	5	275.70	6.33	0.856
					-133.80	4	275.72	6.35	0.858
-0.02 (0.01)					-131.73	6	275.73	6.36	0.859
-0.01 (0.01)			-3.54 (3.30)		-131.74	6	275.74	6.37	0.861
-0.01 (0.01)					-131.74	6	275.75	6.39	0.862
		0.62 (0.63)			-131.75	6	275.77	6.40	0.864
			-3.37 (3.31)		-131.75	6	275.77	6.41	0.866
	2.31 (1.15)			-37.92 (30.52)	-131.79	6	275.84	6.47	0.867
			-3.68 (3.18)		-131.82	6	275.90	6.54	0.869
			-2.46 (3.05)	-48.86 (31.55)	-131.83	6	275.92	6.55	0.870

TABLE 7.28. Continued

Model	Constant	$BIGSAGE_{5km}$	$EDGE_{3km}$	Tmin	$POWER_{1km}$	$PIPE_{250}$	TRI_{18km}	SOLAR
113	1.12 (0.76)	-2.15 (0.75)	-0.03 (0.01)		0.91 (0.65)		-0.02 (0.01)	
114	-3.74 (1.65)	-1.41 (0.80)		-0.32 (0.09)			-0.03 (0.01)	0.02 (0.01)
115	-4.48 (1.58)	-0.35 (0.58)		-0.35 (0.09)	1.32 (0.63)			0.01 (0.01)
116	-2.62 (0.51)	-0.29 (0.53)		-0.35 (0.09)				
117	-1.90 (1.59)	-0.88 (0.55)	-0.03 (0.01)		1.58 (0.70)	-2.54 (1.55)		0.01 (0.01)
118	-2.29 (0.61)	-0.01 (0.56)		-0.35 (0.09)		-1.93 (1.40)		
119	-1.44 (0.82)	-1.19 (0.78)		-0.32 (0.09)		-1.39 (1.34)	-0.02 (0.01)	
120	-2.78 (0.53)	-0.27 (0.53)		-0.36 (0.09)				
121	-1.15 (1.71)	-2.13 (0.75)	-0.03 (0.01)				-0.03 (0.01)	0.02 (0.01)
122	-1.87 (0.86)	-1.16 (0.79)		-0.35 (0.09)	1.14 (0.64)		-0.01 (0.01)	
123	-2.61 (0.53)	-0.34 (0.55)		-0.31 (0.09)		-2.16 (1.48)		
124	-2.50 (0.63)	-0.21 (0.55)		-0.38 (0.09)	1.05 (0.65)			
125	-2.19 (0.59)	-0.13 (0.55)		-0.36 (0.09)				
126	0.03 (0.40)	-1.09 (0.52)	-0.03 (0.01)			-2.01 (1.49)		
127	-2.76 (0.56)	-0.34 (0.56)		-0.36 (0.10)	1.25 (0.63)			
128	-2.45 (0.59)	-0.73 (0.60)		-0.34 (0.09)	1.28 (0.63)			
129	-2.38 (0.62)	-0.36 (0.58)		-0.36 (0.09)	1.24 (0.63)			
130	-1.06 (1.70)	-2.14 (0.74)	-0.03 (0.01)				-0.03 (0.01)	0.02 (0.01)
131	-1.74 (1.54)	-1.16 (0.56)	-0.03 (0.01)		1.22 (0.64)			0.01 (0.01)
132	-3.74 (1.68)	-1.22 (0.79)		-0.31 (0.10)			-0.03 (0.01)	0.02 (0.01)
133	-2.60 (0.60)	-0.58 (0.58)		-0.36 (0.09)	1.06 (0.66)			
134	-4.54 (1.61)	-0.19 (0.56)		-0.37 (0.09)	1.15 (0.65)			0.01 (0.01)
135	-1.58 (0.84)	-1.42 (0.81)		-0.33 (0.09)			-0.02 (0.01)	
136	-1.77 (0.91)	-1.13 (0.80)		-0.34 (0.10)	1.10 (0.65)		-0.02 (0.01)	

[a] Variable definitions provided in Table 4.2

hood of cottontail use of these areas near power lines and potentially indicate that areas near power lines act as an ecological trap (Dwernychuk and Boag 1972, Battin 2004). However, caution should be used in broadly interpreting this as an effect of power lines because our data only contained major transmission corridors and did not include smaller and more common power lines.

Least Chipmunk

Least chipmunk occupancy in the WBEA area was negatively associated with proportion of sagebrush habitat and mixed shrublands, and increased sagebrush edge density. Least chipmunks occur across many habitat types, including areas above treeline, montane forest, and shrublands (Bergstrom and Hoffmann 1991, Verts and Carraway 2001). We sampled gradients of disturbance and productivity within the sagebrush ecosystem along a large elevation gradient. The ability of least chipmunks to occupy forest and woodland habitats, as well as high elevation habitat, may lead to a negative association with large-scale sagebrush metrics. Previous research conducted

TABLE 7.28. Extended

SAND	$WELL_{500}$	$MjRD_{1km}$	$GRASS_{3km}$	MIX_{18km}	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
					-132.89	5	275.97	6.60	0.872
	1.14 (1.20)				-131.87	6	276.01	6.64	0.873
	1.18 (1.20)				-131.87	6	276.02	6.65	0.875
					-134.98	3	276.04	6.67	0.876
					-131.91	6	276.08	6.71	0.877
-0.01 (0.01)		1.10 (0.63)			-131.93	6	276.13	6.76	0.879
					-132.98	5	276.15	6.78	0.880
		0.84 (0.59)			-134.03	4	276.19	6.82	0.881
		0.53 (0.60)			-131.98	6	276.24	6.87	0.883
			-2.13 (3.28)		-131.98	6	276.24	6.87	0.884
	1.50 (1.21)	1.27 (0.63)			-132.01	6	276.29	6.93	0.885
-0.01 (0.01)		0.55 (0.62)			-132.02	6	276.30	6.94	0.887
-0.01 (0.01)					-134.10	4	276.32	6.96	0.888
	2.35 (1.13)				-133.07	5	276.33	6.97	0.889
				-7.66 (31.01)	-133.07	5	276.34	6.97	0.890
	1.18 (1.19)		-3.22 (3.24)		-132.05	6	276.37	7.00	0.891
-0.01 (0.01)	1.03 (1.22)				-132.05	6	276.38	7.01	0.893
			-2.29 (3.13)		-132.06	6	276.38	7.01	0.894
	2.38 (1.15)				-132.06	6	276.39	7.03	0.895
				-20.43 (31.86)	-132.08	6	276.42	7.05	0.896
		0.60 (0.63)	-3.43 (3.28)		-132.08	6	276.43	7.06	0.897
		0.46 (0.64)			-132.09	6	276.44	7.07	0.899
	1.36 (1.21)	0.92 (0.60)			-132.11	6	276.48	7.12	0.900
				-13.41 (31.96)	-132.12	6	276.51	7.15	0.901

within shrubland regions with small elevation gradients found that least chipmunks were sensitive to fragmentation and loss of sagebrush habitat and may be eliminated from landscapes without sagebrush cover (Reynolds 1980, Parmenter and MacMahon 1983) or were absent in sagebrush patches isolated by >450 m in Idaho (Hanser and Huntly 2006). Least chipmunks were absent from grasslands in Oregon and Utah (Feldhamer 1979; Smith and Urness 1984), which corroborates our results. Conversely, in southeast Oregon they were only found in sagebrush and greasewood (*Sarcobatus vermiculatus*) communities (Feldhamer 1979). In addition, least chipmunk predation on passerine nests in Washington was more than twice as common in a continuous shrub steppe community as in a landscape fragmented by agriculture (Vander Haegen et al. 2002), suggesting greater abundance of this species in contiguous habitats. In Utah, least chipmunk abundance was lower in edge habitat between grassland and sagebrush when compared to contiguous sagebrush (Smith and Urness 1984). Mixed shrublands generally represented areas of low productivity and therefore may not

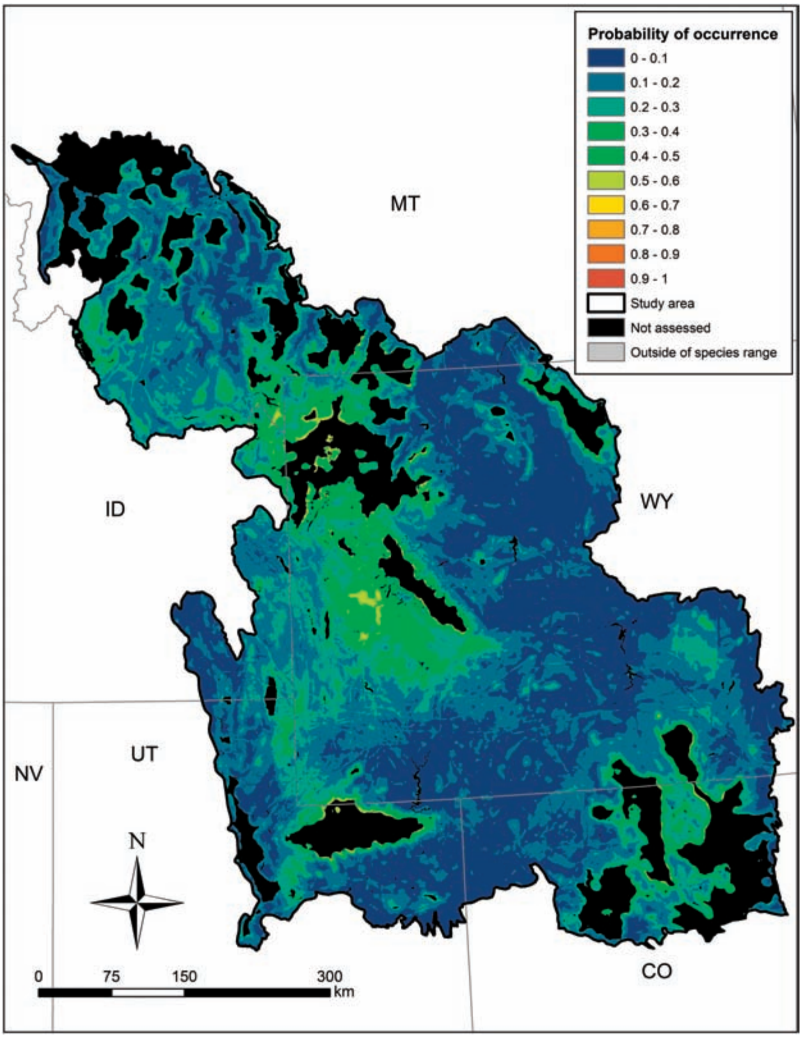

FIG. 7.19. Least chipmunk probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Least chipmunks are likely to occur in areas with probability > 0.18.

have the resources necessary to maintain populations of least chipmunks.

Abiotic factors, including temperature, topographic ruggedness, solar radiation, and soil sand content, also influenced the occurrence of least chipmunks. Least chipmunks are commonly associated with rocky habitats at higher elevations and have been recorded above tree line in Colorado and up to 2,745 m in Oregon (Verts and Carraway 2001). High-elevation habitats have lower minimum temperatures than habitats at low elevation; this relationship is potentially leading to the association of least chipmunks with cooler temperatures in the WBEA area. Minimum temperature (rather than elevation, even though both were evaluated) was an important factor explaining least chipmunk occurrence. Temperature models used in our study were based on additional factors, such as aspect and top-

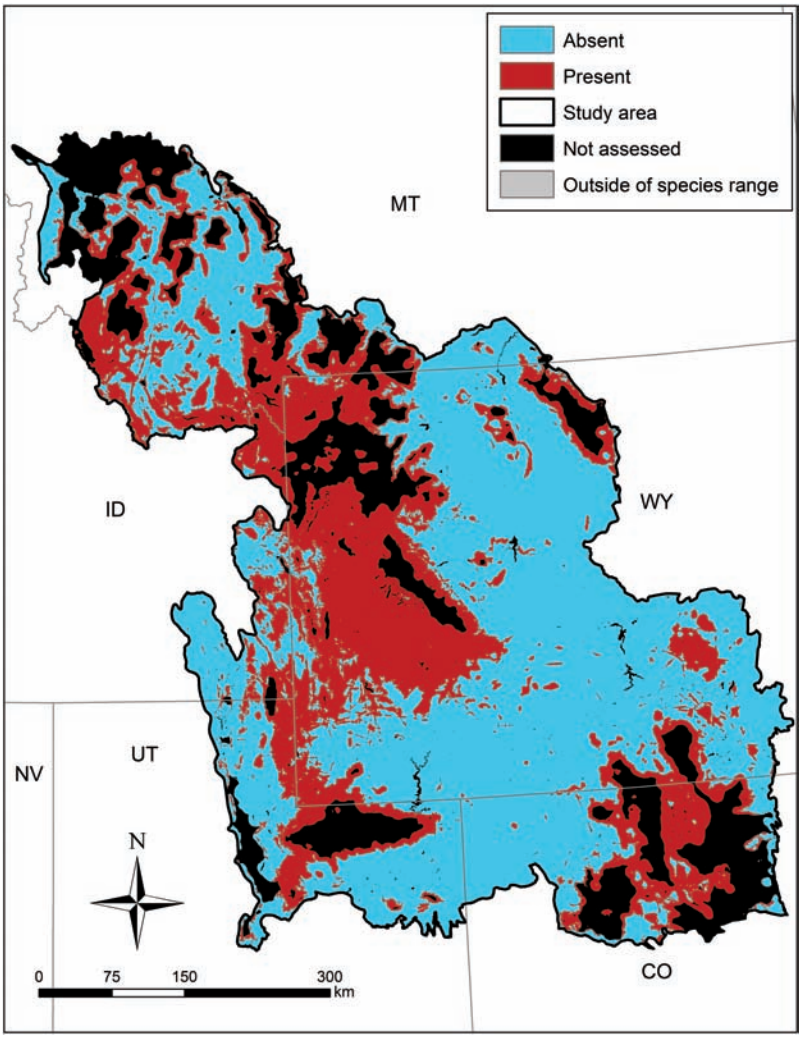

FIG. 7.20. Distribution of least chipmunks in the Wyoming Basins Ecoregional Assessment area based on an optimum probability cutoff threshold of 0.18. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

ographic position. Within a large-scale context, least chipmunks in the WBEA were negatively associated with increased topographic ruggedness. In Colorado, least chipmunks are the only *Tamias* species to occupy level, non-rocky shrubland habitats (Bergstrom and Hoffmann 1991). However, on a local scale, least chipmunks can be numerous on cliffs (Ward and Anderson 1988). Least chipmunk density in Oregon was positively correlated with soil depth and proportion of clay (Feldhamer 1979). Although we did not find a similar relationship with clay soils, clay content is negatively correlated with sand content, for which occurrence of least chipmunks was negatively correlated.

Our results linking anthropogenic factors to least chipmunk occurrence were perplexing. Least chipmunk occurrence was negatively associated with proximity to pipelines. But we also found posi-

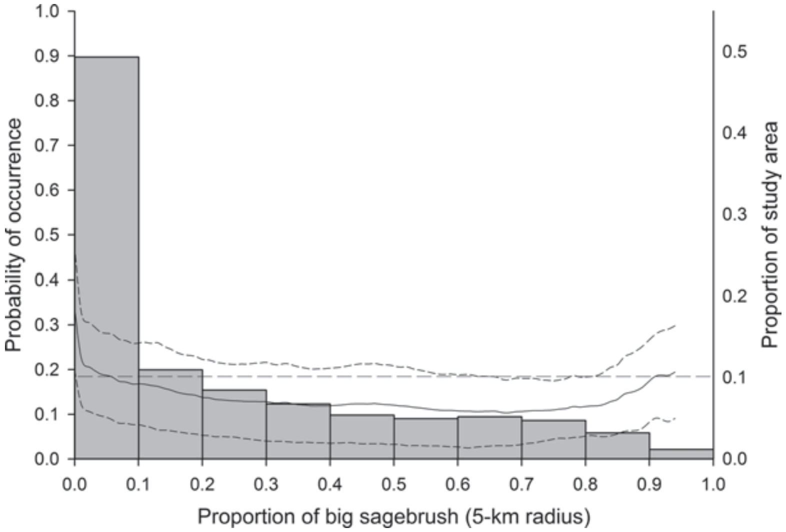

FIG. 7.21. Distribution of least chipmunk probability of occurrence in the Wyoming Basins Ecoregional Assessment area in relation to proportion of big sagebrush (*Artemisia tridentata* spp. *tridentata*, *A. t.* spp. *wyomingensis*) within a 5-km radius. Mean probability of occurrence (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of big sagebrush within a 5-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.18), above which occurrence is predicted. Histogram values represent proportion of the total study area in each 10% segment of big sagebrush within 5 km.

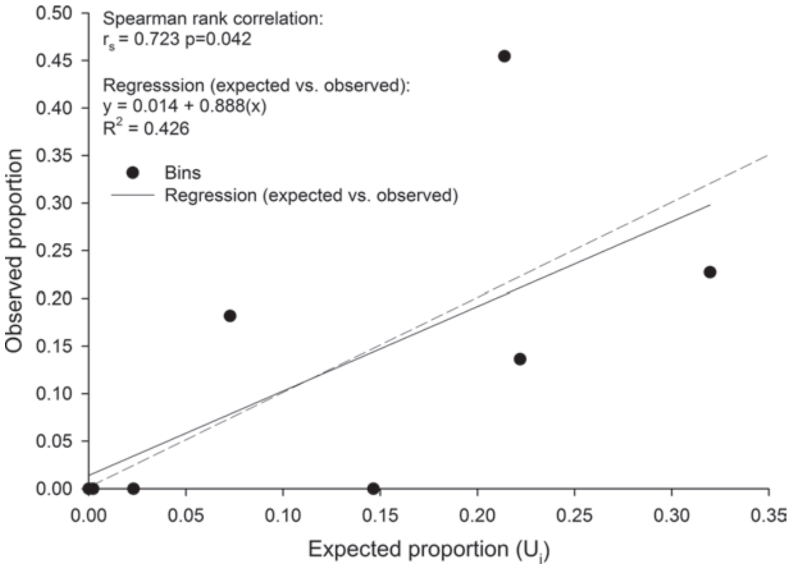

FIG. 7.22. Validation results for short-horned lizard occurrence model in the Wyoming Basins Ecoregional Assessment area. Based on the distribution of values in the probability of occurrence map, we compared expected versus the observed proportion of 22 independent short-horned lizard occurrence locations in 10% probability bins. The fitted regression is shown as a solid line; points represent the location of individual probability of occurrence bins; the dashed line is the 1:1 perfect fit line. Spearman rank correlation and regression metrics are provided.

tive associations between least chipmunk occurrence and proximity to interstates and highways, power lines, and oil and gas wells although error estimates for these coefficients were quite large and indicated weak relationships. We expected negative associations with these factors due to the disturbance associated with these types of development, the clearing of rights-of-way, the resulting lack of shrub cover, and the increased predation risk in the vicinity of these features and their associated infrastructure (Knight and Kawashima 1993, Steenhof et al. 1993, Booth and Cox 2009). Alternatively, interstates and highways, power lines, and oil and gas wells may be a surrogate for low topographic ruggedness; a factor that was positively related to least chipmunk occurrence.

CONCLUSIONS

The majority of species examined in the WBEA area had positive relationships between probability of occurrence and the quantity or configuration of sagebrush habitats across scales ranging from local to large spatial extents (0.27 km–18 km). This highlights the importance of sagebrush and sagebrush habitats to the integrity of insect, reptile, and mammal populations and the wildlife community. Human disturbance also affected the occurrence of sagebrush-dependent species. Although land use or construction of human infrastructure leads to direct loss of sagebrush habitat, the influence of human disturbance, or ecological footprint (Leu et al. 2008), extends beyond the physical extent of the feature. Our results in the WBEA area help to increase our understanding of how individual species respond to different habitats and individual human disturbances. This information will therefore help inform regional management plans and decisions regarding rights-of-way, such as buffer distances around infrastructure projects. We caution that our models of species occurrence represent an initial exploratory effort and that further examination of population processes is necessary in order to determine the mechanisms influencing occupancy and abundance patterns.

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APPENDIX 7.1

Descriptive statistics for explanatory variables used to model harvester ant occurrence. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum and maximum value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 7.2

Descriptive statistics for explanatory variables used to model thatch ant occurrence. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum and maximum value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 7.3

Descriptive statistics for explanatory variables used to model short-horned lizard occurrence. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum and maximum value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 7.4

Descriptive statistics for explanatory variables used to model white-tailed jackrabbit occurrence. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum and maximum value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 7.5

Descriptive statistics for explanatory variables used to model cottontail occurrence. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum and maximum value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 7.6

Descriptive statistics for explanatory variables used to model least chipmunk occurrence. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum and maximum value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

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Chapter 8: Occurrence of Large and Medium-Sized Mammals: Occurrence But Not Count Models Predict Pronghorn Distribution

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Abstract. Management of medium to large-sized terrestrial mammals (Antilocapridae, Canidae, Cervidae, Leporidae, Mustelidae, Ochotonidae) in the western United States is multifaceted and complex. Species in this group generally are charismatic and provide economic opportunities, although others are considered a nuisance at one extreme or are listed as species of conservation concern at the other. Understanding the relative influence of land cover, habitat fragmentation, and human land use on their distribution during the breeding season is imperative to inform management decisions on land use and conservation planning for these species. We surveyed medium to large-sized sagebrush (*Artemisia* spp.)-associated mammal species in 2005 and 2006 on 141 random transects (mean length = 1.1 km) in the Wyoming Basins, an area undergoing rapid land cover transformation due to human actions including energy development. Overall, we observed 10 species but only obtained enough observations of pronghorn (*Antilocapra americana*) to develop spatially explicit distribution models. For pronghorn, occurrence related positively to proportion of sagebrush land cover within 0.27 km, mixed shrubland land cover within 3 km, riparian land cover within 5 km, Normalized Difference Vegetation Index (NDVI) within 0.27 km, road density within 5 km, and decay distance to power line corridors at 1 km, but negatively to salt-desert shrubland cover within 18 km and an interaction between sagebrush and NDVI within 0.27 km. We found excellent predictive capability of this model when evaluated with independent test data. The model provides a basis for assessing the effects of proposed development on pronghorn and can aid planning efforts to avoid or mitigate adverse effects on pronghorn.

Key words: abundance, anthropogenic disturbance, *Antilocapra americana,* count-based regression models, habitat, logistic regression, occurrence, pronghorn.

The Wyoming Basins are called the Serengeti of North America because this region contains a rich diversity of medium to large-sized mammals, particularly ungulates (Sawyer et al. 2005), and supports ungulate migrations between breeding and wintering ranges over distances equal to or exceeding those of well-publicized African ungulate migrations (Berger 2004). Mammalian diversity in the Wyoming Basins is imperiled as many medium- to large-sized species have experienced severe population declines. Wyoming's list of species of special concern includes 50 mammal species, of which six (black-tailed prairie dog [*Cynomys ludovicianus*], white-tailed prairie dog [*C. leucurus*], least weasel [*Mustela nivalis*], pygmy rabbit [*Brachylagus idahoensis*], and spotted ground squirrel [*Xerospermophilus spilosoma*]) overlap with sagebrush (*Artemisia* spp.) steppe habitat (Wyoming Game and Fish Department 2005).

The Wyoming Basins and adjacent areas within Colorado, Utah, and Wyoming have experienced recent rapid expansion in energy development (Braun et al. 2002, Weller 2002, Walker et al. 2007, Doherty et al. 2008, Copeland et al. 2009, Ch. 3).

Many studies have reported negative effects of energy development and other human stressors on mammalian game species. Indirect effects of energy development include habitat avoidance within 2.7 to 3.7 km from well pads by mule deer (*Odocoileus hemionus*) (Sawyer et al. 2006). Pronghorn (*Antilocapra americana*) populations have declined owing to changes in habitat quality and habitat loss from human activities, including urban expansion and energy development (Sawyer et al. 2002). Moreover, oil and gas developments, fences, housing, and highways in the Wyoming Basins disrupt the historic migration route of pronghorn between summering grounds in the Grand Teton National Park and wintering grounds in the Green River Basin of Wyoming; about 75% of this migration corridor has been converted or lost (Berger 2003, Berger 2004). Pronghorn are also sensitive to vehicular traffic, which influences foraging efficiency (Berger et al. 1983, Gavin and Komers 2006). However, little is known how other medium to large-sized terrestrial non-game mammal species respond to energy development and other human stressors. White-tailed prairie dogs occupy roughly 5% of their historic range. Agricultural development, shooting, poisoning, and plague (*Yersinia pestis*) are significant factors contributing to these declines (Miller et al. 1994, Miller et al. 2000, Miller and Cully 2001). Similarly, pygmy rabbits show severe population declines across their range (Flinders 1999, Janson 2002), with loss of sagebrush habitat considered to be the most important factor contributing to population declines (Heady and Laundré 2005). There is a need to identify factors influencing the distribution of medium and large-sized mammal species in relation to human stressors and land cover.

Our objectives were to survey medium- and large-sized sagebrush-associated mammals on randomly walked transects placed along human land use and sagebrush productivity gradients within the Wyoming Basin Ecoregional Assessment (WBEA) area and to develop species distribution models for those species with sufficient sample sizes. These species distribution models are important for assessing effects of additional proposed development across the WBEA area on sagebrush-associated species and in crafting management practices to avoid and/or mitigate potential human stressors.

METHODS

Field Surveys

We surveyed medium to large-sized mammals on 141 randomly placed transects of variable length (Koenen 2002) during May and June of 2005 (n = 90) or 2006 (n = 51). Transect end points overlapped with the center of randomly selected near-road (n = 40) and far-road (n = 101) survey blocks (Ch. 4). We delineated transects using a least-cost path analysis in ArcMap 9.2 (ESRI 2006) based on minimal change in elevation, between far-road and on-road survey blocks, and between near-road survey blocks and a point on nearest road. Transects were uploaded on Global Positioning System (GPS; Garmin eTrex) units (Ch. 4). Average transect length was 1.1 km (SD = 0.84 km; median = 1.06 km, range = 0.11-6.97 km).

Observers geo-referenced locations of individual medium to large-sized mammals or centers of herds (Buckland et al. 2001) while slowly following predetermined transects by recording location of observer (latitude and longitude) using a GPS, measuring azimuth using a compass, and estimating distance between observer and an individual using a rangefinder (Bushnell Yardage Pro Legend). We plotted individual sightings in ArcMap 9.2 (ESRI 2006) and selected only those sightings within a rectangular-shaped inference space centered on transects.

Abundance Categories

We used Program DISTANCE (Thomas et al. 2009) to calculate detection probabilities and transect-specific densities. We included cluster size (number of individuals detected in a herd) when estimating detection probability because of expected increased detection of larger clusters. In addition, we adjusted detection probabilities by year to account for observer bias, and time of year (May vs. June) to account for seasonal effects.

Model Development

We *a priori* excluded predictor variables from the candidate set of predictor data (Table 4.2) deemed biologically irrelevant for medium to large-sized mammal species based on a literature review. We derived predictor variable values for each transect using a slightly different, but equivalent, method than outlined in Chapter 4. Due to the variable length and shape of transects, we used six different sized buffers (0.27, 0.54, 1, 3, 5, and 18 km) around each transect. Within buffers we calculated land cover, vegetation productivity as measured by Normalized Vegetation Difference Index (NDVI), and terrain-derived variables using zonal statistics in ArcMap 9.2 (ESRI 2006). We derived landscape metrics within three buffer distances (1, 3, and 5 km) in FRAGSTATS (McGarigal et al. 2002). We calculated descriptive statistics for all predictor variables within presence/absence or abundance classes for each species modeled. We also determined the number of transects with predictor variable values > 0 within each abundance class and excluded from model development all variables/extents with <20 survey blocks in a class. We excluded correlated predictor variables ($r_s \geq 0.70$) from potential analyses prior to model development (Ch. 4).

We used a hierarchical multi-stage modeling approach (Ch. 4) because little is known about how anthropogenic disturbance and landscape composition and configuration influence the distribution of medium to large-sized mammal species (O'Brien et al. 2005). We based our analyses either on presence/absence data using logistic regression models or on count-based models using either negative binomial or Poisson regression models depending on distribution of data. For count-based models, we first checked if count data were zero-inflated using a Vuong test (Vuong 1989) based on intercept models. We used an offset term in the general linear model (GLM) of observed counts while incorporating transect-specific detection probabilities (Buckland et al. 2009). We used scatterplots and histograms to initially scan for non-linearities and interactions. If visual inspection indicated a potential non-linearity or interaction we included these functions in subsequent modeling steps. We employed Akaike Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002).

We first evaluated each sagebrush and NDVI variable and identified spatial extent and the combination of the sagebrush and NDVI variables that best represented habitat use. We used these selected sagebrush/NDVI variables as our base model to test all spatial extents for each variable in the vegetation, abiotic, and disturbance submodels. We limited the number of variables in all competing models to the smaller of 10% of either occurrence or absence transects (Hosmer and Lemeshow 2000). After identifying the AIC_c-best model within vegetation, abiotic, and disturbance submodels, we allowed variables within these models to compete both within and across submodels to develop the best overall model. We incorporated model uncertainty by averaging coefficients from models within a cumulative AIC_c weight of just ≥ 0.9 (Burnham and Anderson 2002) while setting coefficients to zero for those variables not contained within a model. To assess model fit for logistic regression models, we used receiver operating characteristic (ROC) plots to estimate area under the curve (AUC, Metz 1978). We determined an optimal cutoff threshold for predicting presence-absence of each

TABLE 8.1. Uncorrected total counts and number of transects on which a species occurred (i.e., includes observations that extended beyond transect) for 10 medium to large-sized mammal species surveyed on 141 transects during May and June of 2005 (n = 90) or 2006 (n = 51) in the Wyoming Basins Ecoregional Assessment area.

		Sightings					Transects				
		2005		2006			2005		2006		
Species	Scientific name	May	June	May	June	Total	May	June	May	June	Total
Cottontail	*Sylvilagus* spp.	7	34	4	5	50	6	18	2	5	25
Coyote	*Canis latrans*	1	0	2	7	10	1	0	2	3	8
Elk	*Cervus canadensis*	0	13	42	2	57	0	2	4	2	9
Moose	*Alces alces*	0	0	0	1	1	0	0	0	1	2
Mule deer	*Odocoileus hemionus*	4	4	25	6	39	2	3	6	4	15
Prairie dog	*Cynomys leucurus* or *C. ludovicianus*	42	79	5	22	148	5	7	2	4	15
Pronghorn	*Antilocapra americana*	449	364	124	87	1,024	45	54	20	23	117
Red fox	*Vulpes vulpes*	0	0	0	2	2	0	0	0	1	2
White-tailed jackrabbit	*Lepus townsendii*	1	9	8	2	20	1	8	8	2	18
Wyoming ground squirrel	*Spermophilus elegans*	0	2	2	3	7	0	2	1	1	4

species (habitat or non-habitat) using a sensitivity-specificity equality approach (Liu et al. 2005) and applied this threshold to assess predictive capacity for each model (Nielsen et al. 2004). All statistical analyses were conducted using STATA 10.1 (STATA Corporation, College Station Texas, USA).

Spatial Application and Dose Response

We predicted species densities in a Geographical Information System (GIS) at a 90-m cell size using the final model coefficients in ArcMap 9.2 raster calculator (ESRI 2006) and binned final model predictions, depending on modeling approach, either into 10% probability classes for logistic regression models or 10 equal-area density classes for count-based regression analyses for summary and display. We masked non-sagebrush habitats (areas with <3% sagebrush habitat in a 5-km moving window) and areas outside the known range of each mammal of interest.

We plotted predicted densities or probability of occurrence of medium to large-sized mammals relative to changes in sagebrush quantity or vegetation productivity in order to assess critical levels of sagebrush habitat or habitat productivity. We calculated these values across one percent intervals of the sagebrush predictor or 0.01 intervals of the NDVI predictor using the Dose Response Calculator tool for ArcGIS (Hanser et al. 2011). We used the optimal cutoff threshold to identify the sagebrush or productivity threshold value, above which each mammalian species was likely to occur.

Model Evaluation

We evaluated model fit for species for which independent data were available by comparing observed proportion of independent locations in each probability bin against expected proportion of locations from the model using regression analysis (Johnson et al. 2006). A model with good fit should have a high R^2 value, a slope not different from 1.0, and an intercept not different from zero (Johnson et al. 2006).

RESULTS

Field Surveys

We detected 1,358 individuals of 10 different species of medium to large-sized mammals on 141 transects (Table 8.1) when using uncorrected counts (i.e., observations beyond transect included). Pronghorn were the most commonly detected species, followed by prairie dog (black-tailed and white-tailed combined), elk (*Cervus canadensis*), cottontail (*Sylvilagus* spp.), and mule deer. Pronghorn were the only species that occurred on >50 transects (Fig. 8.1), the minimum number of transects required to adequately model species distributions (Ch. 4). Given insufficient samples sizes to develop species distribution models for the other medium to large-size mammals, we focus on pronghorn in this chapter.

For the pronghorn analyses, we removed all detections that extended beyond the end points of transects; this reduced total number of detected pronghorn on transects from 1,024 to 344. We detected pronghorn on 62 (44.0%) of 141 transects; 42 transects (46.7%, n = 90) in 2005 and 20 transects (39.2%, n = 51) in 2006. Herd size ranged from 1-30 individuals. We accumulated 157 detections with the majority of sightings consisting of singletons (57.3%); the rest of sightings were small herds consisting of doubles (15.9%), triples (8.3%), and quadruples (2.5%).

Abundance Categories

The detection model with observer as a covariate had the lowest AIC value. However, model fit was poor, with observed detections different from expected (goodness-of-fit test, $\chi^2_{10} = 19.45$, $p = 0.04$). Consequently, we used the second best model selected by ΔAIC_c (0.89). This model was based on a half-normal cosine function with distances truncated at 362 m (10% reduc-

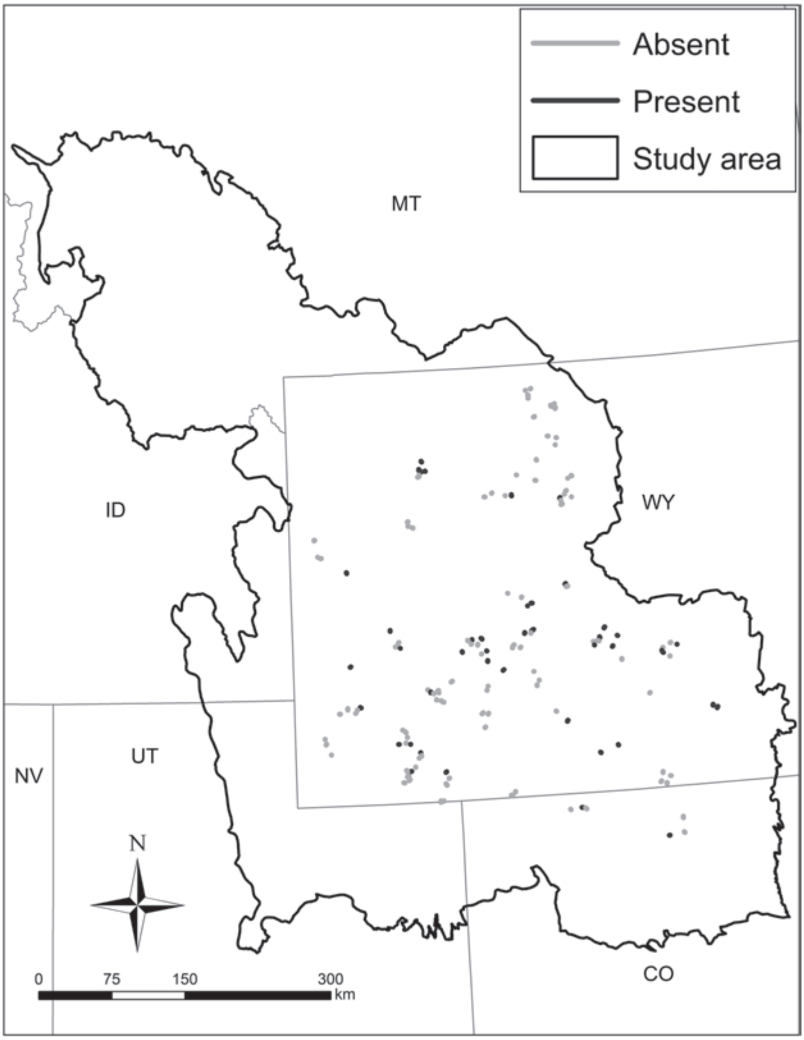

FIG. 8.1. Distribution of transects (n = 141) surveyed for pronghorn in the Wyoming Basins Ecoregional Assessment area. Transects were designated as present (black) and absent (grey) for model development.

tion) and was robust with a non-significant Kolmogorov–Smirnov test (K-S = 0.06, p = 0.57) and goodness-of-fit test ($\chi^2_{14} = 19.81$, p = 0.14). Herd size did not significantly influence detection probability (Student's t = -0.65, df = 139, p = 0.26). Overall detection probability was 0.77 (95% CI = 0.70–0.84) with variance in detection probability explained by detection probability (7.2%), encounter rate (73.0%), and herd size (19.8%). All other models had ΔAIC_c values ranging from 1.67 to 3.96 (observer and sampling May vs. June [round 1 vs. round 2] ΔAIC_c = 1.67, non-covariate model ΔAIC_c = 1.98; sampling May vs. June [round 1 vs. round 2] ΔAIC_c = 3.01; time of day ΔAIC_c = 3.87; year and Julian date ΔAIC_c = 3.96). Overall density was 0.04 pronghorn/ha (95% CI = 0.03–0.05) and ranged between 0-0.33 pronghorn/ha on transects.

Model Development

We excluded three sagebrush variables at the subspecies level (ABIGSAGE ([*A.*

tridentata], BIGSAGE [*A. t.* ssp. *tridentata, A. t.* ssp. *wyomingensis*], and MTNSAGE [*A. t.* ssp. *vaseyana*]) from the analyses (all spatial extents; n = 18) because pronghorn show no preference for one sagebrush type over another (Kilgore and Fairbanks 1997, MacKenzie 2006). In addition, we excluded eight soil variables (acidity, available water capacity, bulk density, clay content, depth, salinity, sand content, and silt content). We excluded several predictor variables from the candidate set, including sagebrush mean patch size ($PATCH_{1km}$, $PATCH_{3km}$, $PATCH_{5km}$) and compound topographic index (CTI) that were correlated with all sagebrush (ALLSAGE); mean annual maximum temperature (T_{max}) was correlated with elevation (ELEV); and precipitation (PRECIP), terrain roughness index (TRI) and slope (SLOPE) were correlated with Normalized Difference Vegetation Index (NDVI). We also excluded predictor variables with values > 0 on <20 transects, including coniferous forest ($CFRST_{270}$ and $CFRST_{540}$) and mixed shrubland (MIX_{270} and MIX_{540}). Overall, we excluded 31 variables leaving 91 predictor variables for the pronghorn model.

Our first step was to model pronghorn density using count-based regression models with transect-level detection probability included as an offset (Buckland et al. 2009). We used a three-tiered approach to determine appropriate error structure (negative-binomial, Poisson, zero-inflated negative-binomial, or zero-inflated Poisson) of the pronghorn count data in general linear models. First, Vuong tests (Vuong 1989) of intercept models without the offset term indicated superior fit of the negative-binomial over the zero-inflated negative binomial, zero-inflated Poisson, and Poisson regression models. Second, we plotted count vs. predicted/observed and found that the negative binomial showed the best data fit. Last, we regressed count against all sagebrush within 0.27 km ($ALLSAGE_{270}$) including the offset term. The Vuong test was non-significant (z = 0.1, p = 0.46), indicating that the negative binomial error structure was appropriate. We then ran all submodels and developed a model-averaged composite model from eight models with cumulative AIC_c weights of just ≥ 0.9. The final negative binomial regression model is below.

$$\text{Density} = \exp(-1.38 + 2.60 * ALLSAGE_{5km} + 3.39 * NDVI - 0.04 * SOLAR - 0.0037 * Tmin - 3.197 * SALT_{18km} + 2.23 * RIP_{5km} + 0.53 * RDdens_{540} - 3.41) \tag{8.1}$$

We spatially applied the composite model and evaluated model prediction with pronghorn aerial counts conducted by the Wyoming Fish and Game Department during May and June of 2005 in the Worland Basin. We found no correlation between predicted density (estimated density from model) and independent counts (r_s = -0.003, p = 0.96, n = 350), indicating that the negative binomial regression model performed poorly. We therefore re-analyzed the presence/absence pronghorn data using logistic regression analyses. After removing observations >362 m, the truncation distance determined by removing 10% of the farthest observations in Program DISTANCE (Thomas et al. 2009), all transects with ≥1 pronghorn were coded as presence.

Logistic regression model

The AIC_c-selected top sagebrush/NDVI model consisted of all sagebrush within 0.27 km ($ALLSAGE_{270}$), NDVI within 0.27 km ($NDVI_{270}$), and an interaction ($ALLSAGE_{270}$ * $NDVI_{270}$) (Table 8.2). The other 3 models with AIC_c ≤ 2 consisted of all sagebrush and NDVI at larger extents with quadratic terms. Within a 0.27-km radius, there was on average 13.3% more all sagebrush land cover at occupied transects (80.6%, SE = 0.03) compared to absence transects (67.3%, SE = 0.03) (Appendix 8.1).

TABLE 8.2. Results of AIC_c-based model selection for pronghorn occurrence in relation to multi-scale sagebrush and NDVI variables in the Wyoming Basins Ecorgional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Number	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ALLSAGE_{270} + NDVI_{270} + ALLSAGE_{270} * NDVI_{270}$	-86.06	4	180.12	0.00	0.13
2	$ALLSAGE_{540} + NDVI_{270} + ALLSAGE_{540} * NDVI_{270}$	-86.16	4	180.33	0.21	0.12
3	$ALLSAGE_{1km} + NDVI_{270} + ALLSAGE_{1km} * NDVI_{270}$	-86.73	4	181.45	1.33	0.07
4	$ALLSAGE_{270} + NDVI_{540} + ALLSAGE_{270} * NDVI_{540}$	-86.92	4	181.84	1.72	0.06

[a] Variable definitions provided in Table 4.2

None of the AIC_c-selected univariate models included a non-linear quadratic term and the moving window radius of selected land cover variables ranged from 1-18 km (Table 8.3). The top vegetation, abiotic and disturbance submodels consisted of one to three variables in addition to the sagebrush/NDVI base model. The top vegetation submodel consisted of mixed shrubland land cover within 3 km (MIX_{3km}), riparian land cover within 5 km (RIP_{5km}), and salt-desert shrubland within 18 km ($SALT_{18km}$); the top abiotic submodel consisted of elevation (ELEV); and the top disturbance model consisted of density of all roads within 5 km ($RDdens_{5km}$) and 1-km distance decay from power lines ($POWER_{1km}$) (Table 8.4).

Pronghorn occurrence during the breeding season was influenced primarily by land cover and to a lesser degree by abiotic and disturbance factors (Table 8.5). Pronghorn occurrence was positively associated with increased land cover of all sagebrush within 0.27 km, riparian land cover within 5 km, mixed shrubland within 3 km, NDVI within 0.27 km, elevation, 1-km distance decay from power lines, and higher road densities within 5 km. Pronghorn occurrence was negatively associated with increased salt desert shrubland within 18 km and an interaction between all sagebrush and NDVI within 0.27 km. The final model was a composite of 15 models, with the top AIC_c model having a low weight of evidence (*wi* = 0.25). The final composite probability of occurrence model is below.

$$\text{Prob} = 1/ (1 + (\exp (-(-7.98 + 8.75 * ALLSAGE_{270} + 14.10 * NDVI_{270} - 19.87 * ALLSAGE_{270} * NDVI_{270} - 6.88 * SALT_{18km} + 2.76 * RIP_{5km} + 7.81 * MIX_{3km} + 0.00047 * ELEV + 1.42 * POWER_{1km} + 0.3 * RDdens_{5km})))) \tag{8.2}$$

The composite model of pronghorn occurrence had good accuracy (ROC AUC = 0.83) and was a slight improvement over the AIC_c-selected top model (ROC AUC = 0.82). This model had an optimal sensitivity-specificity equality threshold of 0.46 with 74.1% of transects correctly classified.

Spatial Application and Dose Response

Pronghorn occurrence was predicted throughout the WBEA area (Fig. 8.2). Based on our optimal cutoff point and a binary presence/absence classification, 9,439 km^2 (13.3%) of suitable pronghorn habitat was predicted within the WBEA study area (Fig. 8.3). Pronghorn were more likely to occur in areas with either <7% or >76% of the landscape containing all sagebrush land cover within a 0.27-km radius (Fig. 8.4) and in areas of medium to high above-ground productivity (NDVI values > 0.26) within a 0.27-km radius (Fig. 8.5).

TABLE 8.3. Evaluation statistics from AIC_c-based univariate model selection for pronghorn occurrence in the Wyoming Basins Ecorgional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). All logistic regression models included all sagebrush within a 0.27-km radius, NDVI within a 0.27-km radius, and an interaction term. We used AIC_c to sort models for each variable in ascending order to identify the extent at which pronghorn respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{18km}$	-85.88	5	182.57	0.00	0.27
	$CFRST_{3km}$	-85.89	5	182.60	0.03	0.26
	$CFRST_{1km}$	-85.97	5	182.75	0.17	0.24
	$CFRST_{5km}$	-86.03	5	182.88	0.31	0.23
	$GRASS_{18km}$	-85.48	5	181.77	0.00	0.27
	$GRASS_{1km}$	-85.99	5	182.80	1.03	0.20
	$GRASS_{270}$	-86.02	5	182.86	1.09	0.20
	$GRASS_{540}$	-86.01	5	182.83	1.06	0.20
	$GRASS_{5km}$	-86.01	5	182.83	1.06	0.20
	$GRASS_{3km}$	-86.05	5	182.92	1.15	0.19
	MIX_{3km}	-85.19	5	181.19	0.00	0.17
	MIX_{1km}	-85.21	5	181.23	0.03	0.17
	MIX_{18km}	-85.21	5	181.24	0.05	0.16
	MIX_{5km}	-85.50	5	181.81	0.61	0.12
	RIP_{5km}	-83.00	5	176.82	0.00	0.17
	RIP_{3km}	-83.54	5	177.90	1.08	0.10
	RIP_{18km}	-83.91	5	178.64	1.82	0.07
	RIP_{540}	-85.20	5	181.21	4.39	0.02
	RIP_{1km}	-85.39	5	181.60	4.78	0.02
	RIP_{270}	-85.74	5	182.30	5.48	0.01
	$SALT_{18km}$	-81.12	5	173.06	0.00	0.94
	$SALT_{5km}$	-84.77	5	180.35	7.29	0.02
	$SALT_{3km}$	-85.19	5	181.18	8.13	0.02
	$SALT_{1km}$	-85.95	5	182.71	9.65	0.01
	$SALT_{270}$	-86.04	5	182.89	9.83	0.01
	$SALT_{540}$	-86.05	5	182.91	9.85	0.01
	$CONTAG_{5km}$	-85.26	5	181.34	0.00	0.39
	$CONTAG_{1km}$	-85.44	5	181.70	0.36	0.33
	$CONTAG_{3km}$	-85.62	5	182.06	0.71	0.28
	$EDGE_{1km}$	-85.75	5	182.32	0.00	0.37
	$EDGE_{5km}$	-85.84	5	182.49	0.17	0.34
	$EDGE_{3km}$	-85.98	5	182.77	0.45	0.29

TABLE 8.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Abiotic	CTI	-86.02	5	182.85	0.00	0.75
	CTI[b]	-86.01	6	184.84	2.18	0.25
	ELEV	-82.51	5	175.83	0.00	0.71
	ELEV[b]	-82.30	6	177.42	1.77	0.29
	SOLAR	-85.66	5	182.14	0.00	0.58
	SOLAR[b]	-84.91	6	182.64	0.68	0.42
	TRI_{1km}	-85.25	5	181.32	0.00	0.14
	TRI_{18km}	-85.37	5	181.56	0.25	0.13
	TRI_{5km}	-85.44	5	181.69	0.37	0.12
	TRI_{18km}[b]	-84.64	6	182.09	0.96	0.09
	TRI	-85.86	5	182.54	1.23	0.08
	TRI[b]	-85.96	5	182.74	1.42	0.07
	TRI_{3km}	-85.96	5	182.74	1.43	0.07
	TRI_{540}	-86.04	5	182.89	1.57	0.07
	TRI_{270}	-86.05	5	182.92	1.60	0.06
	TRI_{1km}[b]	-85.10	6	183.02	1.88	0.06
	TRI_{5km}[b]	-85.38	6	183.57	2.44	0.04
	TRI_{3km}[b]	-85.69	6	184.20	3.06	0.03
	TRI_{270}[b]	-85.93	6	184.68	3.55	0.02
	TRI_{540}[b]	-85.96	6	184.72	3.59	0.02
	Tmin	-84.40	5	179.62	0.00	0.50
	Tmin[b]	-84.40	5	179.62	0.00	0.50
	$iH2Od_{1km}$[c]	-86.03	5	182.88	0.00	0.34
	$iH2Od_{500}$[c]	-86.05	5	182.91	0.03	0.33
	$iH2Od_{250}$[c]	-86.06	5	182.93	0.05	0.33
	$pH2Od_{250}$[c]	-85.91	5	182.64	0.00	0.36
	$pH2Od_{500}$[c]	-85.99	5	182.80	0.16	0.33
	$pH2Od_{1km}$[c]	-86.06	5	182.93	0.29	0.31
Disturbance	AG_{250}[c]	-85.69	5	182.20	0.00	0.42
	AG_{500}[c]	-86.05	5	182.91	0.71	0.29
	AG_{1km}[c]	-86.06	5	182.93	0.73	0.29
	$MjRD_{1km}$[c]	-85.45	5	181.72	0.00	0.37
	$MjRD_{500}$[c]	-85.54	5	181.90	0.19	0.33
	$MjRD_{250}$[c]	-85.65	5	182.11	0.40	0.30
	$PIPE_{250}$[c]	-85.99	5	182.80	0.00	0.34
	$PIPE_{500}$[c]	-86.00	5	182.81	0.01	0.34
	$PIPE_{1km}$[c]	-86.03	5	182.88	0.08	0.33

TABLE 8.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$POWER_{1km}^{c}$	-83.14	5	177.09	0.00	0.42
	$POWER_{500}^{c}$	-83.45	5	177.71	0.62	0.31
	$POWER_{250}^{c}$	-83.61	5	178.03	0.94	0.27
	$2RD_{1km}^{c}$	-86.00	5	182.82	0.00	0.34
	$2RD_{250}^{c}$	-86.02	5	182.86	0.04	0.33
	$2RD_{500}^{c}$	-86.06	5	182.93	0.11	0.32
	$WELL_{500}^{c}$	-86.03	5	182.88	0.00	0.34
	$WELL_{250}^{c}$	-86.04	5	182.90	0.02	0.33
	$WELL_{1km}^{c}$	-86.06	5	182.93	0.06	0.33
	$RDdens_{5km}$	-83.27	5	177.35	0.00	0.68
	$RDdens_{3km}$	-85.16	5	181.13	3.78	0.10
	$RDdens_{270}$	-85.40	5	181.61	4.25	0.08
	$RDdens_{18km}$	-85.89	5	182.60	5.24	0.05
	$RDdens_{540}$	-86.04	5	182.89	5.54	0.04
	$RDdens_{1km}$	-86.05	5	182.92	5.57	0.04

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + $variable^2$)

[c] Distance decay function ($e^{(\text{Euclidean distance from feature/-distance parameter})}$)

Model Evaluation

We evaluated model predictions with pronghorn aerial counts conducted by the Wyoming Fish and Game Department during May and June of 2005 in the Worland Basin. Each observation was spatially geo-referenced and attributed with a herd count (range = 1–16 pronghorn).

We found strong corroboration of the test data with model predictions. Regressing observed probability of occurrence against predicted probability of occurrence resulted in a slope close to 1.0 but significantly different from zero, and an intercept close to zero with a high R^2 (slope = 0.99, SE = 0.20; intercept = 0.00083, SE = 0.02; $R^2 = 0.75$; $F_{1,8} = 24.53$, p = 0.001).

DISCUSSION

We identified three land cover types at three different extents that related positively to pronghorn occurrence during the breeding season. In order of increasing extent, pronghorn were more likely to occur in areas where proportion of sagebrush land cover was either high (>76%) or low (<7%) within 0.27 km, in areas with greater proportions of mixed shrubland (i.e., rubber [*Ericameria* spp.] and yellow [*Chrysothamnus* spp.] rabbitbrush and winterfat [*Krascheninnikovia lanata*]) within 3 km, and in areas with greater proportions of riparian land cover within 5 km. Our findings corroborate other studies that identified the importance of shrubs in pronghorn diet, particularly winterfat (Stephenson et al. 1985), typically found in mixed shrubland, and pronghorn habitat use (Dirschl 1963, Martinka 1967, Bayless 1969, Beale and Smith 1970, Clary and Beale 1983, MacKenzie 2006). Shrub cover was the most important variable predicting pronghorn winter density and fawn:doe ratios (Irwin and Cook 1985).

TABLE 8.4. Results of AIC_c-based submodel selection for pronghorn occurrence in the Wyoming Basins Ecorgional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + MIX_{3km} + RIP_{5km} + $SALT_{18km}$	-77.77	7	171.22	0.00	0.32
	2	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + MIX_{3km} + $SALT_{18km}$	-79.39	6	172.02	0.81	0.22
	3	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + $CFRST_{18km}$ + $SALT_{18km}$	-79.49	6	172.23	1.01	0.20
	4	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + RIP_{5km} + $SALT_{18km}$	-79.81	6	172.88	1.66	0.14
	5	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + $SALT_{18km}$	-81.12	5	173.13	1.91	0.12
Abiotic	1	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + ELEV	-82.51	5	175.91	0.00	0.13
	2	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + ELEV + TRI_{1km}	-81.65	6	176.55	0.65	0.10
	3	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + ELEV + SOLAR	-81.72	6	176.70	0.79	0.09
	4	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + ELEV + SOLAR + TRI_{1km}	-80.82	7	177.33	1.43	0.07
Disturbance	1	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + $RDdens_{5km}$ + $POWER_{1km}$	-80.43	6	173.49	0.00	0.18
	2	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + $PIPE_{250}$ + $RDdens_{5km}$ + $POWER_{1km}$	-79.39	7	173.63	0.14	0.17
	3	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + AG_{250} + $RDdens_{5km}$ + $POWER_{1km}$	-79.63	7	174.11	0.62	0.13
	4	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + $WELL_{500}$ + $RDdens_{5km}$ + $POWER_{1km}$	-79.87	7	174.59	1.10	0.10
	5	$ALLSAGE_{270}$ + $NDVI_{270}$ + $ALLSAGE_{270}$ * $NDVI_{270}$ + $2RD_{1km}$ + $RDdens_{5km}$ + $POWER_{1km}$	-80.32	7	175.48	1.99	0.07

[a] Variable definitions provided in Table 4.2

Our study also corroborates other studies that show riparian land cover is important to pronghorn occurrence. Availability of water is a critical component of pronghorn ranges (Ryder 1983), especially during summer and fall (Einarsen 1948). Drought conditions during midsummer decreased doe survival in the southwestern United States, which was a more important correlative of population trend than winter-rain influence on fawn survival (Brown et al. 2006). Habitats that maintain high pronghorn densities had water available within 1.6 km (Yoakum 1974, Ockenfels et al. 1994). In Wyoming, 95% of over 12,000 pronghorn detections were observed within 6.4 km of water (Sundstrom 1968).

Pronghorn occurrence in the WBEA study area was related negatively to an interaction between all sagebrush and NDVI within 0.27 km, and salt-desert shrubland within 18 km. The interaction between all sagebrush and NDVI indicates that not all sagebrush can be treated equally; our study suggests that pronghorn used sagebrush habitat only in areas with higher above-ground productivity. As above-ground productivity varies spatially and temporally (Bradley and Mustard 2008), it is to be expected that habitat use by pronghorn may shift annually within sagebrush and mixed shrubland. Future studies should investigate how annual variation in above-ground productivity, particularly grass biomass that forms the major component of pronghorn diet (McInnis and Vavra 1986), relates to pronghorn occurrence. In regard to salt-desert shrubland, extensive patches of this ecological system that lack extensive herbaceous cover may offer little forage for pronghorn (West 1983). Shadscale saltbush (*Atriplex confertifolia*), a dominant shrub species, is nearly absent in the pronghorn diet (McInnis and Vara 1987).

For abiotic variables, NDVI within 0.27 km and elevation related positively to pronghorn occurrence in the WBEA area. Selection of sagebrush at higher elevations in areas with higher above-ground biomass, as indicated by higher NDVI values, may maximize caloric intake. Pronghorn consume a higher percentage of forbs during summer (Stephenson et al. 1985), and selection for higher elevations in our study likely captured increases in forb abundance at higher elevations in sagebrush ecosystems (Franklin and Dyrness 1988).

Two anthropogenic features, 1-km distance decay from power lines and road density within 5 km, were positively associated with pronghorn occurrence. This was unexpected because several studies found negative effects of anthropogenic factors on pronghorn occupancy or behavior, including human disturbance (Berger et al. 1983, Easterly and Guenzel 1992, Sawyer et al. 2005), oil and gas extraction (Easterly et al. 1991, Easterly and Guenzel 1992), vehicular traffic volume (Berger et al. 1983, Gavin and Komers 2006, Harrington and Conover 2006), and recreation, such as hiking and mountain biking (Fairbanks and Tullous 2002, Taylor and Knight 2003). We used a stratified sampling design based on sagebrush habitat productivity and cumulative effects of human land use (Ch. 4). Consequently, we may have under-sampled responses by pronghorn to specific anthropogenic stressors, such as high-volume traffic roads. In our study, only 12% of randomly selected transects started on high-traffic interstates/state and federal highways. Alternatively, it is also possible that the two anthropogenic features are surrogate variables for flat areas, in the case of power lines, and food availability, in the case of road density, as road verges may contain higher grass and forb cover, particularly of exotic species, compared to sagebrush habitat adjacent to roads (Gelbard and Belnap 2003, Ch. 10).

Our study indicates that walking-transect sampling works well for large but not for medium-sized mammals. Why the transect method resulted in few medium-sized mammal sightings is perplexing because other studies have successfully employed similar survey methods to study lagomorph

TABLE 8.5. Results of AIC$_c$-based model selection for the combined pronghorn occurrence models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (Beta [SE]) and evaluation statistics (Log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Constant	ALLSAGE$_{270}$	NDVI$_{270}$	ALLSAGE$_{270}$ * NDVI$_{270}$	SALT$_{18km}$	POWER$_{1km}$
1	-8.33 (2.80)	10.14 (3.42)	17.01 (7.16)	-23.59 (9.29)	-11.00 (4.06)	1.97 (0.78)
2	-8.35 (2.81)	10.79 (3.44)	17.24 (7.03)	-24.19 (9.14)	-10.40 (4.24)	2.05 (0.78)
3	-7.20 (2.62)	9.92 (3.31)	15.87 (7.00)	-22.23 (9.07)	-12.13 (4.16)	2.04 (0.78)
4	-12.24 (2.87)	9.92 (3.20)	14.37 (6.95)	-21.61 (8.92)		
5	-12.30 (2.98)	9.90 (3.30)	15.86 (7.24)	-22.44 (9.29)		1.68 (0.75)
6	-11.86 (2.91)	9.24 (3.18)	14.45 (7.14)	-20.27 (9.18)		1.89 (0.76)
7	-12.67 (3.02)	9.71 (3.26)	15.46 (7.28)	-22.50 (9.36)		
8	-8.08 (2.78)	10.30 (3.41)	16.86 (7.26)	-24.23 (9.41)	-9.29 (3.61)	
9	-7.81 (2.74)	10.31 (3.38)	16.43 (6.97)	-23.51 (9.05)	-9.62 (3.87)	
10	-10.34 (2.80)	11.73 (3.42)	20.20 (6.94)	-26.91 (8.96)		1.95 (0.76)
11	-10.93 (2.91)	12.08 (3.52)	20.86 (7.16)	-28.09 (9.24)		1.82 (0.75)
12	-6.68 (2.57)	9.51 (3.26)	15.16 (6.96)	-21.72 (9.03)	-11.28 (3.84)	
13	-8.86 (3.02)	9.22 (3.23)	13.98 (7.17)	-20.61 (9.27)	-8.34 (4.30)	
14	-8.69 (2.88)	10.88 (3.50)	17.61 (7.27)	-25.34 (9.42)	-8.29 (3.68)	
15	-11.54 (2.85)	10.54 (3.25)	15.09 (7.05)	-22.81 (9.03)		

[a] Variable definitions provided in Table 4.2

[b] Values are multiplied by 10^2

(Gross et al. 1974, Daniel et al. 1993, Bartel et al. 2008) and ground squirrel ecology (Greene et al. 2009) in the sagebrush ecosystem. Low detection rates could be attributed to low population densities during 2005 and 2006 when we sampled these species. This may apply to the Wyoming ground squirrel because both transect and survey block surveys resulted in insufficient sample sizes to develop species distribution models (Ch. 7). In contrast, we detected cottontails and white-tailed jackrabbits in sufficient sample sizes using area searches within 7.29-ha survey blocks, but not on transects (Ch. 7). The serpentine sampling pattern on survey blocks may have resulted in higher flushing rates compared to the straight-line walking pattern on transects. In contrast, transect sampling appeared well suited to survey pronghorn, the most commonly observed mammal in this study. Most pronghorn were detected close to transects (mean detection distance = 225 m, SD = 201 m, range = 4-1,041 m, n = 169) with a high detection probability (0.77). Walking transects coupled with distance sampling may be a cost effective alternative to expensive aerial pronghorn surveys (Rabe et al. 2002). In addition, walking transects are well suited for use in citizen science programs, which could be implemented to help evaluate long-term pronghorn population trends. For medium-sized mammals, we recommend the area-search method, which was more effective in achieving minimum sample sizes

TABLE 8.5. Extended

$RDdens_{5km}$	RIP_{5km}	MIX_{3km}	$ELEV^b$	LL	K	AIC_c	ΔAIC_c	Σw_i
0.86 (0.49)				-75.42	7	166.52	0.00	0.25
	9.43 (5.88)			-75.93	7	167.54	1.02	0.41
				-77.28	6	167.82	1.30	0.54
	14.93 (5.79)	46.14 (23.53)	0.20 (0.07)	-76.70	7	169.08	2.56	0.61
1.06 (0.51)			0.17 (0.07)	-76.88	7	169.44	2.92	0.67
		44.45 (22.62)	0.21 (0.07)	-77.03	7	169.74	3.22	0.72
1.11 (0.51)		41.16 (22.45)	0.20 (0.07)	-77.33	7	170.35	3.83	0.76
0.94 (0.50)				-78.97	6	171.18	4.66	0.78
	9.96 (5.67)	39.91 (23.58)		-77.77	7	171.22	4.70	0.81
	15.66 (5.82)	33.71 (19.68)		-77.96	7	171.59	5.07	0.83
0 .74 (0.44)	11.95 (5.79)			-78.13	7	171.95	5.43	0.84
		36.90 (23.31)		-79.39	6	172.02	5.50	0.86
		42.85 (24.55)	0.11 (0.07)	-78.20	7	172.09	5.57	0.88
0 .78 (0.49)	6.72 (5.79)			-78.28	7	172.24	5.72	0.89
	13.17 (5.66)		0.17 (0.06)	-79.52	6	172.29	5.77	0.90

required for species distribution models (Ch. 7). We further suggest multiple visits to each survey block such that species distribution models can be based on occupancy modeling, which adjusts naïve occupancy estimates by detection probabilities (MacKenzie et al. 2006).

Predictive performance of the simple logistic regression model was superior over the more complex count-based negative binomial regression model when evaluated with independent aerial pronghorn survey data (Wyoming Fish and Game Department). Why did the performance between the models differ so profoundly? First, we may have identified the incorrect link function which could have led to invalid model structure and therefore poor model performance (Potts and Elith 2006). Potts and Elith (2006) found that when keeping model structure fixed, the negative binomial regression model performed worst when compared to Poisson, quasi-Poisson, zero-inflated Poisson, and hurdle models. This seems to be less likely as the Vuong test (Vuong 1989) clearly identified the negative binomial regression model as appropriate for the pronghorn density data. Second, it is possible that the set of predictor variables in our study were not a valid index to pronghorn abundance patterns. In our study, 43% of observations consisted of pronghorn herds ranging in size from two to 30 individuals. Herd composition differed among observations because we sampled a mixture of bachelor

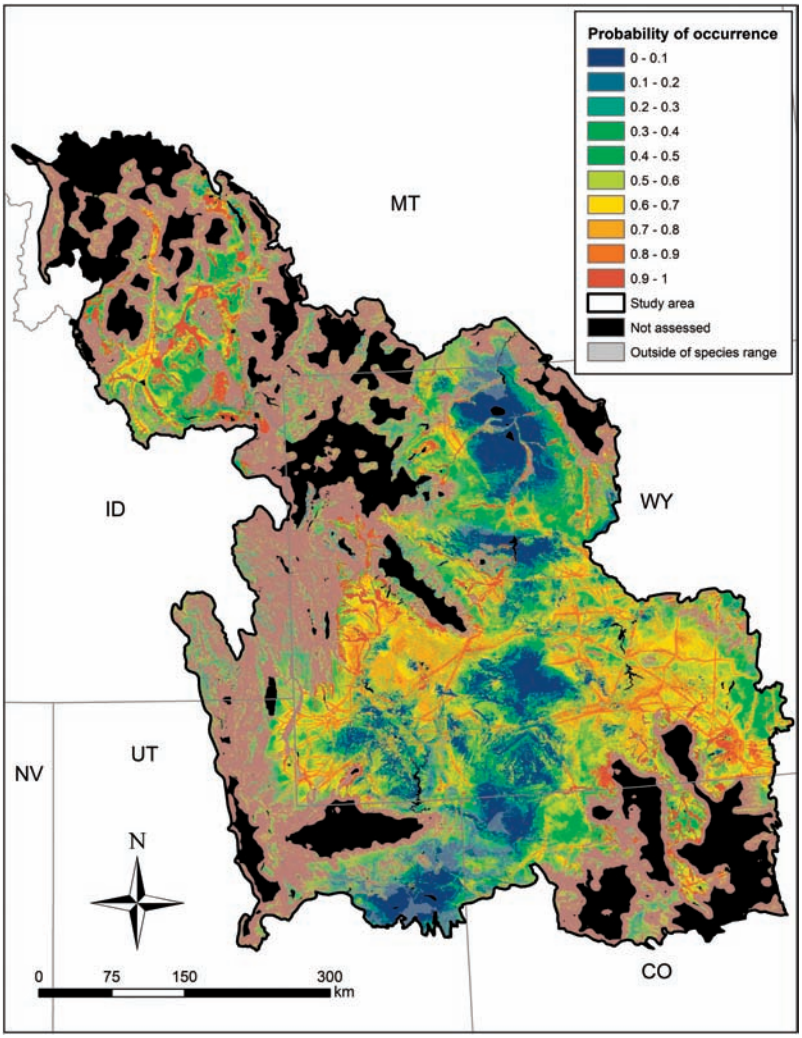

FIG. 8.2. Pronghorn probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Pronghorn are likely to occur in areas with probability > 0.46.

herds, doe-fawn pairs, and herds consisting of multiple doe-fawn pairs and territorial males (Kitchen 1974). Therefore, differences in social interaction and herd composition within high-density pronghorn areas could have led to an invalid model structure as different social structures conceivably overlapped with a different suite of environmental factors not included in our predictor variables (Nielsen et al. 2005) or included only as surrogate variables (Vanreusel et al. 2007). Model structure incongruence between occurrence and abundance models has been shown for bracken fern (*Pteridium aquilinum*) and high-density moose (*Alcer alcer*) areas (Nielsen et al. 2005).

Model structure differed between negative binomial and logistic regression models with transect-level detection probabilities included as offsets (Buckland et al. 2009) in the negative binomial regression model. Some predictor variables were included in both models at the same extent

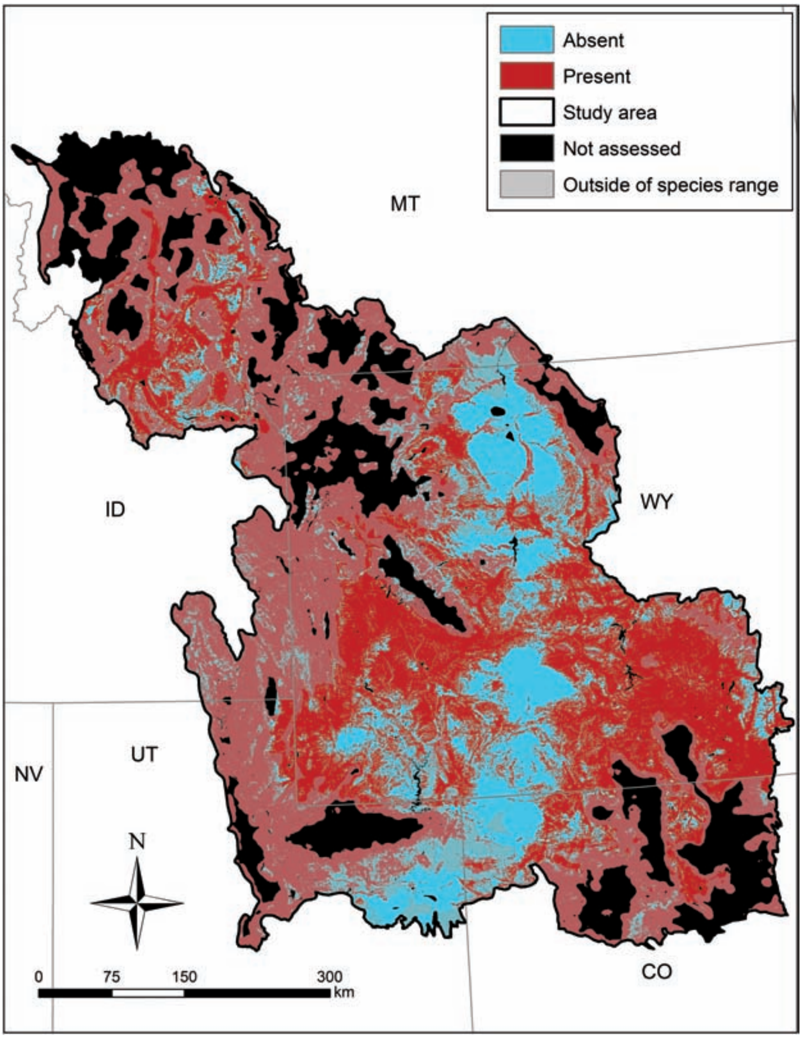

FIG. 8.3. Distribution of pronghorn in the Wyoming Basins Ecoregional Assessment area based on optimum probability cutoff threshold of 0.46. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

(RIP_{5km} and $SALT_{18km}$), while others were unique to one model but not the other (negative binomial regression only: SOLAR and Tmin; logistic regression only: MIX_{3km}, ELEV and $POWER_{1km}$), or were the same type but differed in extent (negative binomial regression vs. logistic regression: $ALLSAGE_{5km}$ vs. $ALLSAGE_{270}$; NDVI vs. $NDVI_{270}$; $RDdens_{540}$ vs. $RDdens_{5km}$). Not including detection probabilities in modeling resource selection could lead to misleading selection of predictor variables; predictor variables can be correlated with detecting individuals rather than habitat use (MacKenzie 2006). For example, MacKenzie (2006) found that the variable "distance to water" was in the top AIC-selected logistic regression models when detection probabilities were not included, but when he included detection probabilities the variable "distance to water" was not in the top AIC-selected logistic regression models. Although we found the predictive capability of the simple lo-

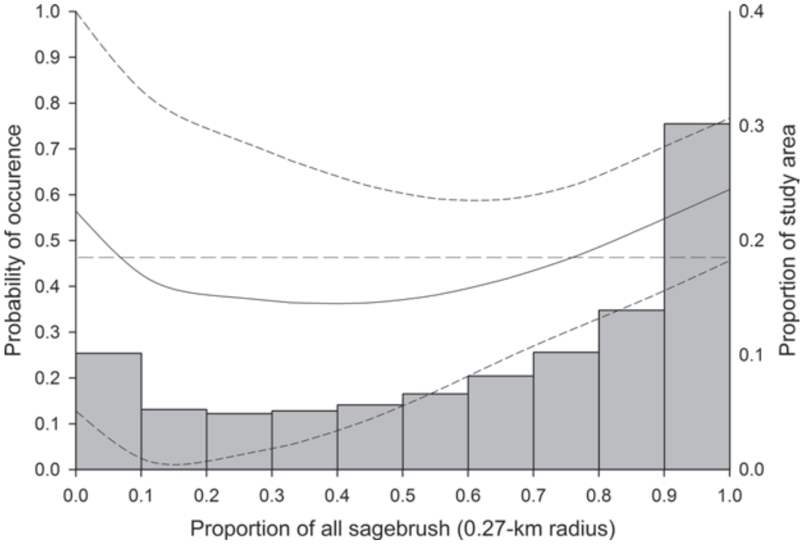

FIG. 8.4. The distribution of pronghorn probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all sagebrush (*Artemisia* spp.) within a 0.27-km radius. Mean probability of occurrence (black line) and standard deviation (dashed lines) values were calculated in each one percent increment of all sagebrush within a 0.27-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.46), above which pronghorn occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all sagebrush within 0.27 km.

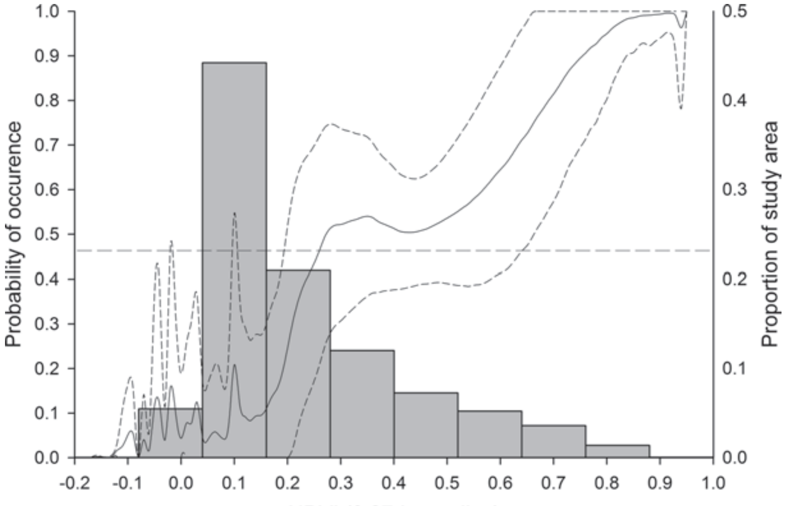

FIG. 8.5. The distribution of pronghorn probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to NDVI (Normalized Difference Vegetation Index) within a 0.27-km radius. Mean probability of occurrence (black line) and standard deviation (dashed lines) values were calculated in each 0.01 increment of NDVI within a 0.27-km radius moving window. Range of predictions relate to the observed range of NDVI at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.46), above which pronghorn occurrence is predicted. Histogram values represent the proportion of the total study area in each 0.01 segment of NDVI within 0.27 km.

gistic regression model to be excellent, the structure of this model needs to be further evaluated against a model developed in an occupancy modeling framework where detection probability is included in the model structure (MacKenzie et al. 2006).

Conclusion

Pronghorn occurrence in the WBEA area was best predicted by the distribution and extent of various land cover types, but current levels of anthropogenic disturbances did not appear to affect occurrence of pronghorn during the breeding season. However, anthropogenic stressors may influence different components of fitness that were not assessed in this study. We were unable to incorporate additional anthropogenic stressors into our analyses, as spatial data for these stressors did not exist at the time of our study. For example, fences restrict daily and seasonal pronghorn movement and may result in injury and mortality (Spillet et al. 1967, Ryder et al. 1984, Yoakum and O'Gara 2000, Harrington and Conover 2006). Despite these limitations, we found that the pronghorn model had superior predictive capabilities and therefore can be an important tool to assess the effects of future development on pronghorn occurrence.

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APPENDIX 8.1.

This appendix contains descriptive statistics for explanatory variables used to model pronghorn occurrence. Variables are summarized by occurrence class, and statistics include mean, standard error, lower and upper 95% confidence interval, and minimum and maximum value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

Sagebrush Ecosystem Conservation and Management: 337–356, 2011

Chapter 9: Occurrence of Small Mammals: Deer Mice and the Challenge of Trapping Across Large Spatial Extents

Steven E. Hanser, Matthias Leu, Cameron L. Aldridge, Scott E. Nielsen, and Steven T. Knick

Abstract. Small mammal communities living in sagebrush (*Artemisia* spp.) may be sensitive to habitat isolation and invasion by exotic grass species. Yet there have been no spatially explicit models to improve our understanding of landscape-scale factors determining small mammal occurrence or abundance. We live-trapped small mammals at 186 locations in the Wyoming Basin Ecoregional Assessment area to develop species distribution (habitat) models for each species. Most small mammal species (n = 14) were trapped at a only few locations. As a result, we developed a small mammal model only for the deer mouse (*Peromyscus maniculatus*). Deer mice were associated with areas having moderately productive habitat as measured by Normalized Difference Vegetation Index (NDVI), increased grassland land cover, contagion of sagebrush land cover, and proximity to intermittent water. The proportion of big sagebrush (*Artemisia tridentata*) within 0.27 km, proportion of mixed shrubland within 5 km, soil clay content, and proximity to pipelines were inversely related to the occurrence of deer mice. Understanding habitat characteristics for deer mice helps our overall understanding of the ecological processes within sagebrush habitats because deer mice act as predator, prey, competitor, and disease reservoir. Development of the empirical data necessary for spatially explicit habitat modeling of small mammal distributions at large spatial extents requires an extensive trapping effort in order to obtain enough observations to construct models, calculate robust detectability estimates, and overcome issues such as trap shyness and population cycling.

Key words: anthropogenic disturbance, deer mouse, occurrence, *Peromyscus maniculatus,* small mammals.

Habitat fragmentation and loss (Soulé et al. 1992, Bentley et al. 2000, Debinski and Holt 2000) as well as anthropogenic activity (Oxley et al. 1974, Germaine et al. 2001, Yale-Conrey and Mills 2001) can influence dispersal, diversity, and abundance of small mammal populations (Dunsten and Fox 1996, Fitzgibbon 1997, Clark et al. 2001, Yale-Conrey and Mills 2001). Similar impacts have been documented for the small mammal community within the sagebrush (*Artemisia* spp.) steppe ecosystem (Dobkin and Sauder 2004, Hanser and Huntly 2006). In addition to these effects, cultivation (crested wheatgrass, *Agropyron cristatum*) or invasion (cheatgrass, *Bromus tectorum*) of exotic grasses within sagebrush ecosystems further alters the composition and abundance of the small mammal community (Reynolds 1980, Hanser and Huntly 2006). Anthropogenic disturbances can also increase predation rates on small mammals through the addition of perch and nest locations, as well as subsidization of synanthropic predators because of the presence of landfills and other anthropogenic food sources (Engel et al. 1992, Knight and Kawashima 1993, Steenhof et al. 1993, Kristan et al. 2004).

Most habitat studies on small mammals have examined the effects of local habitat factors (Dueser and Shugart 1978, Jorgensen 2004). Few have examined regional or landscape effects on small mammals (Orrock et al. 2000, Martin and McComb 2002), likely owing to the difficulty in estimating small mammal occurrence and abundance at large spatial extents and the lack of a systematic monitoring scheme, such as the Breeding Bird Survey (Pardieck and Sauer 2000).

Spatially explicit habitat models that predict and explain factors affecting occurrence and abundance of small mammals would be of substantial value for conservation planning purposes. Our objective was to develop spatially explicit models describing the occurrence and abundance of small mammal species in the Wyoming Basins Ecoregional Assessment (WBEA) area (Ch. 1). We live-trapped small mammals throughout the WBEA area and used Geographic Information System (GIS) derived multi-scale habitat and anthropogenic disturbance metrics to relate species occurrence to landscape factors.

METHODS

Field Surveys

We conducted small mammal trapping surveys between 6 July and 2 September in 2005 and 2006 using a random subset of 7.29-ha survey blocks (n = 330; Ch. 4 for a full explanation of overall study design and site selection). We randomly selected survey blocks stratified by road-distance class to achieve a balanced sampling design; however, logistic constraints led to an unbalanced sample.

We used a three-day schedule for small mammal trapping. On day one, we walked to the center point of the survey block and selected a random direction for the first trapping transect (0.25-km long). We placed one Sherman live trap (23 x 8 x 9 cm; H. B. Sherman Traps, Inc., Tallahassee, Florida) every 10 m along the transect, in a shaded location, if possible. Traps were baited with peanut butter and rolled oats and were locked open using wooden popsicle sticks for the pre-bait period (one night). After the first transect was established, we moved 15 m to a random side (left or right) of the first transect and placed the second transect parallel to the first, using the same trap spacing. If a survey block was centered on a road, the starting point was moved to a randomly selected side of the road at the ecotone between the road and the road verge. We then selected a random direction <180° to avoid crossing roads.

On day two, we traveled to the next trap location and followed the procedures of day one for trap setting. In the evening we returned to the initial survey block location where traps had been pre-baited the previous night. We checked traps to ensure that they were baited, placed cotton in each trap for bedding, and set the traps.

On the morning of day three, we checked each trap line at the initial survey block, removed captured animals, identified individuals to species, and released each animal in place. Once animals were processed we collected traps and moved to the next sampling site and followed day one procedures for setting up the trap plots. In the evening we traveled back to the location where the traps had been pre-baited the previous night and followed protocols of day two. All trapping protocols were approved by the Animal Care and Use Committee (ACUC) of Boise State University (ACUC approval number 692-05-007).

Abundance Categories

We classified abundance levels according to three abundance classes for each species that met the criteria for abundance modeling, a minimum of 100 occurrences and an abundance metric (Ch. 4). Survey blocks with zero detections were categorized as absent. Histograms of survey blocks with counts > 0 were used to categorize survey blocks into two abundance classes (low and high) based on patterns in the frequency distribution.

Model Selection

Variables included in the model selection process included the standard candidate predictor set (Table 4.2) with the exclusion of mountain sagebrush (*A. tridentata* ssp. *vaseyana*), mean annual maximum temperature, precipitation, and three soil variables (pH, salinity, and available water capacity). We calculated descriptive statistics for all predictor variables within presence/absence or abundance classes for each species. We excluded predictor variables with <20 survey blocks within each abundance class with values > 0 and examined correlation of predictor variables prior to analysis (Ch. 4).

We followed a hierarchical multi-stage modeling approach (Ch. 4) assessing all model subsets using logistic, generalized ordered logistic, or count-based regression. We first examined scatter plots and histograms of sagebrush, NDVI, and abiotic variables to look for non-linearities and interactions. If visual inspection indicated a potential non-linearity or interaction, we included these terms in subsequent modeling steps. We used Akaike's Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002). We first evaluated each sagebrush and NDVI variable and identified circular moving window radius (extent) and combination of sagebrush and NDVI variables that had the strongest relationship with small mammal occurrence. We used these selected sagebrush/NDVI variables as a base model and tested the relationship between small mammal occurrence and vegetation, abiotic, and disturbance variables to identify the best spatial extent for each additional variable assessed using AIC_c values. We then allowed the best spatial extent for each variable to compete with all possible combinations of other variables within the same category to identify the AIC_c-selected best model. We limited the number of variables in all competing models to 10% of the sample size in the lowest frequency class due to sample size limitations in generalized ordered logistic and logistic regression models (Hosmer and Lemeshow 2000). After identifying the AIC_c-selected best model within vegetation, abiotic, and disturbance categories, we allowed the variables within these top models to compete both within and across submodels, to develop the best overall composite model, again retaining the sagebrush/NDVI base in all candidate models. In order to incorporate model uncertainty, we created a final composite model using the weighted average of coefficients from models with a cumulative AIC_c weight of just ≥ 0.9 (Burnham and Anderson 2002). Coefficients were set to zero when a model did not contain a particular variable. Accuracy of logistic regression models were evaluated with receiver operating characteristic (ROC) by estimating the area under the curve (AUC, Metz 1978). We determined an optimal cutoff threshold for predicting presence-absence of each species (i.e., habitat or non-habitat) using a sensitivity-specificity equality approach (Liu et al. 2005) and applied this threshold to assess the predictive capacity for each model (Nielsen et al. 2004). All statistical analyses were conducting using STATA 10.1 (Stata Corporation, College Station, Texas, USA).

Spatial Application and Dose Response

We predicted species occurrence in a GIS at a 90-m cell size using the final model coefficients in ArcGIS raster calculator (ESRI 2006). Final model predictions were binned into 10% probability classes for summary and display purposes. Masks of non-sagebrush habitats (areas <3% sagebrush habitat in a 5-km moving window) and those areas outside the known range of each species (Patterson et al. 2003) were used to exclude areas where predictions were either not possible for the species or where extrapolations occurred with high uncertainty. Probability of occurrence maps were subsequently converted to binary presence/absence maps based on the sensitivity-specificity equality threshold to maximize prediction success for each model (Liu et al. 2005). Where applicable, probability of occurrence output from generalized ordered logistic regression models were combined into a composite three class abundance surface, including absent, low, and high abundance. The bin breakpoint separating absent from low/high abundance habitat was based on the sensitivity-specificity equality threshold to maximize prediction success for each model in the ordered logistic process. Within low/high abundance habitat, the threshold was set where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. These maps allowed us to assess the proportion of the WBEA area containing habitat likely to support individuals (presence/absence) and, where data permitted, to separate occurrence into areas capable of supporting low versus high abundances of a species.

Following development of species models, we plotted predicted probability of occurrence relative to changes in sagebrush metrics to assess critical levels of sagebrush required for a species to be present and to characterize response to losses or fragmentation of sagebrush habitat. We calculated these values using the Dose Response Calculator for ArcGIS (Hanser et al. 2011). We used the optimal cut-off threshold to identify the sagebrush threshold value above which the species was likely to occur.

RESULTS

Field Surveys

We surveyed small mammals at 186 of 330 survey blocks (77 in 2005 and 109 in 2006), of which 59 (25 in 2005, 34 in 2006) were on-road survey blocks, 70 (29 in 2005 and 41 in 2006) were near-road (0–750 m) survey blocks, and 57 (23 in 2005 and 34 in 2006) were far-road (>750 m) survey blocks.

We captured 1,533 individuals over 9,300 total trap-nights and identified 15 species, including bushy-tailed woodrat (*Neotoma cinerea*), deer mouse (*Peromyscus maniculatus*), desert cottontail (*Sylvilagus audubonii*), golden-mantled ground squirrel (*Spermophilus lateralis*), Great Basin pocket mouse (*Perognathus parvus*), least chipmunk (*Tamias minimus*), montane vole (*Microtus montanus*), northern grasshopper mouse (*Onychomys leucogaster*), olive-backed pocket mouse (*Perognathus fasciatus*), Ord's kangaroo rat (*Dipodomys ordii*), sagebrush vole (*Lemmiscus curtatus*), thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*), Uinta ground squirrel (*Spermophilus armatus*), western harvest mouse (*Reithrodontomys megalotis*), and Wyoming ground squirrel (*Spermophilus elegans*) (Table 9.1). For 58 (31.2%) survey blocks, no small mammals were captured. The most common species was the deer mouse, occurring on 124 (66.6%) survey blocks and comprising 83% of all captures (Fig. 9.1). Average capture rate of deer mice across all survey blocks was 13.7 individuals per 100 trap nights. The second most common species captured was the least chipmunk, which occurred at 39 (21.0%) survey blocks, with 87 total captures (0.9 individuals per 100 trap nights). Both Ord's kangaroo rat and northern grasshopper mouse occurred on >20 survey blocks. The other 11 species were captured infrequently (30% captured only once). Only four sagebrush voles were captured.

Abundance Categories and Detection

The deer mouse was the only species for which we had a sufficient sample size (>50 occurrence survey blocks) to develop a species occurrence model (but see Ch. 7 for the least chipmunk). No apparent breaks were found in histograms of deer mouse abundance (Fig. 9.2). We therefore used a logistic regression modeling approach to model presence/absence. Count-based regression models were also avoided since we lacked data necessary to determine survey block-level capture probabilities.

Model Selection

We excluded four variables from the total pool of *a priori* predictor variables because they contained values > 0 on <20

TABLE 9.1. Summary of small mammal trapping during 6 July through 2 September of 2005 and 2006 including total individuals captured (number of occurrence survey blocks) by survey block type in the Wyoming Basins Ecoregional Assessment area.

Common name	Scientific name	On road	Near road	Far road	Total
Bushy-tailed woodrat	*Neotoma cinerea*	3 (2)	4 (3)	1 (1)	8 (6)
Deer mouse	*Peromyscus maniculatus*	391 (38)	490 (51)	393 (35)	1,274 (124)
Desert cottontail	*Sylvilagus audubonii*	0 (0)	1 (1)	0 (0)	1 (1)
Golden-mantled ground squirrel	*Spermophilus lateralis*	0 (0)	1 (1)	2 (1)	3 (2)
Great Basin pocket mouse	*Perognathus parvus*	0 (0)	1 (1)	0 (0)	1 (1)
Least chipmunk	*Tamias minimus*	27 (11)	29 (16)	31 (12)	87 (39)
Montane vole	*Microtus montanus*	0 (0)	3 (3)	0 (0)	3 (3)
Northern grasshopper mouse	*Onychomys leucogaster*	13 (9)	12 (7)	8 (8)	33 (24)
Olive-backed pocket mouse	*Perognathus fasciatus*	2 (1)	4 (4)	5 (5)	11 (10)
Ord's kangaroo rat	*Dipodomys ordii*	36 (9)	24 (7)	21 (4)	81 (20)
Sagebrush vole	*Lemmiscus curtatus*	0 (0)	2 (2)	2 (1)	4 (3)
Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*	4 (3)	9 (4)	8 (3)	21 (10)
Uinta ground squirrel	*Spermophilus armatus*	0 (0)	1 (1)	0 (0)	1 (1)
Western harvest mouse	*Reithrodontomys megalotis*	2 (1)	0 (0)	2 (1)	4 (2)
Wyoming ground squirrel	*Spermophilus elegans*	0 (0)	0 (0)	1 (1)	1 (1)

survey blocks. These variables were proportion of coniferous forest (0.27- and 0.54-km radii), mixed shrub (0.27 km), and riparian (0.27 km). Mean sagebrush patch size (1 km), slope, soil bulk density, and soil silt content were removed because of collinearity with other variables that were more biologically relevant.

The AIC_c-selected best sagebrush/NDVI model consisted of all big sagebrush (*A. tridentata*) within 0.27 km ($ABIGSAGE_{270}$) and a non-linear quadratic form of NDVI within 0.27 km ($NDVI_{270}$ * $NDVI_{270}^2$) (Table 9.2). The other 19 models with $\Delta AIC_c \leq 2$ contained local measures of sagebrush in combination with NDVI in quadratic form, as well as sagebrush/NDVI interactions. Within a 0.27-km radius, there was 3.5% more all big sagebrush habitat at absent survey blocks (80.7%, SE = 2.3) than at presence survey blocks (77.14%, SE = 2.1) (Appendix 9.1).

After assessing individual multi-scale covariates (Table 9.3) and developing submodels, the AIC_c-selected vegetation submodel for deer mice included grassland within 18 km ($GRASSLAND_{18km}$), mixed shrubland within 5 km (MIX_{5km}), and all sagebrush contagion within 3 km ($CONTAG_{3km}$), in addition to the sagebrush/NDVI base model (Table 9.4). Soil clay content (CLAY) in quadratic form and 1-km distance decay from intermittent water ($iH2Od_{1km}$) were selected as important abiotic predictors of deer mouse occurrence (Table 9.4). Only one disturbance factor, 1-km distance decay from pipelines

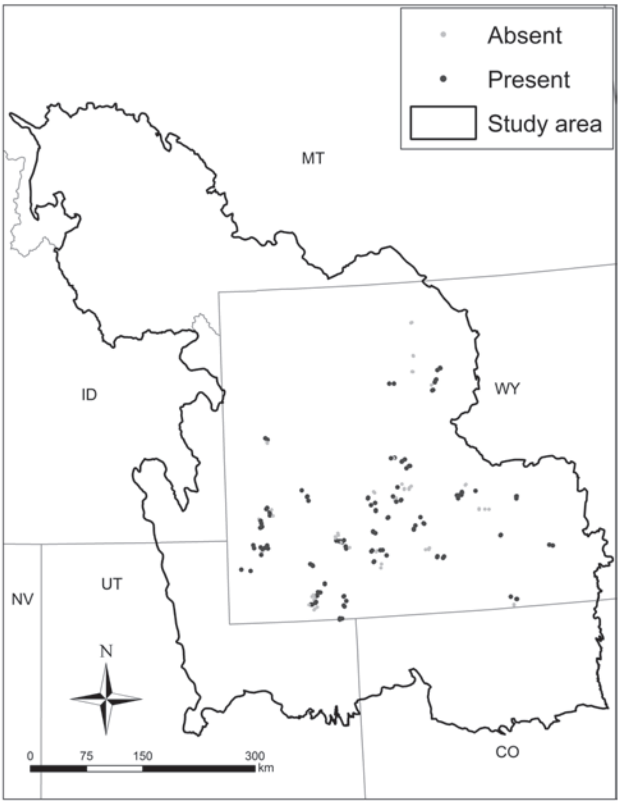

FIG. 9.1. Distribution of survey blocks surveyed for deer mice within the Wyoming Basins Ecoregional Assessment area. Survey blocks were designated as absent (black, zero detections) or present (gray) for model development.

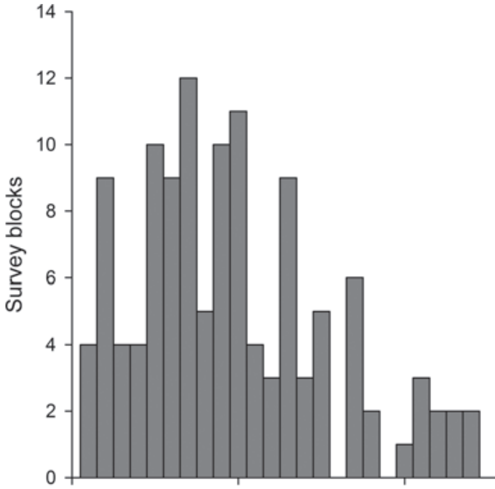

FIG. 9.2. A histogram of 124 survey blocks surveyed for deer mice in the Wyoming Basins Ecoregional Assessment area where number of individuals was > 0. Abundance at each survey block is represented by total number of individuals captured.

TABLE 9.2. Results of AIC_c-based model selection for deer mouse occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI variables; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta\text{AIC}_c \leq 2$ are shown.

Number	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$\text{ABIGSAGE}_{270} + \text{NDVI}_{270} + \text{NDVI}_{270}^2$	-111.56	4	231.34	0.00	0.04
2	$\text{ALLSAGE}_{270} + \text{NDVI}_{270} + \text{NDVI}_{270}^2$	-111.59	4	231.39	0.05	0.04
3	$\text{ABIGSAGE}_{270} + \text{NDVI}_{540} + \text{NDVI}_{540}^2$	-111.62	4	231.46	0.11	0.04
4	$\text{ALLSAGE}_{270} + \text{NDVI}_{540} + \text{NDVI}_{540}^2$	-111.62	4	231.47	0.13	0.04
5	$\text{ABIGSAGE}_{270} + \text{NDVI} + \text{NDVI}^2$	-111.86	4	231.94	0.60	0.03
6	$\text{ALLSAGE}_{270} + \text{NDVI} + \text{NDVI}^2$	-111.91	4	232.03	0.69	0.03
7	$\text{BIGSAGE}_{270} + \text{NDVI}_{270} + \text{BIGSAGE}_{270}\text{\_NDVI}_{270}$	-112.16	4	232.54	1.19	0.02
8	$\text{ALLSAGE}_{540} + \text{NDVI}_{270} + \text{NDVI}_{270}^2$	-112.19	4	232.60	1.25	0.02
9	$\text{ASAGE}_{540} + \text{NDVI}_{540} + \text{NDVI}_{540}^2$	-112.20	4	232.63	1.29	0.02
10	$\text{ABIGSAGE}_{540} + \text{NDVI}_{270} + \text{NDVI}_{270}^2$	-112.24	4	232.69	1.35	0.02
11	$\text{ALLSAGE}_{270} + \text{NDVI}_{1km} + \text{NDVI}_{1km}^2$	-112.24	4	232.71	1.37	0.02
12	$\text{ABIGSAGE}_{270} + \text{NDVI}_{1km} + \text{NDVI}_{1km}^2$	-112.26	4	232.73	1.39	0.02
13	$\text{ABIGSAGE}_{540} + \text{NDVI}_{540} + \text{NDVI}_{540}^2$	-112.26	4	232.74	1.40	0.02
14	$\text{BIGSAGE}_{270} + \text{NDVI} + \text{BIGSAGE}_{270}\text{\_NDVI}$	-112.31	4	232.84	1.50	0.02
15	$\text{BIGSAGE}_{270} + \text{NDVI}_{540} + \text{BIGSAGE}_{270}\text{\_NDVI}_{540}$	-112.32	4	232.87	1.52	0.02
16	$\text{BIGSAGE}_{270} + \text{NDVI}_{270} + \text{NDVI}_{270}^2$	-112.37	4	232.95	1.61	0.02
17	$\text{ALLSAGE}_{540} + \text{NDVI} + \text{NDVI}^2$	-112.47	4	233.16	1.81	0.02
18	$\text{BIGSAGE}_{270} + \text{NDVI} + \text{NDVI}^2$	-112.47	4	233.16	1.82	0.02
19	$\text{ABIGSAGE}_{540} + \text{NDVI} + \text{NDVI}^2$	-112.50	4	233.23	1.88	0.02

[a] Variable definitions provided in Table 4.2

(PIPE_{1km}), was included in the AIC_c-selected disturbance submodel (Table 9.4).

The AIC_c-selected top deer mouse model was a combination of vegetation, abiotic, and disturbance factors. Deer mice were positively associated with moderate vegetation productivity, increased proportion of grassland land cover, and increased contagion of all sagebrush, but negatively associated with small-spatial extent of all big sagebrush and proximity to pipelines (Table 9.5). However, weight of evidence for the top model was low ($w_i = 0.14$), indicating there were other suitable candidate models. Variables in the other 15 candidate models with a cumulative Akaike weight of just ≥ 0.9 showed that, in addition to factors in the top model, deer mouse occurrence was positively associated with proximity to intermittent water but negatively associated with mixed shrubland and increased soil clay content (Table 9.5). The final composite probability of occurrence model is below.

$$\text{Prob} = 1 / (1 + (\exp(-(-3.96 - 2.20 * \text{ABIGSAGE}_{270} + 32.75 * \text{NDVI}_{270} - 41.77 * \text{NDVI}_{270}^2 + 5.87 * \text{GRASS}_{18km} + 0.02 * \text{CONTAG}_{3km} - 0.60 * \text{PIPE}_{1km} - 17.48 * \text{MIX}_{5km} + 0.87 * \text{iH2Od}_{1km} - 0.06 * \text{CLAY} + 0.0026 * \text{CLAY}^2)))) \tag{9.1}$$

The composite model of deer mouse occurrence had good accuracy (ROC AUC = 0.79) when predicting deer mouse presence.

TABLE 9.3. Evaluation statistics from AIC_c-based univariate model selection for deer mouse occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). All logistic regression models included all big sagebrush (0.27-km radius) and the quadratic form of NDVI (0.27-km radius) as the base model for all variables tested. We used AIC_c to identify the scale at which deer mice respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{5km}$	-110.83	5	232.00	0.00	0.33
	$CFRST_{18km}$	-110.99	5	232.31	0.32	0.28
	$CFRST_{1km}$	-111.16	5	232.66	0.67	0.23
	$CFRST_{3km}$	-111.55	5	233.43	1.44	0.16
	$GRASS_{18km}$	-109.85	5	230.02	0.00	0.52
	$GRASS_{3km}$	-111.48	5	233.29	3.26	0.10
	$GRASS_{5km}$	-111.52	5	233.37	3.35	0.10
	$GRASS_{1km}$	-111.54	5	233.40	3.38	0.10
	$GRASS_{270}$	-111.55	5	233.44	3.41	0.09
	$GRASS_{540}$	-111.56	5	233.45	3.43	0.09
	MIX_{5km}	-108.24	5	226.81	0.00	0.63
	MIX_{3km}	-109.71	5	229.74	2.93	0.14
	MIX_{1km}	-110.13	5	230.60	3.79	0.09
	MIX_{18km}	-110.25	5	230.83	4.02	0.08
	MIX_{540}	-110.78	5	231.90	5.09	0.05
	RIP_{3km}	-109.97	5	230.27	0.00	0.36
	RIP_{1km}	-110.32	5	230.97	0.70	0.25
	RIP_{5km}	-110.44	5	231.21	0.94	0.22
	RIP_{18km}	-111.44	5	233.21	2.94	0.08
	RIP_{540}	-111.47	5	233.27	3.00	0.08
	$CONTAG_{3km}$	-108.85	5	228.04	0.00	0.42
	$EDGE_{3km}$	-109.63	5	229.59	1.56	0.19
	$CONTAG_{5km}$	-109.90	5	230.13	2.10	0.15
	$PATCH_{5km}$	-109.97	5	230.27	2.24	0.14
	$EDGE_{5km}$	-111.32	5	232.97	4.93	0.04
	$EDGE_{1km}$	-111.53	5	233.39	5.35	0.03
	$PATCH_{3km}$	-111.53	5	233.40	5.36	0.03
	$SALT_{18km}$	-110.40	5	231.14	0.00	0.29
	$SALT_{5km}$	-110.68	5	231.41	0.27	0.25
	$SALT_{3km}$	-110.91	5	232.16	1.02	0.17
	$SALT_{270}$	-111.37	5	233.07	1.93	0.11
	$SALT_{540}$	-111.50	5	233.34	2.20	0.09
	$SALT_{1km}$	-111.55	5	233.43	2.29	0.09

TABLE 9.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Abiotic	CLAY[b]	-105.92	6	224.23	0.00	0.79
	CLAY	-108.25	5	226.89	2.66	0.21
	CTI[b]	-109.44	6	231.29	0.00	0.72
	CTI	-111.38	5	233.16	1.87	0.28
	ELEV[b]	-109.20	6	230.81	0.00	0.63
	ELEV	-110.75	5	231.90	1.09	0.37
	$iH2Od_{1km}$[c]	-108.14	5	226.60	0.00	0.84
	$iH2Od_{500}$[c]	-110.05	5	230.43	3.83	0.12
	$iH2Od_{250}$[c]	-111.24	5	232.82	6.21	0.04
	$pH2Od_{1km}$[c]	-111.39	5	233.12	0.00	0.36
	$pH2Od_{500}$[c]	-111.50	5	233.33	0.21	0.32
	$pH2Od_{250}$[c]	-111.51	5	233.36	0.24	0.32
	$SOIL_{cm}$	-110.99	5	232.38	0.00	1.00
	SAND	-111.40	5	233.19	0.00	0.70
	SAND[b]	-111.23	6	234.86	1.67	0.30
	SOLAR	-111.51	5	233.42	0.00	0.52
	SOLAR[b]	-110.57	6	233.54	0.12	0.48
	Tmin	-109.97	5	230.34	0.00	0.73
	Tmin[b]	-109.95	6	232.30	1.96	0.27
	TRI_{3km}	-111.31	5	233.00	0.00	0.17
	TRI_{270}	-111.46	5	233.31	0.31	0.15
	TRI	-111.47	5	233.32	0.32	0.15
	TRI_{1km}	-111.51	5	233.41	0.41	0.14
	TRI_{18km}	-111.55	5	233.48	0.48	0.13
	TRI_{540}	-111.56	5	233.51	0.51	0.13
	TRI_{5km}	-111.56	5	233.51	0.51	0.13
Disturbance	AG_{1km}[c]	-111.91	5	234.16	0.00	0.38
	AG_{250}[c]	-112.11	5	234.55	0.40	0.31
	AG_{500}[c]	-112.14	5	234.62	0.47	0.30
	$MjRD_{1km}$[c]	-110.85	5	232.04	0.00	0.53
	$MjRD_{500}$[c]	-111.48	5	233.29	1.25	0.28
	$MjRD_{250}$[c]	-111.86	5	234.05	2.01	0.19
	$PIPE_{1km}$[c]	-109.65	5	229.63	0.00	0.41
	$PIPE_{500}$[c]	-109.76	5	229.84	0.21	0.37
	$PIPE_{250}$[c]	-110.31	5	230.96	1.33	0.21
	$POWER_{250}$[c]	-110.75	5	231.84	0.00	0.45

TABLE 9.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$POWER_{500}{}^{c}$	-111.20	5	232.74	0.90	0.29
	$POWER_{1km}{}^{c}$	-111.29	5	232.91	1.07	0.26
	$RDdens_{18km}$	-111.53	5	233.38	0.00	0.17
	$RDdens_{540}$	-111.78	5	233.89	0.51	0.13
	$RDdens_{5km}$	-111.94	5	234.22	0.84	0.11
	$2RD_{500}{}^{c}$	-111.95	5	234.23	0.85	0.11
	$2RD_{1km}{}^{c}$	-111.97	5	234.27	0.88	0.11
	$2RD_{250}{}^{c}$	-111.98	5	234.30	0.92	0.11
	$RDdens_{3km}$	-112.08	5	234.50	1.12	0.10
	$RDdens_{1km}$	-112.15	5	234.64	1.26	0.09
	$RDdens_{270}$	-112.15	5	234.64	1.26	0.09
	$WELL_{500}{}^{c}$	-112.15	5	234.35	0.00	0.37
	$WELL_{250}{}^{c}$	-112.15	5	234.64	0.29	0.32
	$WELL_{1km}{}^{c}$	-112.15	5	234.64	0.30	0.32

[a] Variable definitions provided in Table 4.2

[b] Quadratic function (variable + variable^2)

[c] Distance decay function ($e^{(\text{Euclidean distance from feature/-distance parameter})}$)

Accuracy of the model-averaged predictor was an improvement over the AIC_c-selected top model (ROC AUC = 0.74). Our model of deer mouse occurrence had an optimal sensitivity-specificity equality threshold of 0.68 when determining presence/absence that resulted in 71.0% of survey block locations being correctly classified.

Spatial Application, Dose Response, and Model Evaluation

Deer mouse occurrence was predicted throughout the WBEA area (Fig. 9.3). Based on our optimal cutoff point and a binary presence/absence classification, 180,321 km^2 (52.5%) of suitable deer mouse habitat was predicted within the Wyoming Basins (Fig. 9.4). Deer mice were more likely to occur in areas with >41% (entire range at +1 SD) all big sagebrush habitat within a 0.27 km (Fig. 9.5). Independent data were not available for evaluating the output of this model.

DISCUSSION

The small mammal community in the WBEA area was dominated by deer mice with predicted suitable habitat occurring throughout the region. Deer mice are habitat generalists and commonly are the most abundant small mammal species (Reynolds 1980, Morris 1992, Hanser and Huntly 2006, Borchgrevink et al. 2010). Despite this generalist nature, our model identifies several habitat, abiotic, and anthropogenic disturbance characteristics that influence the distribution of deer mice.

Importance of the quantity of sagebrush habitat to distribution of deer mice in the region was unclear. Although the regression coefficient was negative, our dose response analysis indicated that deer mice were more likely to occur in habitats with more than 41% all big sagebrush within 0.27 km, once all other factors were considered. Previous research has found both indifference and attraction to shrublands;

deer mouse abundance did not change in response to sagebrush removal (Parmenter and MacMahon 1983), but deer mice have an affinity for shrubland habitat showing increased abundance in sagebrush and other shrubland types (Feldhamer 1979, Reynolds 1980), preferentially foraging under shrubs (Kotler 1984).

Deer mice were positively associated with grasslands and sagebrush contagion. Although these results seem contradictory, these patterns also can be complementary. As grassland land cover increases, the distribution of sagebrush/non-sagebrush land cover patches may have a more clumped distribution across the landscape. The patches of sagebrush may act as refugia during times of disturbance in the surrounding landscape (Hanser and Huntly 2006). Deer mice were also positively associated with moderate habitat productivity (NDVI) and intermittent water sources. In the Great Basin, deer mice are three times more abundant in lowland meadows than in drier, less productive upland habitats (McAdoo et al. 1986), and in New Mexico deer mice are more abundant in arroyos (Jorgensen et al. 1998). Lowland mixed shrubland habitats, dominated by rabbitbrush (*Chrysothamnus* spp.) and other mixed shrubs with low cover of forbs and grasses, are generally less productive sites and therefore, owing to reduced food resources, may not support high densities of deer mice. We found a negative, nonlinear relationship between deer mouse occurrence and percent clay content in soils. Deer mice construct deep, long, and complex burrows in soils with increasing clay content (Laundré and Reynolds 1993). This increased effort for burrow construction may be a response to lack of sufficient above ground cover or other environmental characteristics.

The negative association of deer mice with proximity to pipelines may be due to the altered plant community along pipeline rights-of-way. Alterations can be quite substantial locally, given that pipe-

TABLE 9.4. Results of AIC_c-based submodel selection for deer mouse occurrence in the Wyoming Basins Ecoregional Assessment Area. Log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i) are shown for each model with $\Delta AIC_c \leq 2$.

Category	Number	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + GRASS_{18km} + MIX_{5km} + CONTAG_{3km}$	-102.09	7	218.81	0.00	0.35
	2	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + GRASS_{18km} + RIP_{3km} + CONTAG_{3km}$	-102.31	7	219.24	0.43	0.28
Abiotic	1	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + CLAY + CLAY^2 + iH2Od_{1km}$	-102.54	7	219.72	0.00	0.47
Disturbance	1	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + PIPE_{1km}$	-108.71	5	227.75	0.00	0.12
	2	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + PIPE_{1km} + RDdens_{18km}$	-107.71	6	227.89	0.15	0.11
	3	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + MjRD_{1km} + PIPE_{1km} + RDdens_{18km}$	-107.38	7	229.38	1.63	0.05
	4	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + PIPE_{1km} + POWER_{250}$	-108.50	6	229.47	1.72	0.05
	5	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + PIPE_{1km} + POWER_{250} + RDdens_{18km}$	-107.43	7	229.50	1.75	0.05
	6	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + MjRD_{1km} + PIPE_{1km}$	-108.55	6	229.58	1.83	0.05
	7	$ABIGSAGE_{270} + NDVI_{270} + NDVI_{270}^2 + PIPE_{1km} + RDdens_{18km} + WELL_{500}$	-107.53	7	229.69	1.94	0.04

[a] Variable definitions provided in Table 4.2

TABLE 9.5. Results of AIC$_c$-based model selection for the combined deer mouse occurrence models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC$_c$], change in AIC$_c$ value from the top model [ΔAIC$_c$], and cumulative Akaike weight [Σw_i]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Number	Intercept	ABIGSAGE$_{270}$	NDVI$_{270}$	NDVI$_{270}^2$	GRASS$_{18km}$	CONTAG$_{3km}$	PIPE$_{1km}$
1	-5.26 (2.00)	-2.50 (1.10)	38.75 (11.03)	-49.69 (13.92)	15.46 (5.65)	0.03 (0.01)	-1.43 (0.58)
2	-5.43 (2.05)	-2.55 (1.10)	39.99 (11.32)	-51.13 (14.29)	14.54 (5.70)	0.03 (0.01)	
3	-4.11 (1.86)	-1.75 (0.89)	33.51 (10.49)	-43.17 (13.36)			-1.21 (0.56)
4	-4.12 (1.85)	-2.49 (1.05)	32.14 (10.57)	-40.47 (13.47)		0.02 (0.01)	
5	0.05 (1.94)	-2.78 (1.06)	19.37 (10.99)	-25.21 (13.72)		0.02 (0.01)	
6	-2.40 (2.06)	-1.62 (0.84)	23.15 (10.89)	-29.07 (13.60)			
7	-4.01 (1.85)	-2.57 (1.02)	31.68 (10.40)	-39.81 (13.21)		0.02 (0.01)	-1.41 (0.56)
8	-6.68 (2.08)	-2.31 (1.06)	39.89 (11.17)	-49.06 (14.09)	13.27 (5.74)	0.03 (0.01)	
9	-0.43 (1.93)	-1.63 (0.89)	20.57 (10.92)	-28.09 (13.66)			
10	-5.88 (2.03)	-1.32 (0.89)	38.37 (10.84)	-48.66 (13.74)	9.42 (5.24)		-1.53 (0.56)
11	-0.19 (1.93)	-1.80 (0.88)	22.42 (10.89)	-30.07 (13.61)			-1.17 (0.54)
12	-5.93 (2.07)	-1.30 (0.90)	39.07 (11.20)	-49.33 (14.20)	7.63 (5.24)		
13	-4.56 (1.83)	-1.66 (0.88)	34.33 (10.51)	-43.38 (13.39)			
14	-2.21 (1.70)	-2.83 (1.09)	29.77 (10.34)	-39.48 (13.21)		0.02 (0.01)	-1.09 (0.56)
15	-4.35 (1.83)	-1.79 (0.87)	33.53 (10.32)	-42.39 (13.11)			-1.38 (0.54)
16	-5.87 (2.02)	-2.61 (1.08)	40.60 (11.19)	-50.89 (14.12)	14.99 (5.73)	0.03 (0.01)	

[a] Variable definitions provided in Table 4.2

line construction activities result in ~25-m wide corridors with decreased shrub cover and increased grass cover that persists for years following construction (Booth and Cox 2009). Within the Wyoming Basins, the extensive distribution of pipelines (Knick et al. 2011) may have a broad negative influence on deer mice.

Deer mice serve many roles and are an important species shaping sagebrush ecosystem function (deGroot et al. 2002); understanding the factors influencing this species may increase our ability to manage conservation species of concern. Deer mice are frequent prey for reptilian predators such as gopher snakes (*Pituophis melanoleucus*) and western rattlesnakes (*Crotalus viridis*; Diller and Johnson 1988), avian predators such as burrowing owls (*Speotyto cunicularia*; Plumpton and Lutz 1993) and great horned owls (*Bubo virginianus*; Zimmerman et al. 1996), and mammalian predators, including coyotes (*Canis latrans*; Johnson and Hansen 1979). Deer mice predate avian nests in multiple ecosystems (Bayne and Hobson 1997, Rogers et al. 1997, Pietz and Granfors 2000). Deer mice consume large numbers of seeds (Everett et al. 1978, Kotler 1984), limit beetle abundance (Parmenter and MacMahon 1988) and may, in some cases, competitively exclude other small mammal species (Kotler 1984). Deer mice also serve as a reservoir for zoonotic diseases such as Hantavirus (Childs et al. 1994). Although we were unable to develop models of deer mouse abundance, our data suggest abundance varies widely across habitats. The large distribution and variable abundance of the species suggests that deer mice may play a significant role in overall ecosystem processes in the Wyoming Basins.

TABLE 9.5. Extended

MIX$_{5km}$	iH2Od$_{1km}$	CLAY	CLAY^2	LL	K	AIC$_c$	ΔAIC$_c$	$\sum w_i$
				-101.90	7	218.43	0.00	0.14
-40.14 (17.65)				-102.09	7	218.81	0.38	0.25
-38.76 (18.40)	1.79 (0.66)			-102.35	7	219.32	0.89	0.34
-41.39 (16.84)	1.64 (0.66)			-102.48	7	219.58	1.15	0.42
		-0.28 (0.17)	0.01 (0.01)	-102.51	7	219.66	1.22	0.49
	1.67 (0.66)	-0.19 (0.16)	0.01 (0.01)	-102.54	7	219.72	1.28	0.56
	1.72 (0.66)			-102.56	7	219.74	1.31	0.63
	1.37 (0.66)			-102.81	7	220.26	1.82	0.69
-40.94 (18.48)		-0.21 (0.16)	0.01 (0.01)	-103.04	7	220.72	2.28	0.73
	1.67 (0.65)			-103.15	7	220.92	2.49	0.77
		-0.27 (0.17)	0.01 (0.01)	-103.54	7	221.70	3.27	0.80
-43.16 (18.04)	1.57 (0.65)			-103.58	7	221.79	3.35	0.83
-43.08 (17.42)	1.69 (0.65)			-104.70	6	221.86	3.43	0.85
-36.04 (17.73)				-103.77	7	222.17	3.74	0.87
	1.75 (0.65)			-104.87	6	222.21	3.78	0.89
				-105.03	6	222.54	4.10	0.91

These numerous characteristics of deer mice highlight the interconnectedness of species in the sagebrush ecosystem and underscore the importance of increasing our understanding of factors influencing distribution and abundance of common species within the sagebrush ecosystem in addition to those species currently of conservation concern.

CONCLUSIONS

Our study is an illustration of the challenge that must be confronted when trying to develop models of small mammal occurrence across large spatial extents based on live-trapping. Prior to sampling, we estimated that using 350 traps we could sample up to 112 survey blocks (14 survey blocks per 10-day sample bout with four bouts per year for two years) using a one pre-bait and three trapping night protocol, 168 survey blocks (21 per sample bout) using two trapping nights, and 256 survey blocks (32 per sample bout) using one trapping night. If we were able to sample all potential survey blocks without logistical constraints using a three trapping night protocol, we would have needed to trap a species on >44% of survey blocks (>30% with two trapping nights and >20% with one trapping night) to obtain enough occurrence locations to model a given species. However, in order to build robust models, it was necessary to maximize the total number of survey block samples because of the high potential for species to be absent when sampling across habitat and anthropogenic disturbance gradients.

Our sampling strategy, although optimized to obtain enough samples to construct species models, constrained our

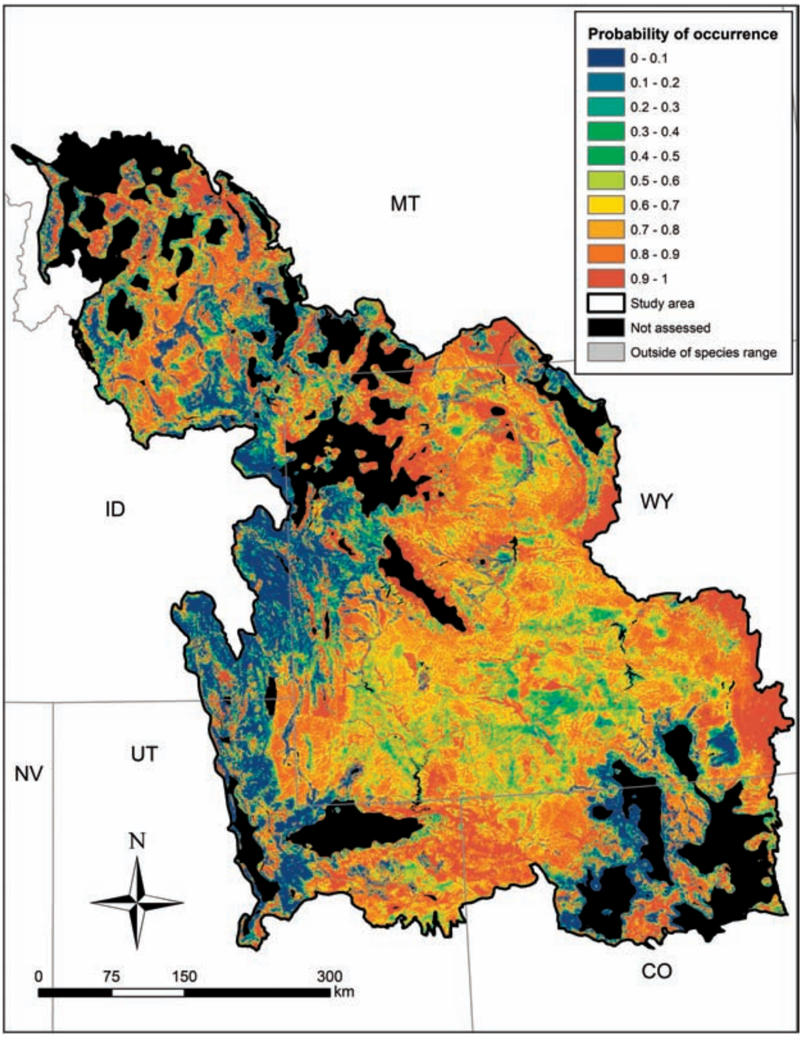

FIG. 9.3. Deer mouse probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Deer mice are likely to occur in areas with >0.68 probability.

ability to develop species-specific density or capture probability estimates. The inability to apply formal statistical analysis techniques forced us to compare our raw capture rates with studies in similar habitat types to assess whether we were achieving comparable capture rates to other studies. Our sampling technique was successful at achieving a higher deer mouse capture rate (13.69 individuals per 100 trap nights) than previous studies in Wyoming where the deer mouse capture rate in sagebrush was 0.55-1.73 individuals per 100 trap nights (Paramenter and MacMahon 1983); in Idaho capture rates range from 3.71 individuals per 100 trap nights on ungrazed sagebrush (Reynolds 1980) to 9.39 on isolated patches of sagebrush in agricultural fields (Hanser and Huntly 2006). Our capture rates for other species, such as least chipmunk (0.93 individuals per 100 trap nights), were similar to previous research

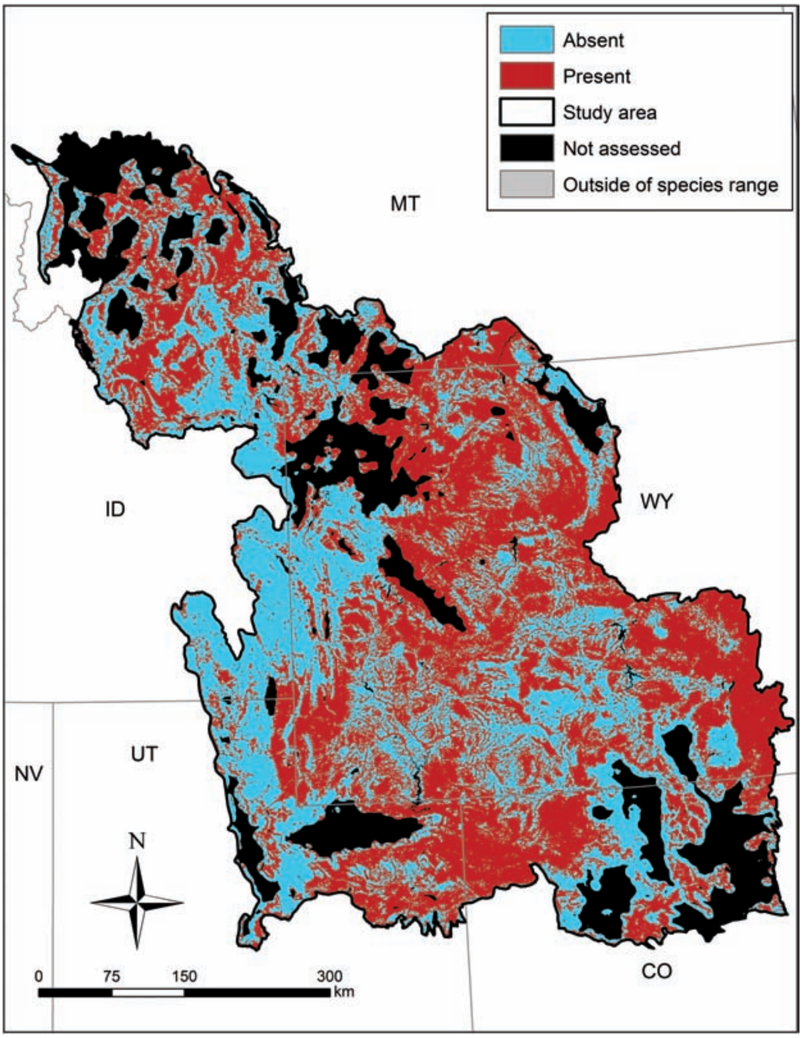

FIG 9.4. Distribution of deer mice in the Wyoming Basins Ecoregional Assessment area based on optimum probability cutoff threshold of 0.68. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

in Wyoming (0.67 individuals per 100 trap nights; Paramenter and MacMahon 1983). Although these comparisons indicate we were successful in trapping a species where it occurred, these comparisons are not a substitute for a formal analysis of detection probability, which would provide a measure of the potential for species to occur on plots where we did not detect it.

Factors that may have influenced our ability to detect individual small mammal species included trap shyness, density and distribution, and population cycling. Trap shyness is a situation in which certain species or individuals are prone to avoid traps, and avoidance may lead to false negative results from trapping surveys (Otis et al. 1978). One way to overcome this constraint would be to provide individuals enough time to become comfortable with the traps and begin to use the provided food resource; this could be achieved

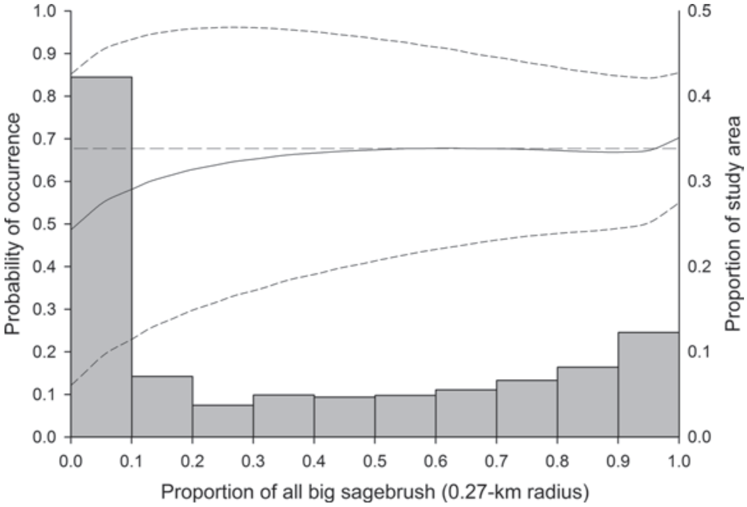

FIG. 9.5. The distribution of deer mouse probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata*) within a 0.27-km radius. Mean probability of occurrence (black line, ±1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 0.27-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.68), above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 0.27 km.

by increasing the length of time a site is trapped. Additional trapping techniques, such as pitfall or snap traps (Gitzen et al. 2001), which have a different mechanism for capture, may increase the likelihood of capture for species shy of Sherman or other live traps. In our case, we made the tradeoff to trap more locations rather than stay at a site, and we were limited to the use of Sherman live traps.

Low population density and clumped distributions influence species detectability. For instance, sagebrush voles have low population densities/capture rates, as well as clumped distributions. Capture rates are usually quite low throughout the range of the sagebrush vole (0.01-5.0 per 100 trap nights); the majority of sagebrush vole studies have capture rates on the low end this range (Dobkin and Sauder 2004). Low capture rates may require a more intense trapping (traps per survey block) to achieve detections of rare or low abundance species. Studies conducted in optimal habitats detected higher sagebrush vole capture rates (Millican and Keller 1986, O'Farrell 1975, Oldemeyer and Allen-Johnson 1988). Therefore, the habitat tolerance range for sagebrush voles may limit the ability for it and other species with similar characteristics to be sampled using random site selection and low intensity trapping.

Population cycling can also influence detectability and is a well-known characteristic of many mammal populations (Korpimäki et al. 2004), with causes ranging from increased food availability to favorable weather conditions. During low abundance periods of these cycles, species may be more difficult to detect. Also, seasonal activity patterns may lead to annual cycles of detectability for certain species. The timing of our trapping (July-September) coincided with the decreasing seasonal phase of activity for many small mammal species in the sagebrush system (O'Farrell 1974) and therefore may have limited our ability to detect some species.

We have demonstrated the challenge of designing and collecting the empirical data necessary to construct spatially explicit statistical models of small mammal distribution and abundance across large spatial extents. Even with a study design optimized for reducing logistical costs associated with sampling large spatial extents (Ch. 4), we were able to only obtain enough samples to model the most common species (but see Ch. 7 for the least chipmunk). Timing of surveys and number of nights available for trapping are important factors in planning field operations if conducting a large multi-taxa effort similar to the WBEA. To adequately sample small mammals at large spatial extents the necessary resources include (1) time to visit a large number of sample locations with multiple nights at each location and (2) a large enough quantity of traps necessary to run multiple crews/survey blocks simultaneously. Future landscape-scale research on small mammal distributions would benefit from additional resources devoted specifically to small mammal sampling.

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APPENDIX 9.1.

Descriptive statistics for explanatory variables used to model deer mouse occurrence. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

Sagebrush Ecosystem Conservation and Management: 357–386, 2011

Chapter 10: Occurrence of Non-Native Invasive Plants: The Role of Anthropogenic Features

Scott E. Nielsen, Cameron L. Aldridge, Steven E. Hanser, Matthias Leu, and Steven T. Knick

Abstract. The invasion of non-native plants in the Wyoming Basins Ecoregional Assessment (WBEA) area is a major economic and ecological stress, with invasions thought to be hastened by energy developments. Given the potential impacts of non-native invasive plants and the rapid changes in land use in the WBEA, broad-scale assessments and predictive models of non-native invasive plant distribution are needed. Using this information, the current extent of populations for targeting treatment and monitoring can be identified, the habitat affinities for forecasting where weeds may establish next determined, and the responses to individual human disturbances (such as energy developments) predicted. To address these needs, we conducted vegetation surveys across the WBEA area at 317 individual survey blocks (five plots per survey block) during the summers of 2005 and 2006. Survey blocks were stratified by both human disturbance and habitat productivity; in each of five plots per survey block the occurrence of 23 common non-native invasive plants was recorded during early and late season surveys. Here, we report on the four most common invasive plants, crested wheatgrass (*Agropyron cristatum*), cheatgrass (*Bromus tectorum*), halogeton (*Halogeton glomeratus*), and Russian thistle (*Salsola* spp.). Occurrence models were generated for each species using random-effects logistic regression to account for nesting of plots within sample sites. Predictors of occupancy included local habitat, abiotic condition, and distance to anthropogenic features. Although occurrences of all four invasive plants were affected by habitat, abiotic, and anthropogenic factors, cheatgrass and Russian thistle were most strongly associated with anthropogenic disturbance, primarily major roads and energy well sites. We assessed relationships between environmental and anthropogenic predictors and species occurrences to identify the major factors affecting current species distribution, examined shape of the response in occurrence in relation to proximity to individual anthropogenic disturbances, and provided spatial predictions of the locations where invasive plants are most likely to occur.

Key words: cheatgrass, crested wheatgrass, energy development, exotic species, halogeton, occurrence, Russian thistle, sagebrush, species distribution, Wyoming.

Energy developments in Colorado, Montana, Utah, and especially Wyoming are largely associated with the sagebrush (*Artemisia* ssp.) ecosystem, a common interior western United States vegetation type named for the dominant shrub species, big sagebrush (*A. tridentata*). Many wildlife species, including pygmy rabbit (*Brachylagus idahoensis*) and greater sage-grouse (*Centrocercus urophasianus*), depend on sagebrush (Green and Flinders 1980, Connelly et al. 2011) and are threatened by the loss and fragmentation of sagebrush habitat (Connelly et al. 2000, Hanser and Huntly 2006, Walker et al. 2007, Aldridge et al. 2008, Doherty et al. 2008). Linear access and transmission corridors associated with energy development also provide preferred habitat and migration corridors for non-native invasive plant species (Bergquist et al. 2007).

In fact, roads and vehicle traffic now provide one of the most effective conduits for non-native plant dispersal, with transport of seed or plant parts on tires/mud and movement of seed through vehicle-related air turbulence being common (Gelbard and Belnap 2003, Davies and Sheley 2007, von der Lippe and Kowarik 2007). As example, in three road tunnels in Berlin, Germany, seed rain due to vehicle transport represented 12.5% of the total flora (197 of 1,606 species; 50% of which were exotics), demonstrating the significance of vehicle-mediated dispersal of plants (von der Lippe and Kowarik 2007). As a consequence of increased plant dispersal, as well as the disturbed nature of road edges, road right-of-ways are often dominated by non-native invasive plants threatening adjacent native habitats (Parendes and Jones 2000, Gelbard and Belnap 2003). With 20% of the continental United States within 127 m of a road and 83% within 1,061 m of a road (Riitters and Wickham 2003), the majority of U.S. lands are threatened by non-native invasive plants. In fact, invasive weeds are estimated to occupy 188,000 km^2 and have an annual spread rate of 8-12% on U.S. federal lands (U.S. Government Accountability Office 2005).

As non-native invasive plants spread into native habitats, they alter ecosystem function (Brooks et al. 2004), with the sagebrush ecosystem being particularly sensitive. Cheatgrass (*Bromus tectorum*) invasions of sagebrush habitats have resulted in dramatic reductions in fire return intervals from historic intervals of 30 to 100 years, or even much longer (centuries), to less than five years following cheatgrass invasion (Whisenant 1990, Baker 2006). At this fire frequency, the defining structural element of the ecosystem – sagebrush – is lost and replaced instead by annual grasses, predominately cheatgrass (Mack 1981, Whisenant 1990, Brooks et al. 2004, Baker 2006). Not surprisingly, the loss of this sagebrush structure and food resource results in cascading losses to sagebrush-obligate species (Knick et al. 2003, Knick et al. 2008).

In addition to major ecological changes, non-native invasive species also cause significant economic damage. Pimentel et al. (2005) estimated that invasive species result in annual economic damages of $138 billion, with $5 billion spent annually on invasive species control and annual forage loss on pastures estimated at $1 billion. Because energy developments are the major source of new roads and, more generally, surface disturbances favored by invasive plants within the sagebrush ecosystem, it is not surprising that energy developments in the sagebrush ecosystem are a major concern for western ranchers, with losses in forage occurring both through direct disturbance (loss of range) or indirectly through invasion by non-native plants into pastures adjacent to energy developments.

Despite these threats, there is no regionally consistent source of information describing where non-native invasive species are most likely to occur across the Wyoming Basins Ecoregional Assessment (WBEA) area or how environmental factors and/or types of human disturbance, such as energy developments, hasten invasions by non-native plants in the sagebrush ecosystem. Understanding these relationships and mapping these threats will inform management of invasive plants in the WBEA area and thus improve our ability to maintain the economic and ecological health of sagebrush ecosystem. Our objectives were two-fold: (1) evaluate the effects of environmental conditions (e.g., habitats and abiotic factors [e.g., climate, topography, and soils]) and anthropogenic stressors on the presence-absence of non-native invasive plants measured at field sites across the WBEA; and (2) to predict (map) probable habitat (occurrence) for non-native invasive plants across the WBEA area to assist with land use planning, decision-making, and prioritization of management actions. For this assessment we chose the following four invasive plant species because they were common throughout the WBEA area: (1) crested wheatgrass (*Agropyron cristatum*), (2) cheatgrass, (3) halogeton (*Halogeton glomeratus*), and (4) Russian thistle (*Salsola* spp.).

METHODS

Field Surveys

Vegetation sampling was completed in 2005 and 2006 at 317 survey blocks located across the WBEA area (Ch. 4). Survey blocks measured 270 m by 270 m (7.29 ha) with five 20-m radius (1,257 m^2) plots systematically located in the survey block at 45º, 135º, 225º, and 315º angles and at a 127.3-m distance from the survey block center resulting in 1,585 total plots. Each survey block was visited twice within a season (1 June – 2 July and 6 July – 2 September) in order to capture the phenology of plants and to reduce observer bias (observers were switched between sampling sessions).

Shrub, grass (non-native and native), and forb (non-native and native) cover was estimated using an ordinal rank scheme: 1 = ≤1%; 2 = 2–5%; 3 = 6–10%; 4 = 11–25%; 5 = 26–50%; 6 = 51–75%; and 7 = 76–100% (modified from Daubenmire 1959). In addition to shrub cover by species, the following estimates were measured in each plot: (1) live shrub canopy cover (total canopy cover of all shrub species combined); (2) dead shrub canopy cover (total, includes the dead portions of live shrubs and cover of shrubs that were 100% dead); (3) bare ground (including rocks, but not rocky outcrops); (4) litter, defined as dead biotic material on the ground (did not include standing dead shrub material, but included vegetation such as dead mats of phlox [*Phlox* spp.], dead grasses, etc.); (5) rocky outcrop (rocky structures projecting above the ground surface or large fields of boulders or very rocky areas [measured in five height classes: 0–10 cm, >10–25 cm, >25–50 cm, >50–75 cm, and >75 cm]); (6) native forb cover (total for all species combined, includes any native forbs for which cover was recorded separately in previous sampling); (7) non-native forb cover (includes any non-native forbs on our list [Appendix 4.3] and non-native plants not on our list); (8) native grass cover (includes any native grasses for which cover was recorded separately in previous sampling); and (9) non-native grass cover (includes non-native grasses on our list and others not on the list [Appendix 4.3]). We also estimated percent cover for 20 target non-native invasive plant species (Appendix 4.3). Non-native invasive target species were selected based on discussions with staff from U.S. Bureau of Land Management (BLM) Field Offices throughout the study area, the Wyoming BLM State Invasive Weed Coordinator, our prior field experience, current state lists of invasive or noxious plants, and several publications that describe invasive plants in the sagebrush ecosystem or arid rangelands of the western U.S. (e.g., Pyke 2000).

Shrub height (live and dead) was measured at four cardinal directions along the periphery of each circle and at the center of each vegetation plot. For each measurement location, the height of the nearest live or dead shrub was measured within a 2-m circle (five vegetation plots per survey block, total height measurements per survey block = 25). Those sites containing no shrubs received a zero height score.

For tree species, the number of trees was counted according to four height classes: <1 m, >1–5 m, >5–8 m, and >8 m. For juniper (*Juniperus* spp.), we also assigned successional classes: (1) pre-settlement = old trees, (2) mixed = old and young trees, and (3) post-settlement = young trees.

We assessed plant community dominance within plots by ranking dominant species by class. Dominance was based on the percent canopy among all species present in the plot within that class (e.g., native forb, shrub). We recorded the name of the dominant shrub, native grass, native forb, exotic grass, and non-native forb, by species, for each plot. If no individual species was clearly dominant for that class of vegetation, we recorded the two co-dominant species. If dominants or co-dominants were not apparent, we noted that fact and did not assign a dominance rank to any species. A dominant native forb was listed only if cover exceeded 5%. Here we report on the occurrence of the four most common non-native invasive species – cheatgrass, crested wheatgrass, halogeton, and Russian thistle – encountered within the plots over the two seasonal periods (seasonal observations were combined).

Environmental and Anthropogenic Predictors of Invasive Plant Occurrence

To predict non-native invasive plant occurrence and to evaluate the responses of species to environmental and anthropogenic features, we used field plot measures of non-native invasive plant occurrence and a suite of common Geographic Information Systems (GIS) predictor variables consisting of vegetation productivity, distance to anthropogenic features, and abiotic environments (e.g., terrain-derived variables, soil characteristics, and climate). Unlike prior work in this volume, vegetation characteristics measured in field plots were used rather than from remote sensing products because direct measures of vegetation cover were made at the scale relevant to the plants being assessed. To thematically link these field measures to spatial data, we used the collected vegetation characteristics to classify each plot to the appropriate ecological system (Comer et al. 2003), the classification system used in the LANDFIRE existing vegetation type (LANDFIRE 2007) spatial dataset, and we applied the crosswalk used to reclassify the spatial data (Appendix 1.1) to label plots as either sagebrush or non-sagebrush. Vegetation productivity was measured as the maximum Normalized Difference Vegetation Index (NDVI) for the growing season (May through August) using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery (Carroll et al. 2006). Distances from anthropogenic disturbances were measured in a GIS for 10 feature types that included: agriculture (AG), communication towers (TOWER), oil-gas wells as of August 2005 (WELL), pipelines (PIPE), power lines (POWER), populated areas defined in year 2005 (POP), railroads (RAIL), secondary roads (2RD), major roads (MjRD), and all road types (RD). Both Euclidian distance and distance decay functions were used. Distance decay functions ($e^{(\text{Euclidean distance from feature (km)/-distance parameter})}$) with the distance parameter set at 0.05, 0.25, 0.5, 1, and 5 km (Nielsen et al. 2009) allowed for nonlinear responses of species to distance from anthropogenic features. Several terrain-derived variables were generated from a 90-m digital elevation model (DEM) including growing season (May to August) global solar radiation (SOLR, Area Solar Radiation Analysis, ESRI 2006), topographic relative moisture index (TRMI, Manis et al. 2001), and topographic ruggedness index (TRI, Riley et al. 1999).

We used the conterminous United States multilayer soil characteristics dataset (Miller and White 1998) to characterize soil information including: soil depth (SOIL_{cm}), available water content (AWC), salinity (SALIN), and percentages of sand (SAND) and clay (CLAY). Distance from perennial (pH2Od) water sources were estimated in a GIS from hydrological features and were also transformed into negative exponential decays using the same distance parameters used for the anthropogenic disturbance variables. Finally, mean annual minimum temperature (Tmin) was estimated from Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Group 2007).

Species Occurrence Modeling

Because plots were nested within survey blocks, we used a random-effects logistic regression model (survey block was used as a random effect to account for non-independence of plots) using the XTLOGIT command in STATA 10.1 (Stata Corporation, College Station, TX) to estimate the probability of occurrence for each of the four non-native invasive plant species. Predictors included local habitat, abiotic, and anthropogenic factors. Because we lacked knowledge about specific responses of species to anthropogenic disturbances, as well as appropriate extents for assessing habitat conditions, we refrained from using an *a priori* model building and assessment approach (Burnham and Anderson 2002). Instead, we modeled species occurrences using a multi-stage hierarchical design reflecting the three major groupings of factors influencing occupancy of our four selected invasive plants: habitat effects (sagebrush and NDVI), abiotic effects (climate, soils, and terrain), and human disturbance effects (roads, railroads, well-pads, etc.). Sub-models were developed individually for each major group and combined into a final composite model by assessing all possible combinations of variables chosen in sub-models and ranking models using Akaike's Information Criterion (AIC) to penalize for complexity.

First, to account for the fact that two habitat variables were originally used for stratification of survey blocks, a single 'base' model was selected using AIC from models containing either sagebrush, NDVI (including a quadratic term), or sagebrush and NDVI variables (note that interaction terms were not assessed due to difficultly in interpretation). The top ranked base model then was carried forward for inclusion in each of the three sub-models and the final composite model. Total number of model variables considered for each species was limited to a ratio of one variable per ten occurrences (e.g., 10 variables if found in 100 plots). To determine which factors to include within each sub-model, univariate models (including hypothesized quadratic terms) were fit for all variables and multicollinearity among variables assessed using Spearman rank (Rho) correlations. The final model was selected from the set of composite models based on all combinations of the sagebrush-NDVI base model and the variables from the AIC-best abiotic and anthropogenic disturbance sub-models. To incorporate model uncertainty, weighted-average coefficients (Burnham and Anderson 2002) were estimated from top-ranked composite models having a cumulative AIC weight (w_i) of just ≥ 0.9. Coefficients were set to zero when a model did not contain a particular variable. Model accuracy was assessed using a receiver operating characteristic (ROC) area under the curve (AUC) estimate (Metz 1978).

Model Predictions

We predicted species occurrence using the final model coefficients in our GIS at a 90-m cell size (0.81 ha) using ArcGIS 9.3 raster calculator (ESRI 2006) and displayed final model predictions in 10% probability classes. When sagebrush was a variable in the final model, the all sagebrush (*Artemisia* spp.; ALLSAGE) spatial dataset (Ch. 4) was used as a substitute for the field-derived sagebrush variable to facilitate spatial extrapolation of the statistical model. To prevent predictions in high-elevation conifer forests or alpine vegetation where we did not sample (study design was focused on sagebrush vegetation) and would not expect similar responses, we masked areas having <3% of the landscape dominated by sagebrush vegetation within a 5-km radius moving window. To examine responses in occurrence to selected anthropogenic disturbances, we calculated the mean predicted species occurrence by distance classes using the Dose Response Calculator for ArcGIS (Hanser et al. 2011) and interpreted this as a dose-response function. We also estimated risk ratios using mean map predictions at or adjacent to an anthropogenic disturbance in comparison to distant locations for exponential decay distance variables (risk ratios = $p_{0\text{m}}/p_{\text{far}}$) or a 1-km distance for Euclidean distance variables (risk ratios = $p_{0\text{m}}/p_{1\text{km}}$).

TABLE 10.1. Summary of invasive plant detections in the Wyoming Basins Ecoregional Assessment area at the plot sample level within survey blocks stratified to on-road, near-road, or far-road classes. Number of occurrences reported by species and frequency of detection in parentheses. Total plots per stratum reported under stratum name. Refer to Appendix 4.3 for a list of sampled species.

Common name	Scientific name	On-road (n = 590)	Near-road (n = 510)	Far-road (n = 485)	Total (n = 1,585)
Russian knapweed	*Acroptilon repens*	0 (0%)	1 (0.2%)	0 (0%)	1 (0.1%)
Crested wheatgrass	*Agropyron cristatum*	39 (7.6%)	30 (5.1%)	14 (2.9%)	83 (5.2%)
Cheatgrass	*Bromus tectorum*	76 (14.9%)	80 (13.6%)	58 (12%)	214 (13.5%)
Whitetop	*Cardaria draba*	0 (0%)	0 (0%)	1 (0.2%)	1 (0.1%)
Curveseed bitterwort	*Ceratocephala testiculata*	9 (1.8%)	5 (0.8%)	0 (0%)	14 (0.9%)
Canada thistle	*Cirsium arvense*	13 (2.5%)	1 (0.2%)	7 (1.4%)	21 (1.3%)
Halogeton	*Halogeton glomeratus*	51 (10%)	51 (8.6%)	28 (5.8%)	130 (8.2%)
Perennial pepperweed	*Lepidium latifolium*	1 (0.2%)	0 (0%)	0 (0%)	1 (0.1%)
Russian thistle	*Salsola* spp.	40 (7.8%)	37 (6.3%)	8 (1.6%)	85 (5.4%)
Tumble mustard	*Sisymbrium altissimum*	4 (0.8%)	10 (1.7%)	1 (0.2%)	15 (0.9%)
Tamarisk	*Tamarix ramosissima*	1 (0.2%)	0 (0%)	1 (0.2%)	2 (0.1%)

RESULTS

Crested Wheatgrass

Crested wheatgrass was found at 5.2% of sampled plots (n = 83), with frequency of occurrence highest in the on-road stratum at 6.6% of sites (Table 10.1). Of the two top-supported AIC models ($\Delta AIC \leq 2$), crested wheatgrass was explained by one survey design habitat variable, three abiotic factors, and four anthropogenic factors (Table 10.2). For the habitat-based survey design factor, crested wheatgrass was more likely to occur in areas of intermediate vegetation productivity as measured by NDVI (Table 10.2). For abiotic factors, crested wheatgrass occurrence was more likely in areas of less rugged terrain (TRI) and in soils with either moderate amounts of clay (CLAY) or high salinity levels (SALIN) (Table 10.2). Finally, anthropogenic predictors of crested wheatgrass included areas near major roads with a 1-km distance parameter ($MjRD_{1km}$), local areas around energy wells with a 0.05-km distance parameter ($WELL_{50}$), and near populated places (POP_d) or agricultural (AG_d) areas (Table 10.2). Although only two models were most supported ($\Delta AIC \leq 2$), a total of 20 candidate models were used to derive model-averaged coefficients predicting the probability of crested wheatgrass occurrence using summed AIC weights (w_i) of just ≥ 0.9 (Table 10.3). The final composite crested wheatgrass occurrence model had a ROC AUC value of 0.88 (SE = 0.01), suggesting very good predictive accuracy.

Crested wheatgrass was predicted to occur along major road corridors and around energy wells throughout the WBEA area (Figure 10.1). Although occurrence of crested wheatgrass was reduced in areas of more rugged terrain, anthropogenic factors were the most important predictor of crested wheatgrass occurrence, with individual roads and energy wells easily observed as hot spots on the distribution map. Based on mean predicted occur-

TABLE 10.2. Log-likelihood (LL), number of parameters (K), Akaike's Information Criterion (AIC), change in AIC value from the top model (ΔAIC), and Akaike weight (w_i) of (A) crested wheatgrass, (B) cheatgrass, (C) halogeton, and (D) Russian thistle random-effects logistic regression models of species occurrence in the Wyoming Basins Ecoregional Assessment area. Only models with ΔAIC ≤ 2 are shown.

Species – Model[a]	LL	K	AIC	ΔAIC	w_i
A. Crested wheatgrass (*Agropyron cristatum*)					
$NDVI + NDVI^2 + TRI + CLAY + CLAY^2 + MjRD_{1km} + WELL_{50} + POP_d$	-203.25	10	426.50	0.00	0.222
$NDVI + NDVI^2 + TRI + SALIN + MjRD_{1km} + WELL_{50} + AG_d + POP_d$	-203.99	10	427.98	1.47	0.106
B. Cheatgrass (*Bromus tectorum*)					
$NDVI + NDVI^2 + SOLR + SOLR^2 + Tmin + Tmin^2 + TRMI + TRMI^2 + MjRD_{50} + WELL_{50}$	-319.79	12	663.57	0.00	0.349
$NDVI + NDVI^2 + SOLR + SOLR^2 + Tmin + Tmin^2 + TRMI + TRMI^2 + MjRD_{50} + WELL_{50} + RAIL_d$	-319.42	13	664.85	1.27	0.185
$NDVI + NDVI^2 + SOLR + SOLR^2 + Tmin + Tmin^2 + TRMI + TRMI^2 + MjRD_{50} + WELL_{50} + POP_{1km}$	-319.62	13	665.25	1.67	0.151
C. Halogeton (*Halogeton glomeratus*)					
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SALIN + SALIN^2 + AWC + AWC^2 + RAIL_d + TOWER_{500} + POWER_{50} + AGd + WELL_{50} + RD_{1km}$	-247.53	15	531.05	0.00	0.068
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SALIN + SALIN^2 + AWC + AWC^2 + RAIL_d + TOWER_{500} + POWER_{50} + WELL_{50} + RD_{1km}$	-248.57	14	531.14	0.09	0.065
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SAND + SAND^2 + SALIN + SALIN^2 + AWC + AWC^2 + SOIL_{cm} + RAIL_d + TOWER_{500} + POWER_{50} + AG_d + WELL_{50} + RD_{1km}$	-244.87	18	531.74	0.69	0.048
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SAND + SAND^2 + SALIN + SALIN^2 + AWC + AWC^2 + RAIL_d + TOWER_{500} + POWER_{50} + AG_d + WELL_{50} + RD_{1km}$	-246.21	17	532.42	1.37	0.034
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SAND + SAND^2 + SALIN + SALIN^2 + AWC + AWC^2 + SOIL_{cm} + RAIL_d + TOWER_{500} + POWER_{50} + WELL_{50} + RD_{1km}$	-246.23	17	532.45	1.40	0.034
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SAND + SAND^2 + SALIN + SALIN^2 + AWC + AWC^2 + SOILc_m + RAIL_d + TOWER_{500} + POWER_{50} + WELL_{50} + RD_{1km}$	-246.23	17	532.45	1.40	0.034
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SAND + SAND^2 + SALIN + SALIN^2 + AWC + AWC^2 + SOIL_{cm} + TOWER_{500} + POWER_{50} + AG_d + WELL_{50} + RD_{1km}$	-246.35	17	532.69	1.64	0.030
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SALIN + SALIN^2 + AWC + AWC^2 + SOIL_{cm} + RAIL_d + TOWER_{500} + POWER_{50} + AG_d + WELL_{50} + RD_{1km}$	-247.36	16	532.71	1.66	0.030
$SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SAND + SAND^2 + AWC + AWC^2 + SOIL_{cm} + RAIL_d + TOWER_{500} + POWER_{50} + WELL_{50} + RD1km$	-248.40	15	532.81	1.76	0.028

TABLE 10.2. Continued

Species – Model[a]	LL	K	AIC	ΔAIC	w_i
SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SALIN + SALIN^2 + AWC + AWC^2 + SOIL$_{cm}$ + RAIL$_d$ + TOWER$_{500}$ + POWER$_{50}$ + WELL$_{50}$ + RD$_{1km}$	-248.41	15	532.82	1.77	0.028
SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SALIN + SALIN^2 + AWC + AWC^2 + TOWER$_{500}$ + POWER$_{50}$ + AG$_d$ + WELL$_{50}$ + RD$_{1km}$	-249.41	14	532.82	1.77	0.028
SAGE + NDVI + SOLR + SOLR^2 + Tmin + Tmin^2 + SAND + SAND^2 + SALIN + SALIN^2 + AWC + AWC^2 + RAIL$_d$ + TOWER$_{500}$ + POWER$_{50}$ + WELL$_{50}$ + RD$_{1km}$	-247.47	16	532.94	1.89	0.026
SAGE + NDVI + SOLR + SOLR2 + Tmin + Tmin^2 + SAND + SAND2 + AWC + AWC2 + SOILcm + RAIL$_d$ + TOWER500 + POWER50 + AG$_d$ + WELL50 + RD1km	-247.50	16	533.00	1.95	0.026
D. Russian thistle (*Salsola* spp.)					
NDVI + NDVI^2 + SOLR + pH2Od$_{1km}$ + POP$_d$ + 2RD$_{250}$ + WELL$_{1km}$ + MjRD$_{500}$	-211.33	10	442.67	0.00	0.462

[a] See Appendix 10.1 for variable definitions

rences of crested wheatgrass by distance classes, crested wheatgrass was predicted to occur, on average (threshold probability predicting occurrence at 0.05), when within 270 m of energy wells, 825 m of major roads, 2.5 km of railroads, 1.6 km of populated places (Figure 10.2), and 100 m of agriculture. Associations of crested wheatgrass were strongest for major roads and energy wells with mean probabilities of occurrence adjacent to major roads at 0.33 and for energy wells at 1.0 (Figure 10.2). Railroads also showed associations with mean probabilities of occurrence adjacent to railroads at 0.23. When comparing mean probabilities of occurrence at sites closest to anthropogenic disturbances to sites furthest from those disturbances, risk ratios were estimated at 79.0 for major roads, 59.0 for energy wells, 19.0 for railroads, and 3.2 for populated places.

Cheatgrass

Cheatgrass occurred at 13.5% of sampled plots (n = 214), with frequency of occurrence highest in the near-road stratum at 15.7% of plots (Table 10.1). Of the three top-supported AIC models (ΔAIC < 2), cheatgrass occurrence was explained by one survey design habitat variable, three abiotic factors, and four anthropogenic factors (Table 10.2). For the habitat-based survey design factor, cheatgrass occurrence was more likely in areas of intermediate vegetation productivity (NDVI) (Table 10.2). For abiotic factors, cheatgrass occurrence was more likely in areas of intermediate summertime solar radiation (SOLR), areas of warmer minimum temperatures (Tmin), and showed non-linear responses to topographic-related moisture (TRMI) (Table 10.2). Anthropogenic predictors of cheatgrass included areas very close to major roads or energy wells with a distance parameter of 50 m for both disturbances (MjRD$_{50}$ and WELL$_{50}$), areas near populated places with a 1-km distance parameter (POP$_{1km}$), and areas near railroads (RAIL$_d$) (Table 10.2). Although three models were most supported (ΔAIC ≤ 2), a total of six candidate models were used to derive model-averaged coefficients predicting the probability of cheatgrass occurrence using summed AIC weights (w_i) of just ≥ 0.9 (Table 10.4). The final composite cheatgrass occurrence model had a ROC AUC value of 0.91 (SE = 0.01), suggesting excellent predictive accuracy.

Cheatgrass was predicted to be prevalent throughout the Wind River/Bighorn Basin in Wyoming, the far northern parts of the Wyoming Basins in Montana, the area southeast of the Uintas Mountains in eastern Utah and along the Colorado border, and the southwestern and eastern boundaries of the Wyoming Basins (Figure 10.3). Distribution patterns of cheatgrass appear to be driven mainly by abiotic limitations, although anthropogenic disturbances increase local patterns of cheatgrass occupancy (Figure 10.4). Associations of cheatgrass were strongest for major roads and energy wells, with mean probabilities of occurrence adjacent to major roads at 0.71 and for energy wells at 1.0 (Figure 10.4). When comparing mean probabilities of occurrence at sites closest to anthropogenic disturbances to sites furthest from those disturbances, risk ratios for major roads and energy wells were estimated at 3.0 and 4.1 respectively.

Halogeton

Halogeton occurred at 8.2% of sampled plots (n = 130), with frequency of occurrence highest in the near-road stratum at 10.0% of plots (Table 10.1). Support was high (ΔAIC ≤ 2) for 13 halogeton models that contained two habitat-based survey design variables, six abiotic factors, and six anthropogenic disturbance factors (Table 10.2). The habitat-based survey design factors included both sagebrush habitat (SAGE) and vegetation productivity (NDVI), with halogeton positively associated with sagebrush and negatively associated with vegetation productivity (NDVI) (Table 10.2). For abiotic factors, halogeton responded in a non-linear manner to summertime solar radiation (SOLR) and positively related to minimum temperatures (Tmin) but negatively related to available soil water content (AWC) (Table 10.2). For anthropogenic effects, halogeton was predicted to occur in areas near railroads ($RAIL_d$), close to agriculture (AG_d), near transmission towers with a distance parameter of 0.5 km ($TOWER_{500}$), very close to power lines with a distance parameter of 0.05 km ($POWER_{50}$), very close to energy wells with a distance decay parameter of 0.05-km ($WELL_{50}$), and near roads with a distance parameter of 1 km (RD_{1km}) (Table 10.2). Although 13 models were most supported (ΔAIC ≤ 2), a total of 93 candidate models were used to derive model-averaged coefficients predicting the probability of halogeton occurrence with summed AIC weights (w_i) of just ≥ 0.9 (Table 10.5). The final composite halogeton occurrence model had a ROC AUC value of 0.91 (SE = 0.01), suggesting excellent predictive accuracy.

Similar to the distribution of cheatgrass, but at a reduced extent and lower probabilities, halogeton was predicted throughout the Wind River/Bighorn Basin in Wyoming, the far northern parts of the Wyoming Basins in Montana, and in the area southeast of the Uintas Mountains in eastern Utah and along the Colorado border (Figure 10.5). Like cheatgrass, abiotic factors appear to be particularly important in limiting the distribution of halogeton, but with additional anthropogenic effects increasing local occurrences of halogeton. Associations of halogeton with anthropogenic disturbances were strongest for transmission towers and energy wells with mean probabilities of occurrence adjacent to towers at 0.99 and for energy wells at 1.0 (Figure 10.6). When comparing mean probabilities of occurrence at sites closest to anthropogenic disturbances to those sites furthest from those disturbances, risk ratios were estimated at 6.6 for towers and 6.5 for energy wells.

TABLE 10.3. Crested wheatgrass random-effects logistic regression model[a] parameter estimates (beta [SE]), model log-likelihood (LL), number of parameters (K), Akaike's Information Criterion (AIC), change in AIC value from the top model (ΔAIC), and Akaike weight (w_i) for all candidate models in the Wyoming Basins Ecoregional Assessment area where Akaike weights sum to just ≥ 0.9. Superscript numbers reflect quadratic terms, while subscript numbers for anthropogenic and water variables represent the distance parameter value of the exponential distance decay function used to scale distance effects. Anthropogenic terms ending in the subscript letter "d" reflect Euclidian distance variables rather than distance decay functions.

Rank	Intercept	NDVI	NDVI^2	TRI	CLAY	CLAY^2	MjRD$_{1km}$	WELL$_{50}$
1	-3.68 (1.82)	9.77 (3.77)	-14.35 (6.96)	-0.08 (0.02)	0.16 (0.23)	-0.01 (0.01)	4.53 (0.97)	44.76 (14.66)
2	-4.00 (0.97)	5.59 (3.45)	-8.13 (5.98)	-0.08 (0.02)			4.18 (0.95)	47.82 (15.13)
3	-4.79 (1.00)	6.94 (3.47)	-9.46 (6.19)	-0.08 (0.03)			4.63 (1.00)	45.68 (15.32)
4	-4.53 (0.95)	7.21 (3.41)	-9.64 (6.13)	-0.08 (0.02)			4.41 (0.96)	45.95 (14.83)
5	-4.88 (1.03)	7.50 (3.45)	-9.61 (6.16)	-0.08 (0.02)			4.19 (0.98)	46.43 (14.87)
6	-4.57 (0.95)	7.45 (3.44)	-10.04 (6.20)	-0.08 (0.03)			4.41 (0.97)	45.72 (14.83)
7	-3.63 (0.95)	5.21 (3.57)	-8.38 (6.24)	-0.08 (0.02)			4.03 (1.00)	49.56 (15.85)
8	-3.35 (0.88)	4.60 (3.61)	-8.41 (6.33)	-0.08 (0.03)			4.62 (1.03)	48.35 (16.38)
9	-3.08 (0.84)	4.93 (3.56)	-8.67 (6.26)	-0.08 (0.03)			4.41 (0.99)	48.62 (15.86)
10	-5.47 (0.96)	6.19 (3.53)	-8.13 (6.28)	-0.08 (0.02)			3.84 (0.98)	50.01 (15.42)
11	-6.75 (1.89)	11.57 (3.93)	-15.02 (7.45)	-0.07 (0.03)	0.28 (0.24)	-0.01 (0.01)	4.31 (1.00)	46.39 (14.79)
12	-3.90 (0.86)	6.29 (3.57)	-10.02 (6.47)	-0.08 (0.03)			4.88 (1.06)	46.25 (16.04)
13	-3.64 (0.82)	6.67 (3.52)	-10.35 (6.42)	-0.08 (0.03)			4.67 (1.02)	46.65 (15.58)
14	-4.46 (1.00)	6.71 (3.61)	-9.92 (6.49)	-0.08 (0.03)			4.59 (1.06)	46.83 (16.01)
15	-3.14 (0.85)	5.21 (3.59)	-9.12 (6.33)	-0.08 (0.03)			4.41 (1.00)	48.39 (15.86)
16	-4.17 (0.96)	7.08 (3.56)	-10.26 (6.43)	-0.08 (0.03)			4.38 (1.03)	47.23 (15.55)
17	-5.08 (0.92)	5.29 (3.68)	-8.27 (6.59)	-0.07 (0.03)			4.20 (1.05)	50.60 (16.62)
18	-3.96 (0.87)	6.58 (3.60)	-10.5 (6.55)	-0.08 (0.03)			4.88 (1.06)	45.97 (16.02)
19	-4.79 (0.87)	5.60 (3.63)	-8.53 (6.53)	-0.08 (0.02)			3.98 (1.02)	50.88 (16.09)
20	-3.70 (0.82)	6.95 (3.55)	-10.81 (6.50)	-0.08 (0.03)			4.67 (1.02)	46.39 (15.56)

[a] See Appendix 10.1 for variable definitions

[b] Coefficients and standard errors multiplied by 10^3

TABLE 10.4. Cheatgrass random-effects logistic regression model[a] parameter estimates (beta [SE]), model log-likelihood (LL), number of parameters (K), Akaike's Information Criterion (AIC), change in AIC value from the top model (ΔAIC), and Akaike weight (w_i) for all candidate models in the Wyoming Basins Ecoregional Assessment area where Akaike weights sum to just ≥ 0.9. Superscript numbers reflect quadratic terms, while subscript numbers for anthropogenic and water variables represent the distance parameter value of the exponential distance decay function used to scale distance effects. Anthropogenic terms ending in the subscript letter "d" reflect Euclidian distance variables rather than distance decay functions.

Rank	Intercept	NDVI	NDVI^2	SOLR[b]	SOLR^2[c]	Tmin	Tmin^2	TRMI
1	-221.56 (123.88)	11.70 (2.68)	-12.71 (3.73)	0.59 (0.30)	-0.38 (0.18)	1.94 (0.48)	0.17 (0.07)	-0.27 (0.15)
2	-223.75 (124.01)	11.62 (2.69)	-13.11 (3.85)	0.59 (0.30)	-0.38 (0.18)	1.97 (0.49)	0.18 (0.07)	-0.26 (0.16)
3	-240.86 (125.62)	11.56 (2.69)	-12.77 (3.86)	0.63 (0.31)	-0.41 (0.19)	2.05 (0.50)	0.20 (0.07)	-0.26 (0.16)
4	-236.95 (125.35)	11.66 (2.68)	-12.35 (3.75)	0.62 (0.31)	-0.41 (0.19)	2.00 (0.50)	0.19 (0.07)	-0.27 (0.15)
5	-235.27 (122.90)	11.57 (2.59)	-12.07 (3.56)	0.62 (0.30)	-0.40 (0.18)	1.82 (0.46)	0.16 (0.07)	
6	-250.02 (124.28)	11.54 (2.59)	-11.71 (3.58)	0.65 (0.30)	-0.42 (0.18)	1.88 (0.47)	0.17 (0.07)	

[a] See Appendix 10.1 for variable definitions

[b] Coefficients and standard errors multiplied by 10^3

[c] Coefficients and standard errors multiplied by 10^9

TABLE 10.3. Extended

POP_d^b	SALIN	$2RD_{50}$	$RAIL_{5km}$	AG_d^b	$pH2Od_{50}$	LL	K	AIC	ΔAIC	$\sum w_i$
-0.10 (0.04)						-203.25	10	426.78	0.00	0.222
-0.10 (0.04)	0.33 (0.16)			-0.10 (0.10)		-203.99	10	428.26	1.48	0.328
-0.10 (0.04)	0.33 (0.17)	0.84 (0.56)				-204.28	10	428.85	2.06	0.407
-0.10 (0.04)	0.33 (0.16)					-205.33	9	428.88	2.15	0.483
-0.10 (0.04)	0.31 (0.16)		1.50 (1.50)			-204.84	10	429.96	3.17	0.528
-0.10 (0.04)	0.33 (0.16)				-18.66 (32.07)	-204.92	10	430.13	3.34	0.570
-0.10 (0.04)			2.31 (1.53)	-0.10 (0.10)		-204.96	10	430.20	3.41	0.610
-0.10 (0.04)		0.85 (0.56)		-0.10 (0.10)		-205.07	10	430.42	3.64	0.646
-0.10 (0.04)				-0.10 (0.10)		-206.14	9	430.51	3.77	0.680
	0.31 (0.17)		3.14 (1.41)	-0.20 (0.10)		-205.22	10	430.73	3.94	0.711
			3.99 (1.43)			-205.33	10	430.93	4.15	0.739
-0.10 (0.04)		0.88 (0.56)				-206.40	9	431.04	4.30	0.765
-0.10 (0.04)						-207.54	8	431.27	4.58	0.787
-0.10 (0.04)		0.89 (0.56)	2.01 (1.57)			-205.57	10	431.43	4.64	0.809
-0.10 (0.04)				-0.10 (0.10)	-20.41 (32.80)	-205.66	10	431.60	4.82	0.829
-0.10 (0.04)			1.94 (1.54)			-206.74	9	431.71	4.98	0.847
		0.90 (0.56)	3.76 (1.47)	-0.20 (0.10)		-205.84	10	431.96	5.18	0.864
-0.10 (0.04)		0.89 (0.56)			-21.82 (33.76)	-205.90	10	432.09	5.30	0.880
			3.71 (1.44)	-0.20 (0.10)		-207.03	9	432.28	5.55	0.894
-0.10 (0.04)					-20.45 (33.17)	-207.08	9	432.39	5.66	0.907

TABLE 10.4. Extended

$TRMI^2$	$MjRD_{50}$	$WELL_{50}$	POP_{1km}	$RAIL_d^b$	LL	K	AIC	ΔAIC	$\sum w_i$
0.01 (0.004)	3.71 (1.03)	15.05 (7.70)			-319.79	12	663.97	0.00	0.349
0.01 (0.004)	3.71 (1.03)	14.96 (7.69)	1.57 (2.71)		-319.42	13	665.31	1.27	0.534
0.01 (0.004)	3.67 (1.03)	15.09 (7.79)	1.85 (2.74)	-0.01 (0.01)	-319.62	13	665.71	1.67	0.685
0.01 (0.004)	3.67 (1.03)	15.19 (7.80)		-0.01 (0.01)	-323.03	10	666.35	2.49	0.785
	3.79 (1.02)	14.59 (7.37)			-319.20	14	666.94	2.83	0.870
	3.75 (1.02)	14.73 (7.46)		-0.01 (0.01)	-322.68	11	667.70	3.79	0.923

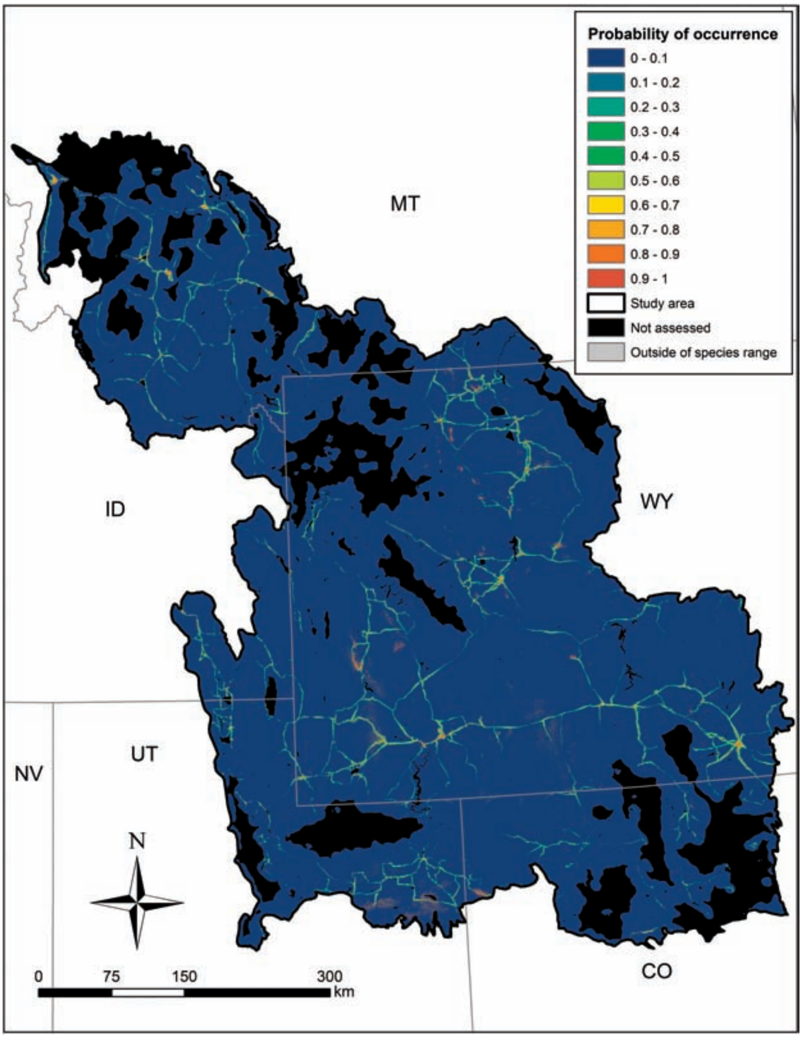

FIG. 10.1. Predicted probability of occurrence for crested wheatgrass in the Wyoming Basins Ecoregional Assessment. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

Russian Thistle

Russian thistle was found at 5.4% of sampled plots (n = 85), with frequency of occurrence highest in the near-road stratum at 7.3% of plots (Table 10.1). Support was high (ΔAIC ≤ 2) for a single Russian thistle model that contained one habitat-based survey design variable, two abiotic factors, and three anthropogenic disturbance factors (Table 10.2). For the habitat-based survey design variable, Russian thistle occurrence was predicted to increase in areas associated with intermediate vegetation productivity as measured by NDVI (Table 10.6). For abiotic factors, Russian thistle occurrence was more likely in areas of low summertime solar radiation (SOLR) and in areas further away from perennial sources of water with a distance parameter of 1 km ($pH2Od_{1km}$) (Table 10.6). For anthropogenic factors, Russian thistle occurrence was more likely along secondary

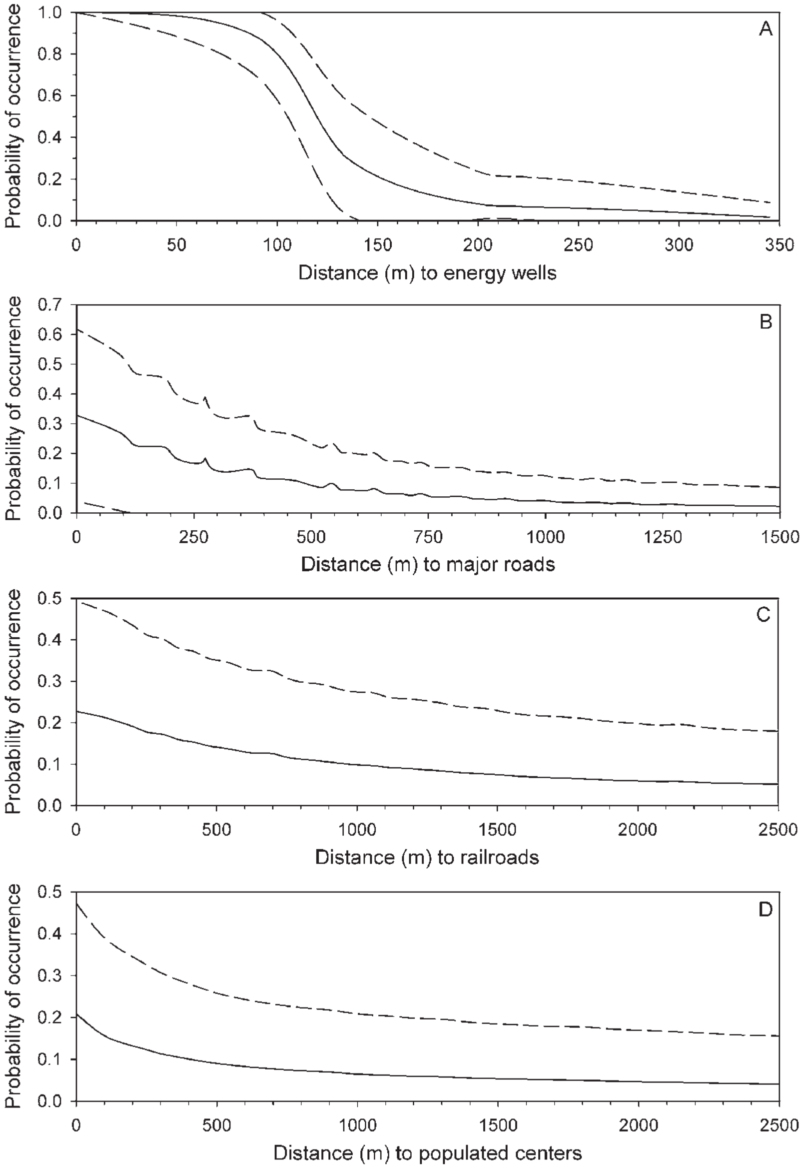

FIG. 10.2. Dose-response curves illustrating mean predicted probability of occurrence (±1 SD) of crested wheatgrass across the Wyoming Basins Ecoregional Assessment area as a function of distance from anthropogenic feature types of energy wells (A), major roads (B), railroads (C), and populated centers (D).

roads with a distance parameter of 0.25 km ($2RD_{250}$), in areas near energy wells with a distance decay parameter of 1 km ($WELL_{1km}$), and in areas near major roads with a distance decay parameter of 0.5 km ($MjRD_{500}$) (Table 10.6). Although a single model was most supported, a total of 13 candidate models were used to derive model-averaged coefficients predicting the probability of Russian thistle occurrence with summed AIC weights (w_i) of just ≥ 0.9 (Table 10.6). The final composite Russian thistle occurrence model had a ROC AUC value of 0.89 (SE = 0.02), suggesting very good predictive accuracy.

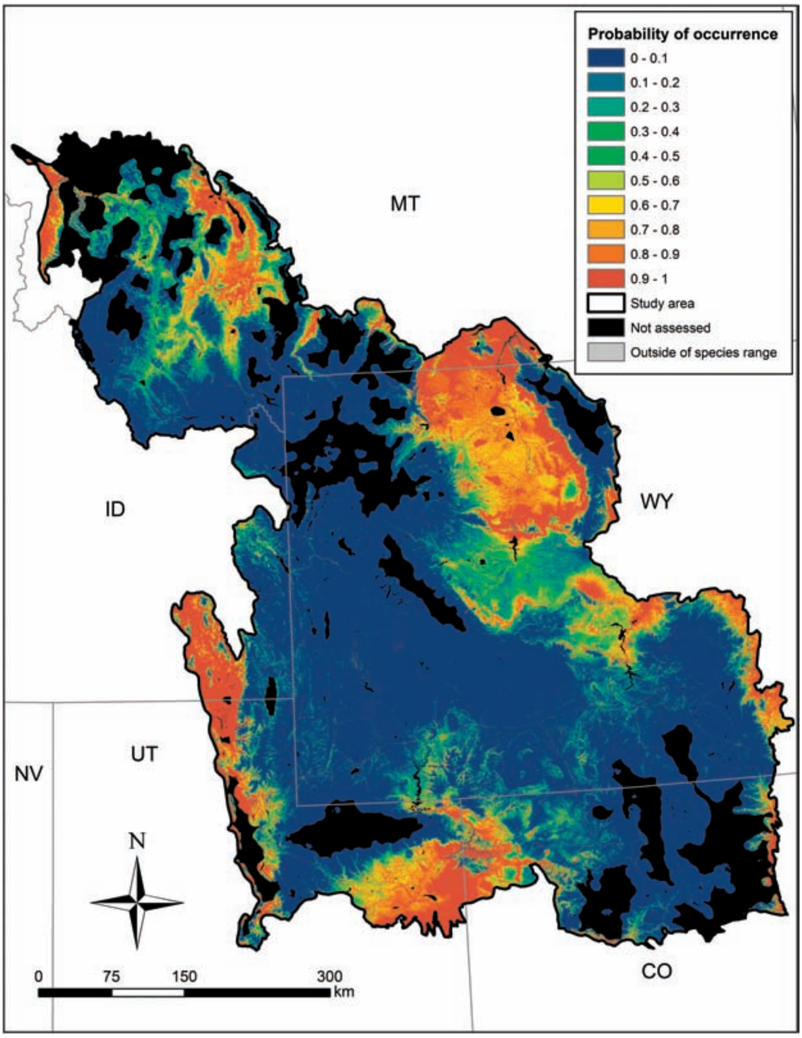

FIG. 10.3. Predicted probability of occurrence for cheatgrass in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

A probability of occurrence map for Russian thistle was generated for the WBEA area using model-averaged coefficients and associated GIS variables. Russian thistle was predicted to occur throughout the Wind River/Bighorn Basin in Wyoming, along the I-80 corridor in Wyoming and associated secondary roads in the area, and finally in the area southeast of the Uintas Mountains in eastern Utah (Figure 10.7). The distribution map for Russian thistle illustrates the importance of anthropogenic factors with individual roads and energy wells easily observed as hot spots. Based on mean predicted occurrences of Russian thistle by distance classes, Russian thistle was predicted to occur, on average (threshold probability > 0.05), within 700 m of populated places, 550 m of major roads, 90 m of secondary roads, 1 km of pipelines, and 1.3 km of energy wells (Figure 10.8). Associations of Russian

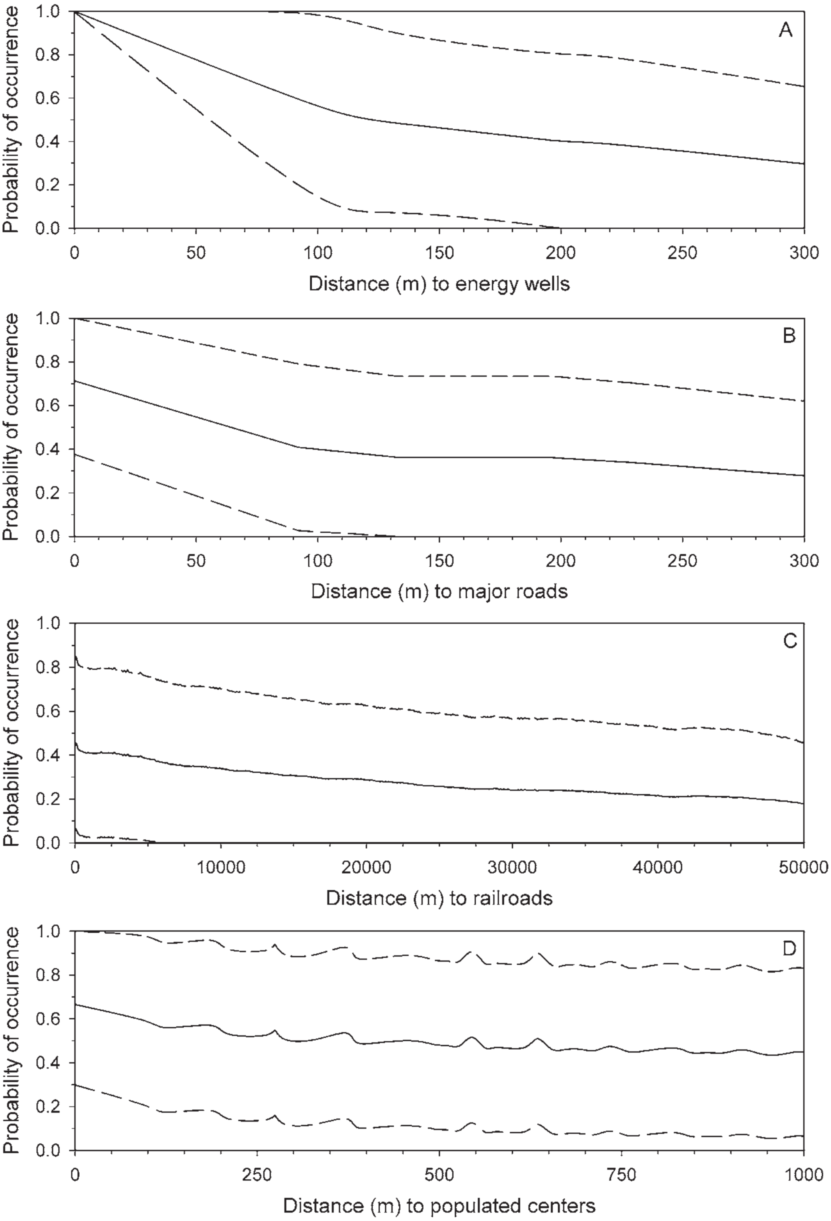

FIG. 10.4. Dose-response curves illustrating mean predicted probability of occurrence (±1 SD) of cheatgrass across the Wyoming Basins Ecoregional Assessment area as a function of distance from anthropogenic feature types of energy wells (A), major roads (B), railroads (C), and populated centers (D).

thistle were strongest for major roads and energy wells with mean probabilities of occurrence adjacent to major roads at 0.23 and for energy wells at 0.36 (Figure 10.8). When comparing mean probabilities of occurrence at sites closest to anthropogenic disturbances to those sites furthest from those disturbances, risk ratios were estimated at 11.4 for major roads and 17.2 for energy wells.

TABLE 10.5. Halogeton random-effects logistic regression model[a] parameter estimates (beta [SE]), model log-likelihood (LL), number of parameters (*K*), Akaike's Information Criterion (AIC), change in AIC value from the top model (ΔAIC), and Akaike weight (w_i) for all candidate models in the Wyoming Basins Ecoregional Assessment area where Akaike weights sum to just ≥ 0.9. Superscript numbers reflect quadratic terms, while subscript numbers for anthropogenic and water variables represent the distance parameter value of the exponential distance decay function used to scale distance effects. Anthropogenic terms ending in the subscript letter "d" reflect Euclidian distance variables rather than distance decay functions.

Rank	Intercept	SAGE	NDVI	SOLR[b]	SOLR^2[c]	Tmin	Tmin^2	SALIN	SALIN^2	AWC	AWC^2	RAIL$_d$[e]
1	377.29 (160.35)	-0.58 (0.38)	-1.83 (2.75)	-0.88 (0.3)	0.51 (0.24)	-0.08 (0.54)	-0.18 (0.12)	1.36 (0.69)	-0.12 (0.08)	-1.99 (0.94)	0.13 (0.08)	-0.32 (0.17)
2	401.08 (156.33)	-0.55 (0.37)	-1.47 (3.07)	-0.93 (0.38)	0.54 (0.23)	-0.03 (0.56)	-0.16 (0.12)	1.20 (0.68)	-0.10 (0.08)	-1.82 (1.00)	0.11 (0.09)	-0.35 (0.18)
3	356.20 (164.07)	-0.59 (0.37)	-2.05 (2.42)	-0.84 (0.40)	0.49 (0.24)	-0.08 (0.59)	-0.21 (0.14)	1.42 (0.62)	-0.17 (0.08)	-1.71 (0.93)	0.07 (0.08)	-0.30 (0.17)
4	352.93 (162.40)	-0.55 (0.40)	-1.51 (2.49)	-0.83 (0.39)	0.48 (0.24)	-0.17 (0.58)	-0.20 (0.13)	1.18 (0.68)	-0.10 (0.08)	-1.67 (0.96)	0.10 (0.08)	-0.31 (0.20)
5	389.36 (159.09)	-0.56 (0.37)	-0.92 (2.12)	-0.92 (0.39)	0.53 (0.23)	-0.01 (0.60)	-0.19 (0.14)	1.38 (0.63)	-0.16 (0.08)	-1.65 (0.87)	0.07 (0.07)	-0.32 (0.16)
6	389.36 (159.09)	-0.56 (0.37)	-0.92 (2.12)	-0.92 (0.39)	0.53 (0.23)	-0.01 (0.60)	-0.19 (0.14)	1.38 (0.63)	-0.16 (0.08)	-1.65 (0.87)	0.07 (0.07)	-0.32 (0.16)
7	392.25 (162.98)	-0.50 (0.37)	-2.17 (2.07)	-0.93 (0.40)	0.54 (0.24)	-0.24 (0.62)	-0.24 (0.16)	1.72 (0.82)	-0.19 (0.10)	-1.92 (0.96)	0.09 (0.08)	
8	398.98 (175.11)	-0.60 (0.36)	-2.14 (2.88)	-0.93 (0.42)	0.54 (0.26)	-0.05 (0.55)	-0.19 (0.12)	1.45 (0.69)	-0.14 (0.09)	-2.19 (0.96)	0.13 (0.08)	-0.34 (0.18)
9	403.69 (162.43)	-0.46 (0.36)	-2.25 (2.33)	-0.95 (0.40)	0.55 (0.24)	0.10 (0.55)	-0.17 (0.13)			-1.39 (0.85)	0.04 (0.07)	-0.32 (0.18)
10	411.66 (160.00)	-0.59 (0.37)	-1.37 (2.72)	-0.96 (0.39)	0.56 (0.24)	-0.01 (0.57)	-0.17 (0.12)	1.35 (0.69)	-0.13 (0.09)	-2.02 (0.99)	0.11 (0.08)	-0.35 (0.17)
11	422.42 (158.42)	-0.51 (0.37)	-1.78 (2.07)	-0.99 (0.39)	0.58 (0.23)	-0.25 (0.55)	-0.22 (0.12)	1.79 (0.71)	-0.17 (0.08)	-2.24 (0.96)	0.15 (0.08)	
12	385.08 (157.40)	-0.51 (0.37)	-0.68 (2.19)	-0.90 (0.38)	0.52 (0.23)	-0.12 (0.56)	-0.18 (0.13)	1.15 (0.60)	-0.10 (0.07)	-1.60 (0.89)	0.09 (0.07)	-0.33 (0.17)
13	402.23 (170.86)	-0.43 (0.37)	-2.46 (2.07)	-0.94 (0.42)	0.54 (0.25)	0.15 (0.53)	-0.17 (0.12)			-1.81 (0.87)	0.09 (0.07)	-0.31 (0.15)
14	451.86 (164.34)	-0.54 (0.36)	-1.08 (2.11)	-1.05 (0.40)	0.61 (0.24)	-0.24 (0.62)	-0.21 (0.13)	1.61 (0.67)	-0.14 (0.08)	-2.04 (0.99)	0.13 (0.08)	
15	390.95 (167.73)	-0.51 (0.36)	-2.61 (1.93)	-0.89 (0.41)	0.51 (0.25)	0.19 (0.63)	-0.12 (0.13)			-1.76 (0.96)	0.09 (0.08)	-0.39 (0.16)
16	415.20 (169.96)	-0.44 (0.37)	-1.97 (2.15)	-0.98 (0.41)	0.57 (0.25)	-0.40 (0.54)	-0.27 (0.15)	1.38 (0.60)	-0.11 (0.07)	-1.90 (1.01)	0.12 (0.08)	
17	372.48 (170.70)	-0.51 (0.36)	-2.50 (2.31)	-0.86 (0.42)	0.50 (0.25)	0.11 (0.60)	-0.14 (0.14)			-1.21 (0.92)	0.05 (0.08)	-0.36 (0.16)
18	422.81 (158.32)	-0.54 (0.38)	-1.81 (2.14)	-0.99 (0.39)	0.58 (0.23)	-0.27 (0.59)	-0.23 (0.13)	1.92 (0.92)	-0.19 (0.12)	-2.32 (0.94)	0.14 (0.08)	
19	346.91 (168.04)	-0.59 (0.39)	-2.65 (7.25)	-0.80 (0.41)	0.46 (0.25)	-0.25 (0.53)	-0.20 (0.12)	1.30 (1.21)	-0.11 (0.16)	-2.11 (1.54)	0.13 (0.15)	-0.39 (0.19)
20	425.14 (158.20)	-0.50 (0.36)	-1.60 (2.15)	-1 (0.38)	0.58 (0.23)	-0.03 (0.61)	-0.18 (0.12)	1.53 (0.69)	-0.18 (0.09)	-1.56 (0.83)	0.06 (0.07)	
21	391.24 (171.88)	-0.50 (0.36)	-3.22 (2.10)	-0.90 (0.42)	0.52 (0.25)	0.20 (0.61)	-0.13 (0.12)			-1.86 (0.93)	0.11 (0.08)	-0.38 (0.15)
22	375.35 (159.61)	-0.55 (0.38)	-1.83 (2.74)	-0.87 (0.39)	0.50 (0.24)	-0.18 (0.56)	-0.18 (0.12)	1.22 (0.65)	-0.11 (0.08)	-2.00 (1.02)	0.12 (0.09)	-0.41 (0.17)
23	333.83 (174.72)	-0.53 (0.38)	-2.68 (2.47)	-0.77 (0.42)	0.44 (0.26)	0.02 (0.61)	-0.16 (0.14)			-1.30 (0.97)	0.06 (0.08)	-0.36 (0.15)
24	391.87 (163.26)	-0.49 (0.37)	-1.91 (2.37)	-0.91 (0.39)	0.53 (0.24)	-0.06 (0.54)	-0.18 (0.12)	1.31 (0.63)	-0.11 (0.07)	-2.10 (0.86)	0.14 (0.08)	-0.34 (0.16)
25	389.66 (160.02)	-0.53 (0.36)	-2.22 (1.90)	-0.89 (0.39)	0.51 (0.23)	0.17 (0.60)	-0.13 (0.13)			-1.88 (0.88)	0.09 (0.07)	-0.42 (0.18)
26	389.40 (160.33)	-0.57 (0.36)	-1.21 (2.34)	-0.90 (0.39)	0.52 (0.23)	0.01 (0.53)	-0.17 (0.12)	1.48 (0.62)	-0.12 (0.07)	-2.19 (0.88)	0.15 (0.07)	-0.36 (0.16)
27	363.44 (163.74)	-0.59 (0.36)	-1.12 (2.18)	-0.84 (0.40)	0.48 (0.24)	0.08 (0.56)	-0.15 (0.12)	1.28 (0.59)	-0.10 (0.07)	-1.67 (0.86)	0.09 (0.08)	-0.37 (0.16)
28	355.75 (159.33)	-0.53 (0.37)	-2.33 (2.26)	-0.84 (0.39)	0.49 (0.23)	0.00 (0.58)	-0.18 (0.13)	1.38 (0.62)	-0.17 (0.08)	-1.72 (0.92)	0.08 (0.08)	-0.31 (0.16)
29	355.75 (159.33)	-0.53 (0.37)	-2.33 (2.26)	-0.84 (0.39)	0.49 (0.23)	0.00 (0.58)	-0.18 (0.13)	1.38 (0.62)	-0.17 (0.08)	-1.72 (0.92)	0.08 (0.08)	-0.31 (0.16)
30	323.35 (161.44)	-0.58 (0.36)	-2.21 (2.41)	-0.76 (0.39)	0.43 (0.24)	-0.29 (0.59)	-0.24 (0.15)	1.40 (0.60)	-0.16 (0.08)	-1.90 (0.90)	0.09 (0.08)	-0.36 (0.17)
31	404.28 (162.20)	-0.48 (0.36)	-1.15 (2.51)	-0.94 (0.39)	0.54 (0.24)	-0.04 (0.54)	-0.17 (0.12)	1.18 (0.60)	-0.10 (0.07)	-1.96 (0.93)	0.13 (0.08)	-0.36 (0.16)

TABLE 10.5. Extended

$TOWER_{500}$	$POWER_{50}$	AG_d^e	$WELL_{50}$	RD_{1km}	SAND	$SAND^{2f}$	$SOIL_{cm}$	LL	K	AIC	ΔAIC	$\sum w_i$
15.79 (8.26)	3.03 (1.30)	-0.78 (0.59)	27.88 (30.16)	2.42 (1.11)				-247.53	15	531.94	0.00	0.068
15.40 (7.70)	3.11 (1.31)		28.08 (29.45)	2.49 (1.10)				-248.57	14	531.93	0.09	0.133
15.15 (7.76)	2.89 (1.30)	-1.00 (0.65)	25.00 (30.03)	2.71 (1.20)	0.23 (0.12)	-0.37 (0.19)	0.03 (0.02)	-244.87	18	532.93	0.69	0.181
15.66 (8.54)	3.05 (1.33)	-0.87 (0.63)	25.72 (30.28)	2.50 (1.18)	0.17 (0.10)	-0.24 (0.16)		-246.21	17	533.50	1.37	0.216
15.08 (7.25)	3.06 (1.34)		26.43 (30.78)	2.71 (1.17)	0.22 (0.13)	-0.35 (0.20)	0.03 (0.02)	-246.23	17	533.54	1.40	0.249
15.08 (7.25)	3.06 (1.34)		26.43 (30.78)	2.71 (1.17)	0.22 (0.13)	-0.35 (0.20)	0.03 (0.02)	-246.23	17	533.54	1.40	0.283
16.14 (7.44)	3.03 (1.33)	-1.21 (0.68)	22.73 (27.16)	2.71 (1.16)	0.25 (0.13)	-0.40 (0.20)	0.04 (0.03)	-246.35	17	533.78	1.64	0.313
16.00 (8.15)	3.02 (1.29)	-0.82 (0.62)	29.18 (30.85)	2.49 (1.12)			0.01 (0.02)	-247.36	16	533.70	1.66	0.343
15.46 (6.94)	2.97 (1.34)		25.27 (30.08)	2.75 (1.13)	0.27 (0.15)	-0.42 (0.23)	0.03 (0.01)	-248.40	15	533.69	1.76	0.371
15.46 (7.47)	3.12 (1.31)		29.14 (29.91)	2.58 (1.10)			0.01 (0.02)	-248.41	15	533.70	1.77	0.399
16.86 (7.13)	3.18 (1.33)	-1.01 (0.65)	25.74 (30.49)	2.54 (1.03)				-249.41	14	533.61	1.77	0.427
15.51 (8.22)	3.15 (1.33)		27.11 (30.24)	2.62 (1.17)	0.16 (0.11)	-0.23 (0.16)		-247.47	16	533.92	1.88	0.453
17.10 (8.41)	2.82 (1.39)	-0.86 (0.60)	25.64 (30.17)	2.69 (1.04)	0.26 (0.15)	-0.41 (0.23)	0.03 (0.01)	-247.50	16	533.99	1.95	0.479
16.99 (6.47)	3.36 (1.30)		25.51 (30.95)	2.64 (1.12)				-250.86	13	534.43	2.68	0.497
15.00 (7.11)	3.08 (1.37)		25.35 (29.56)	2.85 (1.10)				-251.90	12	534.42	2.74	0.514
16.86 (7.92)	3.23 (1.31)	-1.26 (0.71)	26.01 (31.34)	2.74 (1.18)	0.20 (0.11)	-0.30 (0.17)		-247.98	16	534.95	2.91	0.530
14.11 (6.95)	3.17 (1.30)		23.00 (28.77)	2.94 (1.14)	0.19 (0.13)	-0.28 (0.18)		-250.19	14	535.17	3.33	0.543
16.70 (7.07)	3.18 (1.33)	-1.01 (0.65)	25.55 (30.33)	2.58 (1.06)			0.01 (0.02)	-249.21	15	535.31	3.38	0.555
	3.05 (1.29)	-0.87 (0.66)	27.52 (30.60)	2.82 (1.19)				-250.22	14	535.24	3.40	0.568
16.83 (6.64)	3.13 (1.30)		22.20 (28.59)	2.51 (1.14)	0.23 (0.12)	-0.38 (0.19)	0.03 (0.02)	-248.25	16	535.48	3.45	0.580
15.70 (7.65)	2.96 (1.40)	-0.64 (0.54)	25.37 (29.77)	2.72 (1.08)				-251.27	13	535.23	3.48	0.592
	3.11 (1.34)		27.67 (29.75)	2.86 (1.14)				-251.28	13	535.26	3.50	0.604
14.48 (7.61)	3.00 (1.31)	-0.80 (0.62)	22.55 (25.78)	2.85 (1.12)	0.21 (0.13)	-0.31 (0.20)		-249.36	15	535.60	3.67	0.614
16.13 (8.35)		-0.84 (0.56)	27.95 (30.52)	2.20 (1.04)				-250.43	14	535.66	3.82	0.625
15.56 (7.48)	3.03 (1.41)		26.46 (29.57)	2.75 (1.12)			0.01 (0.01)	-251.45	13	535.61	3.86	0.634
19.71 (7.59)	2.75 (1.25)	-0.77 (0.55)	32.98 (30.79)					-250.47	14	535.74	3.90	0.644
19.20 (7.05)	2.96 (1.23)		31.91 (30.12)					-251.48	13	535.65	3.90	0.654
15.06 (7.71)		-1.03 (0.61)	23.35 (28.32)	2.53 (1.17)	0.23 (0.12)	-0.36 (0.18)	0.04 (0.02)	-247.57	17	536.23	4.09	0.663
15.06 (7.71)		-1.03 (0.61)	23.35 (28.32)	2.53 (1.17)	0.23 (0.12)	-0.36 (0.18)	0.04 (0.02)	-247.57	17	536.23	4.09	0.671
	3.03 (1.31)	-1.09 (0.68)	24.50 (28.24)	3.18 (1.24)	0.24 (0.12)	-0.38 (0.19)	0.03 (0.02)	-247.61	17	536.32	4.18	0.68
15.75 (8.02)			28.65 (30.02)	2.26 (1.02)				-251.65	13	536.01	4.26	0.688

TABLE 10.5. Continued

Rank	Intercept	SAGE	NDVI	SOLR[b]	SOLR^{2c}	Tmin	Tmin^2	SALIN	SALIN^2	AWC	AWC^2	RAIL$_d$[e]
32	448.96 (160.81)	-0.55 (0.36)	-1.01 (2.09)	-1.05 (0.39)	0.61 (0.24)	-0.25 (0.63)	-0.21 (0.13)	1.68 (0.72)	-0.16 (0.09)	-2.10 (0.94)	0.13 (0.08)	
33	345.85 (160.81)	-0.57 (0.43)	-0.53 (2.10)	-0.80 (0.39)	0.46 (0.24)	-0.42 (0.62)	-0.23 (0.14)	1.31 (0.66)	-0.12 (0.08)	-1.76 (0.91)	0.10 (0.08)	-0.43 (0.18)
34	314.75 (162.14)	-0.61 (0.39)	-1.83 (3.48)	-0.73 (0.39)	0.42 (0.24)	-0.45 (0.57)	-0.24 (0.13)	1.29 (0.68)	-0.11 (0.09)	-1.84 (0.94)	0.11 (0.08)	-0.40 (0.19)
35	364.71 (162.73)	-0.47 (0.39)	-2.32 (2.34)	-0.85 (0.40)	0.48 (0.24)	-0.08 (0.58)	-0.18 (0.14)			-1.67 (0.90)	0.06 (0.07)	-0.41 (0.18)
36	352.09 (161.40)	-0.57 (0.38)	-0.80 (2.12)	-0.82 (0.39)	0.47 (0.24)	-0.25 (0.60)	-0.22 (0.14)	1.43 (0.61)	-0.17 (0.08)	-1.81 (0.87)	0.08 (0.07)	-0.40 (0.17)
37	458.31 (175.73)	-0.50 (0.36)	-1.60 (2.18)	-1.08 (0.43)	0.63 (0.26)	-0.15 (0.56)	-0.21 (0.13)	1.40 (0.61)	-0.13 (0.07)	-1.46 (0.91)	0.08 (0.07)	
38	400.03 (172.27)	-0.53 (0.37)	-3.47 (2.58)	-0.92 (0.42)	0.53 (0.25)	0.12 (0.58)	-0.15 (0.13)			-2.05 (0.92)	0.10 (0.08)	-0.42 (0.17)
39	385.88 (158.34)	-0.49 (0.38)	-1.25 (2.16)	-0.91 (0.38)	0.53 (0.23)	0.07 (0.57)	-0.16 (0.13)	1.31 (0.62)	-0.16 (0.08)	-1.61 (0.87)	0.07 (0.08)	-0.33 (0.16)
40	331.83 (173.75)	-0.55 (0.39)	-2.75 (2.45)	-0.77 (0.42)	0.44 (0.25)	-0.21 (0.61)	-0.22 (0.16)			-1.75 (0.97)	0.07 (0.08)	-0.42 (0.18)
41	311.60 (160.38)	-0.50 (0.39)	-2.00 (2.43)	-0.71 (0.39)	0.40 (0.24)	-0.13 (0.62)	-0.16 (0.13)			-1.46 (1.06)	0.06 (0.09)	-0.44 (0.18)
42	383.24 (156.10)	-0.38 (0.37)	-2.71 (2.13)	-0.89 (0.38)	0.52 (0.23)	0.21 (0.53)	-0.14 (0.12)			-1.81 (0.84)	0.09 (0.07)	-0.36 (0.15)
43	365.82 (180.57)	-0.58 (0.37)	-2.51 (3.51)	-0.85 (0.44)	0.49 (0.26)	-0.20 (0.54)	-0.20 (0.12)	1.38 (0.74)	-0.13 (0.10)	-2.36 (1.11)	0.15 (0.10)	-0.39 (0.18)
44	406.64 (163.47)	-0.54 (0.36)	-2.26 (2.43)	-0.95 (0.40)	0.55 (0.24)	-0.02 (0.55)	-0.18 (0.12)	1.43 (0.67)	-0.14 (0.09)	-2.27 (0.86)	0.14 (0.07)	-0.35 (0.16)
45	383.86 (162.10)	-0.57 (0.37)	-1.76 (3.04)	-0.89 (0.39)	0.51 (0.24)	-0.16 (0.56)	-0.19 (0.12)	1.31 (0.69)	-0.13 (0.09)	-2.14 (1.14)	0.12 (0.10)	-0.41 (0.17)
46	399.06 (160.77)	-0.39 (0.36)	-2.20 (2.19)	-0.93 (0.39)	0.54 (0.24)	0.23 (0.54)	-0.13 (0.12)			-1.69 (0.85)	0.08 (0.07)	-0.39 (0.18)
47	359.13 (162.19)	-0.48 (0.37)	-1.86 (2.42)	-0.84 (0.39)	0.49 (0.24)	-0.14 (0.56)	-0.19 (0.12)	1.10 (0.62)	-0.09 (0.08)	-1.70 (0.95)	0.11 (0.08)	-0.32 (0.17)
48	363.97 (162.50)	-0.54 (0.36)	-0.75 (2.16)	-0.85 (0.39)	0.49 (0.24)	-0.07 (0.51)	-0.18 (0.12)	1.37 (0.58)	-0.11 (0.06)	-1.89 (0.96)	0.12 (0.08)	-0.34 (0.16)
49	426.70 (166.73)	-0.40 (0.37)	-3.01 (1.83)	-1.01 (0.41)	0.58 (0.25)	-0.10 (0.53)	-0.23 (0.13)			-1.56 (0.97)	0.05 (0.08)	
50	377.15 (165.77)	-0.56 (0.35)	-0.54 (2.02)	-0.88 (0.40)	0.51 (0.24)	0.16 (0.54)	-0.18 (0.13)	1.47 (0.65)	-0.16 (0.08)	-2.04 (1.27)	0.11 (0.11)	-0.32 (0.14)
51	375.29 (149.29)	-0.42 (0.37)	-2.47 (2.06)	-0.89 (0.36)	0.52 (0.22)	-0.09 (0.58)	-0.19 (0.13)	1.64 (0.74)	-0.19 (0.10)	-1.84 (0.91)	0.09 (0.08)	
52	390.21 (160.37)	-0.61 (0.38)	-1.40 (2.31)	-0.90 (0.39)	0.52 (0.23)	0.03 (0.54)	-0.17 (0.13)	1.61 (0.71)	-0.15 (0.09)	-2.27 (0.88)	0.14 (0.07)	-0.36 (0.16)
53	366.37 (173.07)	-0.60 (0.36)	-1.11 (2.26)	-0.84 (0.42)	0.49 (0.25)	0.08 (0.57)	-0.15 (0.12)	1.32 (0.64)	-0.11 (0.08)	-1.74 (1.00)	0.09 (0.09)	-0.36 (0.17)
54	343.62 (159.23)	-0.49 (0.38)	-2.49 (1.98)	-0.77 (0.39)	0.44 (0.23)	0.01 (0.61)	-0.14 (0.12)			-2.10 (1.03)	0.12 (0.08)	-0.46 (0.16)
55	418.08 (165.54)	-0.52 (0.37)	-1.32 (2.29)	-0.97 (0.40)	0.56 (0.24)	0.01 (0.56)	-0.17 (0.12)	1.29 (0.62)	-0.12 (0.08)	-2.12 (0.89)	0.13 (0.08)	-0.37 (0.16)
56	382.79 (170.91)	-0.55 (0.35)	-0.51 (2.18)	-0.89 (0.41)	0.51 (0.25)	0.01 (0.52)	-0.17 (0.12)	1.27 (0.64)	-0.10 (0.06)	-1.76 (0.98)	0.11 (0.09)	-0.37 (0.17)
57	386.46 (166.30)	-0.47 (0.37)	-2.28 (2.12)	-0.91 (0.40)	0.53 (0.25)	-0.47 (0.60)	-0.28 (0.15)	1.83 (0.67)	-0.21 (0.09)	-2.25 (1.04)	0.11 (0.09)	
58	373.87 (192.67)	-0.54 (0.36)	-4.69 (1.97)	-0.91 (0.47)	0.54 (0.28)	0.41 (0.48)	-0.13 (0.13)	1.64 (0.58)	-0.17 (0.07)			-0.30 (0.14)
59	278.78 (155.25)	-0.53 (0.37)	-2.47 (2.48)	-0.63 (0.38)	0.36 (0.23)	-0.21 (0.59)	-0.18 (0.14)			-1.46 (0.99)	0.07 (0.08)	-0.43 (0.17)
60	369.83 (153.82)	-0.58 (0.35)	-1.09 (2.21)	-0.86 (0.37)	0.50 (0.23)	-0.17 (0.55)	-0.21 (0.12)	1.92 (0.73)	-0.17 (0.09)	-2.10 (1.05)	0.13 (0.09)	
61	475.65 (174.33)	-0.49 (0.35)	-2.32 (1.88)	-1.12 (0.43)	0.65 (0.26)	0.04 (0.56)	-0.20 (0.12)			-1.57 (0.85)	0.06 (0.07)	
62	382.30 (158.63)	-0.45 (0.36)	-0.93 (2.23)	-0.89 (0.38)	0.52 (0.23)	-0.11 (0.55)	-0.18 (0.13)	1.09 (0.58)	-0.09 (0.06)	-1.55 (0.88)	0.09 (0.07)	-0.35 (0.16)
63	431.51 (204.29)	-0.49 (0.35)	-4.23 (2.02)	-1.04 (0.50)	0.62 (0.30)	0.49 (0.47)	-0.11 (0.14)	1.57 (0.59)	-0.15 (0.07)			-0.28 (0.13)
64	339.86 (151.87)	-0.55 (0.36)	-1.32 (2.23)	-0.80 (0.37)	0.47 (0.22)	0.01 (0.57)	-0.18 (0.13)	1.74 (0.71)	-0.19 (0.10)	-1.63 (0.92)	0.07 (0.08)	
65	419.48 (155.17)	-0.44 (0.36)	-1.92 (2.17)	-0.98 (0.38)	0.57 (0.23)	-0.28 (0.56)	-0.22 (0.12)	1.71 (0.72)	-0.15 (0.09)	-2.28 (0.93)	0.15 (0.08)	
66	332.12 (167.56)	-0.51 (0.40)	-3.08 (2.16)	-0.75 (0.41)	0.43 (0.25)	-0.04 (0.63)	-0.15 (0.13)			-2.06 (0.99)	0.12 (0.09)	-0.45 (0.17)

TABLE 10.5. Extended

$TOWER_{500}$	$POWER_{50}$	AG_d^e	$WELL_{50}$	RD_{1km}	SAND	$SAND^{2f}$	$SOIL_{cm}$	LL	K	AIC	ΔAIC	$\sum w_i$
17.04 (6.52)	3.33 (1.30)		24.96 (30.50)	2.60 (1.07)			0.01 (0.02)	-250.66	14	536.11	4.27	0.696
	3.24 (1.51)		27.06 (31.29)	3.29 (1.41)	0.19 (0.12)	-0.27 (0.18)		-249.67	15	536.23	4.29	0.704
	3.21 (1.39)	-1.02 (0.82)	25.57 (30.29)	3.13 (1.32)	0.18 (0.10)	-0.27 (0.15)		-248.68	16	536.35	4.32	0.712
	3.04 (1.35)		23.45 (28.58)	3.05 (1.24)	0.26 (0.12)	-0.39 (0.18)	0.02 (0.01)	-250.72	14	536.23	4.39	0.719
	3.16 (1.34)		25.79 (31.21)	3.24 (1.27)	0.24 (0.13)	-0.37 (0.20)	0.03 (0.02)	-248.73	16	536.45	4.41	0.727
16.98 (6.52)	3.43 (1.29)		25.44 (31.25)	2.78 (1.22)	0.15 (0.10)	-0.24 (0.15)		-249.75	15	536.39	4.45	0.734
15.74 (7.95)	2.98 (1.39)	-0.72 (0.62)	26.59 (30.45)	2.76 (1.18)			0.02 (0.01)	-250.84	14	536.48	4.64	0.741
15.21 (7.47)			25.07 (30.29)	2.46 (1.11)	0.21 (0.13)	-0.35 (0.20)	0.03 (0.02)	-249.10	16	537.19	5.16	0.746
	2.99 (1.40)	-0.89 (0.66)	23.54 (23.93)	3.14 (1.20)	0.30 (0.16)	-0.44 (0.22)	0.02 (0.01)	-250.11	15	537.10	5.16	0.751
	3.09 (1.28)		21.41 (24.77)	3.16 (1.21)	0.21 (0.13)	-0.30 (0.18)		-252.11	13	536.92	5.17	0.756
17.00 (9.02)		-0.88 (0.57)	23.52 (27.37)	2.40 (1.00)	0.23 (0.13)	-0.37 (0.19)	0.03 (0.01)	-250.14	15	537.18	5.24	0.761
	3.04 (1.28)	-0.88 (0.67)	28.37 (31.06)	2.83 (1.16)			0.01 (0.01)	-250.15	15	537.18	5.25	0.766
16.04 (8.07)		-0.87 (0.58)	28.83 (30.97)	2.33 (1.08)			0.01 (0.02)	-250.19	15	537.26	5.32	0.771
	3.12 (1.33)		28.44 (30.13)	2.90 (1.12)			0.01 (0.02)	-251.20	14	537.20	5.36	0.776
15.66 (7.64)			23.75 (29.06)	2.40 (1.13)	0.20 (0.12)	-0.32 (0.18)	0.03 (0.01)	-251.22	14	537.23	5.39	0.780
15.42 (8.05)		-0.93 (0.61)	24.99 (30.08)	2.35 (1.12)	0.16 (0.11)	-0.24 (0.16)		-249.22	16	537.43	5.40	0.785
19.88 (7.65)	2.82 (1.21)	-0.86 (0.58)	30.98 (31.03)		0.19 (0.12)	-0.28 (0.17)		-249.27	16	537.53	5.50	0.789
17.73 (6.79)	3.29 (1.26)	-0.95 (0.77)	24.18 (25.91)	3.14 (1.16)	0.39 (0.17)	-0.60 (0.26)	0.03 (0.01)	-250.29	15	537.47	5.54	0.793
21.72 (9.46)	2.73 (1.29)		32.81 (32.58)		0.33 (0.24)	-0.52 (0.36)	0.04 (0.02)	-249.32	16	537.62	5.58	0.798
16.11 (7.61)		-1.18 (0.61)	20.09 (22.28)	2.51 (1.06)	0.24 (0.13)	-0.39 (0.20)	0.04 (0.02)	-249.34	16	537.66	5.63	0.802
19.56 (7.28)	2.74 (1.28)	-0.80 (0.56)	33.50 (31.14)				0.01 (0.02)	-250.36	15	537.61	5.68	0.806
19.08 (7.03)	2.92 (1.26)		32.05 (30.13)				0.00 (0.02)	-251.37	14	537.53	5.69	0.810
	3.05 (1.37)		23.55 (28.71)	3.12 (1.17)				-254.40	11	537.34	5.75	0.813
15.75 (7.74)			29.47 (30.23)	2.34 (1.04)			0.01 (0.02)	-251.42	14	537.63	5.79	0.817
20.18 (7.57)	2.94 (1.18)		31.32 (30.81)		0.19 (0.16)	-0.28 (0.23)		-250.44	15	537.77	5.84	0.821
	3.18 (1.41)	-1.28 (0.64)	23.13 (25.73)	3.18 (1.24)	0.28 (0.14)	-0.44 (0.22)	0.04 (0.03)	-249.50	16	537.99	5.96	0.824
17.92 (7.02)	3.08 (1.52)	-1.08 (0.65)	27.10 (32.39)	2.61 (1.12)	0.23 (0.12)	-0.41 (0.19)		-250.58	15	538.05	6.12	0.827
	3.02 (1.31)	-0.84 (0.64)	21.50 (20.90)	3.17 (1.21)	0.23 (0.13)	-0.33 (0.19)		-251.58	14	537.96	6.12	0.831
20.37 (7.30)	3.04 (1.27)	-1.05 (0.64)	28.68 (30.68)					-252.59	13	537.88	6.12	0.834
19.30 (6.82)	3.41 (1.36)		25.68 (29.95)	3.42 (1.23)	0.30 (0.13)	-0.49 (0.20)	0.03 (0.01)	-251.63	14	538.06	6.22	0.837
15.37 (8.01)			26.86 (30.46)	2.41 (1.07)	0.15 (0.11)	-0.22 (0.16)		-250.64	15	538.16	6.23	0.840
18.32 (6.88)	3.20 (1.80)		28.19 (32.73)	2.87 (1.32)	0.22 (0.13)	-0.39 (0.20)		-251.66	14	538.12	6.28	0.843
19.76 (7.52)	2.78 (1.23)	-1.05 (0.68)	25.03 (29.67)		0.26 (0.14)	-0.43 (0.22)	0.03 (0.02)	-249.71	16	538.40	6.37	0.846
16.97 (7.58)		-1.09 (0.63)	24.94 (30.01)	2.36 (1.05)				-252.75	13	538.21	6.45	0.848
	2.97 (1.35)	-0.65 (0.60)	23.38 (28.24)	2.98 (1.15)				-253.75	12	538.13	6.45	0.851

TABLE 10.5. Continued

Rank	Intercept	SAGE	NDVI	SOLR[b]	$SOLR^{2c}$	Tmin	$Tmin^2$	SALIN	$SALIN^2$	AWC	AWC^2	$RAIL_d^e$
67	390.66 (173.78)	-0.57 (0.36)	-3.77 (2.00)	-0.93 (0.42)	0.55 (0.26)	0.16 (0.50)	-0.16 (0.12)	1.42 (0.55)	-0.11 (0.06)			-0.29 (0.13)
68	391.64 (166.02)	-0.39 (0.37)	-1.91 (2.14)	-0.92 (0.40)	0.53 (0.24)	-0.58 (0.56)	-0.29 (0.14)	1.41 (0.62)	-0.11 (0.07)	-2.40 (1.12)	0.15 (0.09)	
69	439.25 (181.61)	-0.57 (0.36)	-3.40 (2.02)	-1.04 (0.44)	0.61 (0.27)	0.17 (0.49)	-0.16 (0.12)	1.31 (0.55)	-0.09 (0.06)			-0.29 (0.14)
70	416.03 (159.99)	-0.44 (0.38)	-1.80 (2.17)	-0.97 (0.39)	0.56 (0.24)	-0.43 (0.57)	-0.25 (0.12)	1.93 (0.77)	-0.18 (0.09)	-2.73 (1.00)	0.18 (0.08)	
71	465.37 (163.73)	-0.68 (0.35)	-0.84 (1.73)	-1.08 (0.39)	0.62 (0.24)	0.45 (0.43)	-0.18 (0.10)			-1.99 (0.83)	0.09 (0.06)	-0.37 (0.13)
72	381.32 (163.33)	-0.46 (0.36)	-2.73 (1.91)	-0.87 (0.40)	0.50 (0.24)	0.19 (0.60)	-0.11 (0.12)			-1.71 (0.88)	0.10 (0.07)	-0.46 (0.18)
73	384.17 (155.34)	-0.61 (0.35)	-0.11 (2.29)	-0.89 (0.38)	0.51 (0.23)	-0.14 (0.66)	-0.20 (0.13)	1.97 (0.94)	-0.18 (0.12)	-1.97 (1.08)	0.12 (0.09)	
74	393.17 (156.95)	-0.52 (0.35)	-1.39 (2.27)	-0.91 (0.38)	0.53 (0.23)	-0.02 (0.50)	-0.18 (0.11)	1.38 (0.59)	-0.11 (0.07)	-2.14 (0.82)	0.15 (0.07)	-0.39 (0.16)
75	352.85 (162.90)	-0.52 (0.38)	-2.31 (2.60)	-0.81 (0.39)	0.47 (0.24)	-0.23 (0.55)	-0.20 (0.13)	1.32 (0.64)	-0.12 (0.08)	-2.26 (0.94)	0.15 (0.08)	-0.40 (0.16)
76	416.83 (164.94)	-0.64 (0.36)	-1.28 (1.89)	-0.97 (0.40)	0.56 (0.24)	0.45 (0.43)	-0.17 (0.10)			-1.91 (0.82)	0.09 (0.06)	-0.37 (0.13)
77	355.71 (158.71)	-0.52 (0.38)	-2.42 (2.04)	-0.80 (0.38)	0.46 (0.23)	-0.01 (0.60)	-0.15 (0.13)			-2.18 (1.06)	0.12 (0.08)	-0.46 (0.16)
78	385.37 (159.48)	-0.45 (0.36)	-3.52 (2.07)	-0.88 (0.39)	0.51 (0.23)	0.21 (0.59)	-0.12 (0.11)			-1.88 (0.88)	0.11 (0.07)	-0.42 (0.14)
79	413.35 (163.47)	-0.54 (0.35)	-0.92 (2.52)	-0.95 (0.39)	0.55 (0.24)	0.01 (0.54)	-0.17 (0.12)	1.19 (0.61)	-0.09 (0.07)	-2.06 (0.99)	0.14 (0.09)	-0.41 (0.17)
80	450.57 (198.69)	-0.51 (0.36)	-3.44 (2.06)	-1.08 (0.48)	0.64 (0.29)	0.27 (0.51)	-0.16 (0.16)	1.48 (0.57)	-0.12 (0.07)			-0.29 (0.12)
81	349.48 (151)	-0.57 (0.35)	-1.03 (2.25)	-0.82 (0.37)	0.47 (0.22)	-0.24 (0.53)	-0.22 (0.13)	1.67 (0.64)	-0.14 (0.08)	-1.59 (0.94)	0.09 (0.08)	
82	370.37 (176.29)	-0.58 (0.37)	-3.95 (2.05)	-0.89 (0.43)	0.53 (0.26)	0.25 (0.52)	-0.15 (0.14)	1.54 (0.57)	-0.14 (0.07)			-0.29 (0.13)
83	385.24 (169.61)	-0.56 (0.36)	-1.14 (3.60)	-0.88 (0.41)	0.51 (0.25)	-0.02 (0.54)	-0.17 (0.12)	1.22 (0.64)	-0.10 (0.07)	-2.32 (1.87)	0.15 (0.17)	-0.45 (0.18)
84	373.16 (163.09)	-0.47 (0.37)	-1.52 (2.69)	-0.86 (0.39)	0.50 (0.24)	-0.15 (0.56)	-0.17 (0.13)	1.18 (0.63)	-0.10 (0.07)	-2.14 (1.07)	0.14 (0.09)	-0.42 (0.16)
85	430.90 (161.21)	-0.47 (0.37)	-1.04 (2.09)	-1.00 (0.39)	0.58 (0.24)	-0.33 (0.60)	-0.23 (0.12)	1.74 (0.69)	-0.16 (0.08)	-2.56 (1.08)	0.16 (0.09)	
86	382.35 (171.29)	-0.57 (0.36)	-2.99 (2.65)	-0.88 (0.42)	0.51 (0.25)	0.36 (0.65)	-0.10 (0.15)			-1.19 (0.89)	0.05 (0.07)	-0.44 (0.20)
87	356.24 (164.11)	-0.47 (0.36)	-2.41 (2.17)	-0.82 (0.40)	0.47 (0.24)	0.16 (0.58)	-0.11 (0.12)			-1.42 (0.96)	0.08 (0.08)	-0.43 (0.18)
88	327.73 (158.33)	-0.52 (0.36)	-2.39 (2.22)	-0.77 (0.38)	0.44 (0.23)	-0.22 (0.58)	-0.22 (0.13)	1.38 (0.59)	-0.17 (0.08)	-1.90 (0.89)	0.09 (0.08)	-0.36 (0.16)
89	392.72 (158.97)	-0.47 (0.36)	-2.34 (1.94)	-0.90 (0.38)	0.52 (0.23)	0.20 (0.57)	-0.12 (0.12)			-1.95 (0.88)	0.10 (0.07)	-0.46 (0.18)
90	332.14 (159.08)	-0.49 (0.37)	-2.69 (2.49)	-0.76 (0.39)	0.44 (0.23)	0.08 (0.60)	-0.14 (0.13)			-1.57 (0.93)	0.09 (0.08)	-0.41 (0.15)
91	395.74 (153.97)	-0.40 (0.36)	-2.22 (2.19)	-0.93 (0.37)	0.54 (0.23)	-0.33 (0.55)	-0.23 (0.12)	1.42 (0.61)	-0.11 (0.07)	-1.86 (0.99)	0.12 (0.08)	
92	345.55 (152.60)	-0.52 (0.38)	-1.54 (2.22)	-0.81 (0.37)	0.47 (0.22)	0.10 (0.52)	-0.16 (0.12)	1.49 (0.63)	-0.17 (0.09)	-1.77 (0.93)	0.08 (0.08)	-0.32 (0.15)
93	372.30 (154.57)	-0.58 (0.35)	-1.06 (2.22)	-0.86 (0.38)	0.50 (0.23)	-0.16 (0.56)	-0.21 (0.12)	1.95 (0.77)	-0.18 (0.10)	-2.14 (1.03)	0.13 (0.09)	

[a] See Appendix 10.1 for variable definitions

[b] Coefficients and standard errors multiplied by 10^3

[c] Coefficients and standard errors multiplied by 10^9

[e] Coefficients and standard errors multiplied by 10^4

[f] Coefficients and standard errors multiplied by 10^2

TABLE 10.5. Extended

$TOWER_{500}$	$POWER_{50}$	AG_d^e	$WELL_{50}$	RD_{1km}	SAND	$SAND^{2f}$	$SOIL_{cm}$	LL	K	AIC	ΔAIC	$\sum w_i$
17.75 (7.50)	3.24 (1.43)	-0.72 (0.54)	30.34 (31.66)	2.43 (1.05)			-0.03 (0.01)	-251.75	14	538.30	6.46	0.854
	3.27 (1.37)	-1.26 (0.65)	24.62 (29.71)	3.15 (1.27)	0.20 (0.11)	-0.31 (0.17)		-250.77	15	538.43	6.50	0.856
18.39 (7.32)	3.42 (1.43)		31.45 (31.50)	2.67 (1.15)			-0.03 (0.01)	-252.79	13	538.29	6.54	0.859
	3.29 (1.37)	-1.07 (0.65)	25.78 (30.14)	2.90 (1.16)				-252.80	13	538.30	6.54	0.862
27.26 (8.11)	3.07 (1.23)		36.40 (37.94)		0.35 (0.12)	-0.54 (0.19)	0.03 (0.01)	-251.94	14	538.67	6.83	0.864
14.99 (7.86)			24.54 (29.03)	2.44 (1.07)				-254.98	11	538.50	6.91	0.866
20.92 (7.69)	3.24 (1.34)		27.64 (31.50)					-253.99	12	538.60	6.93	0.868
19.30 (7.49)		-0.84 (0.55)	33.68 (31.68)					-253.02	13	538.74	6.99	0.87
		-0.91 (0.61)	26.93 (30.83)	2.57 (1.11)				-253.11	13	538.92	7.17	0.872
26.39 (8.60)	2.88 (1.24)	-0.53 (0.56)	34.65 (37.52)		0.33 (0.13)	-0.52 (0.20)	0.03 (0.01)	-251.13	15	539.14	7.20	0.874
	3.08 (1.42)		24.99 (29.49)	3.16 (1.27)			0.01 (0.01)	-254.15	12	538.92	7.25	0.876
15.72 (8.18)		-0.76 (0.54)	24.29 (29.19)	2.42 (1.00)				-254.17	12	538.95	7.28	0.877
18.93 (7.24)			33.74 (31.31)					-254.18	12	538.97	7.30	0.879
18.12 (7.03)	3.31 (1.60)		30.72 (33.61)	2.94 (1.18)	0.16 (0.11)	-0.28 (0.18)	-0.02 (0.01)	-251.2	15	539.29	7.36	0.881
20.74 (7.42)	3.12 (1.28)	-1.15 (0.71)	27.69 (31.28)		0.17 (0.11)	-0.27 (0.16)		-251.24	15	539.37	7.44	0.883
17.48 (7.14)	3.21 (1.68)	-0.98 (0.59)	27.98 (32.53)	2.67 (1.06)	0.18 (0.12)	-0.31 (0.19)	-0.01 (0.01)	-250.26	16	539.50	7.46	0.884
	2.81 (1.20)		32.37 (31.20)					-254.33	12	539.27	7.60	0.886
			27.15 (30.24)	2.56 (1.07)				-254.34	12	539.29	7.62	0.887
	3.40 (1.29)		25.82 (30.20)	2.75 (1.26)				-254.34	12	539.31	7.64	0.889
18.25 (7.00)	3.14 (1.29)		25.79 (30.92)		0.22 (0.12)	-0.32 (0.17)		-253.35	13	539.40	7.65	0.890
14.30 (7.61)			21.84 (27.49)	2.52 (1.10)	0.12 (0.10)	-0.19 (0.14)		-253.35	13	539.41	7.65	0.892
		-1.10 (0.63)	23.58 (26.53)	2.97 (1.20)	0.24 (0.12)	-0.39 (0.19)	0.03 (0.02)	-250.36	16	539.70	7.66	0.893
15.72 (7.95)			26.31 (29.32)	2.48 (1.07)			0.01 (0.01)	-254.36	12	539.34	7.67	0.895
15.17 (8.27)		-0.94 (0.64)	22.27 (25.01)	2.58 (1.05)	0.16 (0.12)	-0.25 (0.18)		-252.36	14	539.51	7.67	0.896
16.39 (7.79)		-1.23 (0.64)	22.93 (28.20)	2.60 (1.13)	0.17 (0.11)	-0.27 (0.16)		-251.37	15	539.63	7.69	0.898
18.42 (7.05)		-0.94 (0.59)	27.73 (30.86)		0.24 (0.14)	-0.38 (0.22)	0.04 (0.02)	-250.39	16	539.76	7.73	0.899
20.36 (7.33)	3.01 (1.28)	-1.04 (0.64)	28.81 (30.62)				0 .00 (0.02)	-252.45	14	539.69	7.85	0.900

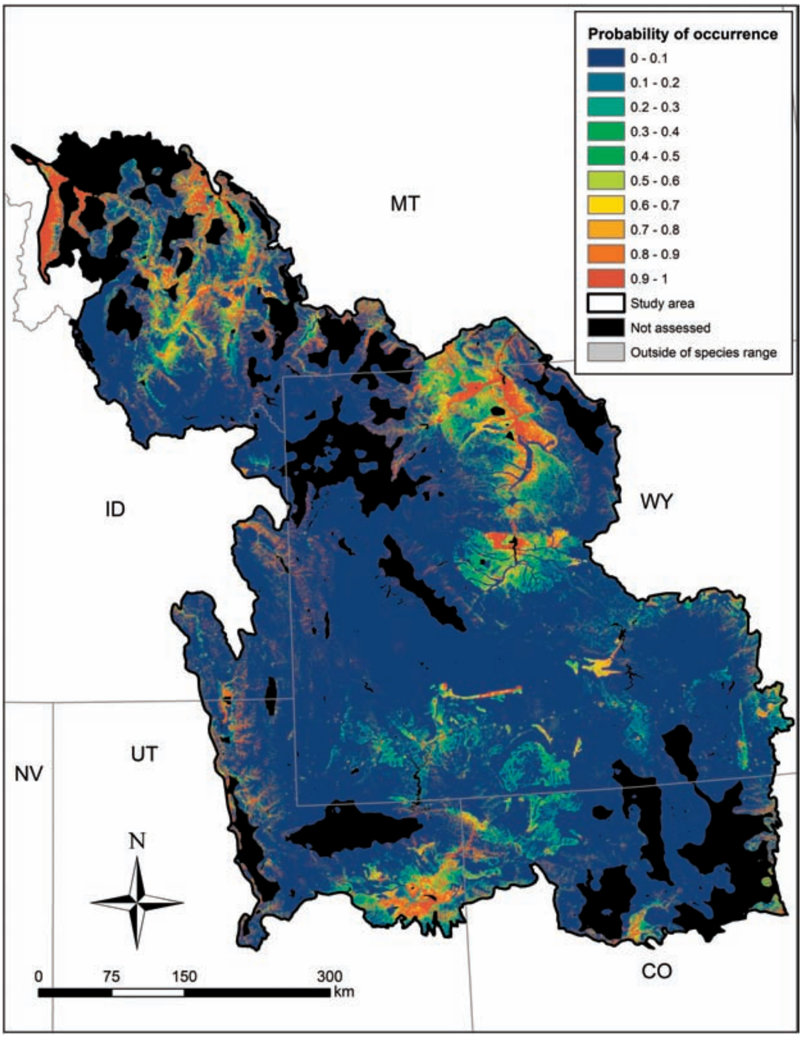

FIG. 10.5. Predicted probability of occurrence for halogeton in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

DISCUSSION

Fragmentation of sagebrush by anthropogenic disturbance, particularly major roads and energy wells, increased the occurrence of the four most common invasive plants in the Wyoming Basins: crested wheatgrass, cheatgrass, halogeton, and Russian thistle. Although the positive association between anthropogenic disturbance and non-native invasive plants was common across all species examined, the shape of the response to individual anthropogenic disturbances (i.e., the dose-response) varied among species. Response shapes were often non-linear and dependent on distance from disturbance type and species and limited by abiotic environments of climate, soils, and terrain. Anthropogenic factors that influenced non-native species occurrence included major roads, secondary roads, all road types, energy wells, railroads, agricultural areas, pipelines, power lines, transmission towers, and populated places. Crested wheatgrass and Russian thistle showed the strongest association with anthropogenic

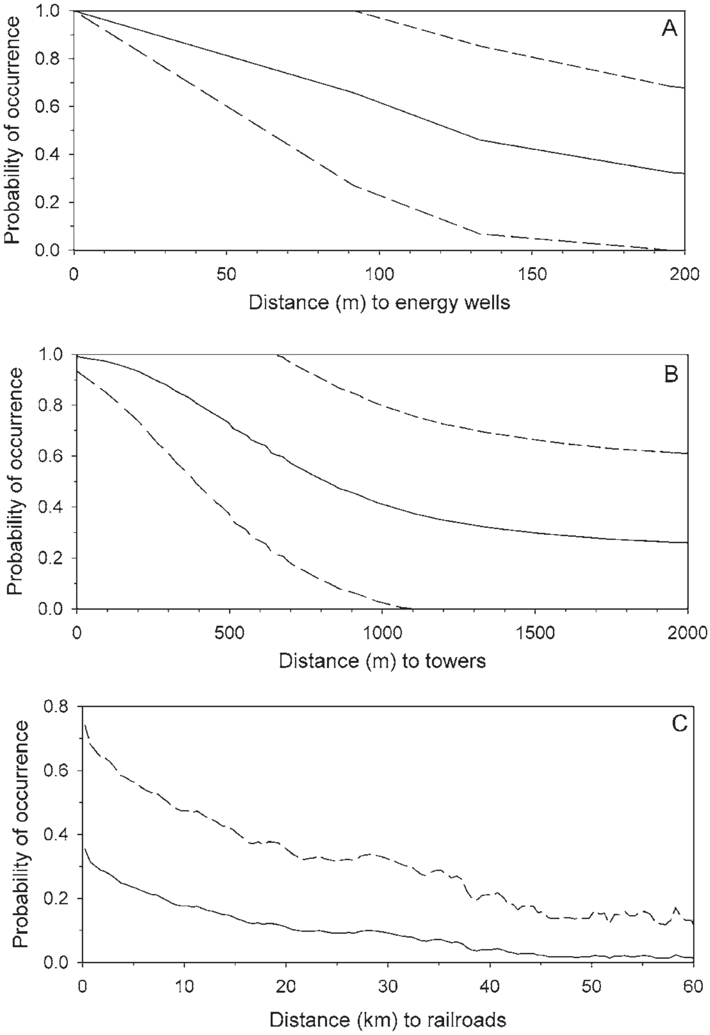

FIG. 10.6. Dose-response curves illustrating mean predicted probability of occurrence (±1 SD) of halogeton across the Wyoming Basins Ecoregional Assessment area as a function of distance from anthropogenic feature types of energy wells (A), towers (B), and railroads (C).

disturbances, particularly major roads and energy wells, which were included and among the strongest anthropogenic factors in all four invasive species models. Crested wheatgrass was often planted by management agencies to reduce erosion (Lorenz 1986, Lesica and DeLuca 1996). Thus, the distribution of this species likely reflects the location of those past activities. Crested wheatgrass has been one of the most commonly planted non-native grasses in western North America occupying between 6 and 10.5 million hectares (Holchek 1981, Rogler and Lorenz 1983). Several million hectares of crested wheatgrass were planted on idle farmland as part of the Conservation Reserve Program (Lesica and DeLuca 1996). The success of crested wheatgrass is due in part to its wide adaptability to different soil types and cold tolerance (Lesica and DeLuca 1996). Unlike the prior two species, cheatgrass and halogeton were predicted to occur across a much wider area of the Wyoming Basins, and thus appear to be limited by either abiotic environments or alternatively, biotic mechanisms associated

TABLE 10.6. Russian thistle random-effects logistic regression model[a] parameter estimates (beta [SE]), model log-likelihood (LL), number of parameters (K), Akaike's Information Criterion (AIC), change in AIC value from the top model (ΔAIC), and Akaike weight (w_i) for all candidate models in the Wyoming Basins Ecoregional Assessment area where Akaike weights sum to just ≥ 0.9. Superscript numbers reflect quadratic terms, while subscript numbers for anthropogenic and water variables represent the distance parameter value of the exponential distance decay function used to scale distance effects. Anthropogenic terms ending in the subscript letter "d" reflect Euclidian distance variables rather than distance decay functions.

Rank	Intercept	NDVI	NDVI^2	SOLR[b]	pH2Od$_{1km}$	POP$_d$[b]	2RD$_{250}$	WELL$_{1km}$	MjRD$_{500}$
1	29.71 (6.45)	3.98 (3.60)	-10.44 (7.25)	-0.04 (0.01)	-3.29 (1.53)	-0.08 (0.03)	2.76 (0.68)	3.47 (1.12)	3.35 (0.98)
2	27.66 (6.43)	1.57 (3.55)	-12.11 (8.31)	-0.04 (0.01)		-0.09 (0.03)	2.74 (0.69)	3.36 (1.15)	3.46 (1.01)
3	26.79 (6.47)	1.81 (3.56)	-11.72 (8.24)	-0.04 (0.01)		-0.09 (0.03)	2.77 (0.69)	3.19 (1.16)	3.07 (1.06)
4	30.71 (6.59)	4.68 (3.59)	-9.70 (7.24)	-0.04 (0.01)	-4.37 (1.60)		2.76 (0.68)	4.23 (1.16)	3.24 (1.00)
5	30.99 (6.62)	3.21 (3.55)	-18.43 (8.21)	-0.04 (0.01)		-0.12 (0.03)	2.64 (0.67)		2.88 (0.97)
6	25.88 (7.91)	0.87 (3.44)	-12.10 (7.53)	-0.04 (0.01)		-0.10 (0.03)	2.92 (0.68)		3.47 (1.00)
7	33.03 (6.56)	6.12 (3.56)	-11.68 (7.54)	-0.05 (0.01)	-3.86 (1.53)		2.75 (0.67)	4.08 (1.14)	3.53 (0.99)
8	27.35 (6.54)	1.37 (3.63)	-11.90 (8.34)	-0.04 (0.01)		-0.09 (0.03)	2.73 (0.69)	3.40 (1.16)	3.43 (1.02)
9	31.98 (6.62)	6.16 (3.57)	-11.42 (7.50)	-0.05 (0.01)	-3.64 (1.54)		2.77 (0.68)	3.90 (1.15)	3.16 (1.04)
10	34.21 (7.75)	6.00 (3.45)	-13.87 (7.06)	-0.05 (0.01)	-3.74 (1.44)		2.92 (0.66)		3.48 (0.96)
11	31.24 (6.53)	3.60 (3.54)	-17.26 (8.08)	-0.04 (0.01)		-0.11 (0.03)	2.24 (0.64)	2.56 (1.07)	
12	28.81 (6.49)	3.98 (3.53)	-18.11 (8.08)	-0.03 (0.01)		-0.11 (0.03)	2.41 (0.65)		
13	22.37 (7.71)	1.34 (3.39)	-10.36 (7.18)	-0.03 (0.01)		-0.09 (0.03)	2.66 (0.65)		

[a] See Appendix 10.1 for variable definitions

[b] Coefficients and standard errors multiplied by 10^3

with dispersal capabilities and competition (thus a much more diffuse distribution from anthropogenic disturbances).

The shape of the response to anthropogenic disturbances (distances) varied substantially among species and disturbance types, showing local (<100 m) to meso-scale (100 m to 1 km) associations, such as energy wells and major roads respectively, to more macro-scale (>1 km) associations, particularly railroads and agricultural disturbances. In general, energy wells illustrated very strong local effects, roads and other linear features showed strong meso-scale effects, and agriculture and railroads displayed weaker macro-scale responses. The more local effects of energy wells may be simply an artifact of being a relatively young disturbance compared to other disturbance types. The zone of influence around energy wells may expand with time.

Similar to the results of our study, Bergquist et al. (2007) found in the Powder River Basin of Wyoming that non-native invasive plant occurrence varied based on the type of disturbance (coal bed methane developments), although they did not examine the zone (distance) of influence around individual disturbance types or make spatially explicit predictions of the overall landscape effect. Comparing the results of our analysis of non-native invasive species in the WBEA area (using much larger-sized quadrats at 1,257 m^2) to the Powder River Basin work (1-m^2 quadrats) by Bergquist et al. (2007), halogeton was much rarer in the Powder River Basin, while the overall occurrence of both crested wheatgrass and Russian thistle were similar among study areas. Cheatgrass was much more common in the Powder River Basin, being found in approximately 60% of sampled 1-m^2 quadrats, while frequency of occurrence in the

TABLE 10.6. Extended

PIPE$_{250}$	CLAY	CLAY^2	Tmin	Tmin^2	AG$_d$^{b}	LL	K	AIC	ΔAIC	Σw_i
						-211.33	10	442.95	0.00	0.462
						-214.06	9	446.34	3.44	0.545
1.30 (0.97)						-213.18	10	446.63	3.69	0.618
					-0.09 (0.05)	-213.43	10	447.14	4.20	0.675
	-0.45 (0.14)	0.012 (0.004)				-213.59	10	447.46	4.52	0.723
			0.90 (0.45)	0.16 (0.06)		-213.85	10	447.98	5.04	0.760
						-214.87	9	447.96	5.07	0.797
					-0.01 (0.05)	-214.03	10	448.33	5.39	0.828
1.22 (0.95)						-214.06	10	448.40	5.46	0.858
			0.72 (0.43)	0.16 (0.06)		-215.06	10	450.41	7.46	0.869
	-0.43 (0.14)	0.012 (0.004)				-215.09	10	450.46	7.52	0.880
2.15 (0.88)	-0.44 (0.14)	0.012 (0.004)				-215.15	10	450.58	7.63	0.890
2.87 (0.91)			0.96 (0.44)	0.17 (0.06)		-215.15	10	450.59	7.64	0.900

WBEA quadrats was only 13.5%, despite the larger size of our plots. This difference may reflect the study extent of the Powder River Basin work, which at the regional scale occurs in optimal climates for cheatgrass, consistent with our model predictions. Our predictions of cheatgrass occurrence were also similar to those estimated using bioclimatic envelopes by Bradley (2009), even though we used only one climate variable – mean annual minimum temperature. However, in both cases cheatgrass appears to be limited by cold temperatures (winter or annual temporal scale). We also used additional environmental habitat predictors, including remotely-sensed vegetation productivity (found most commonly in intermediate areas of NDVI) and terrain-based solar radiation (found most commonly in sites having intermediate amounts of summertime solar radiation). Both NDVI and solar radiation are likely to be correlated with other climate variables, including those used by Bradley (2009). Without further experiments it is not possible to distinguish which factors are more important or what specific factors (physiological limitations, competition effects, etc.) limit the distribution of cheatgrass.

CONCLUSIONS

Distribution maps and dose-response predictions for four major non-native invasive plants offer an important regional management and planning tool for stakeholders and management agencies interested in controlling invasive plants. Knowledge about the current distribution and potential risk of further developments can help target implementation of management actions and effectiveness monitoring, improve assessments of the long-term spread of invasive species,

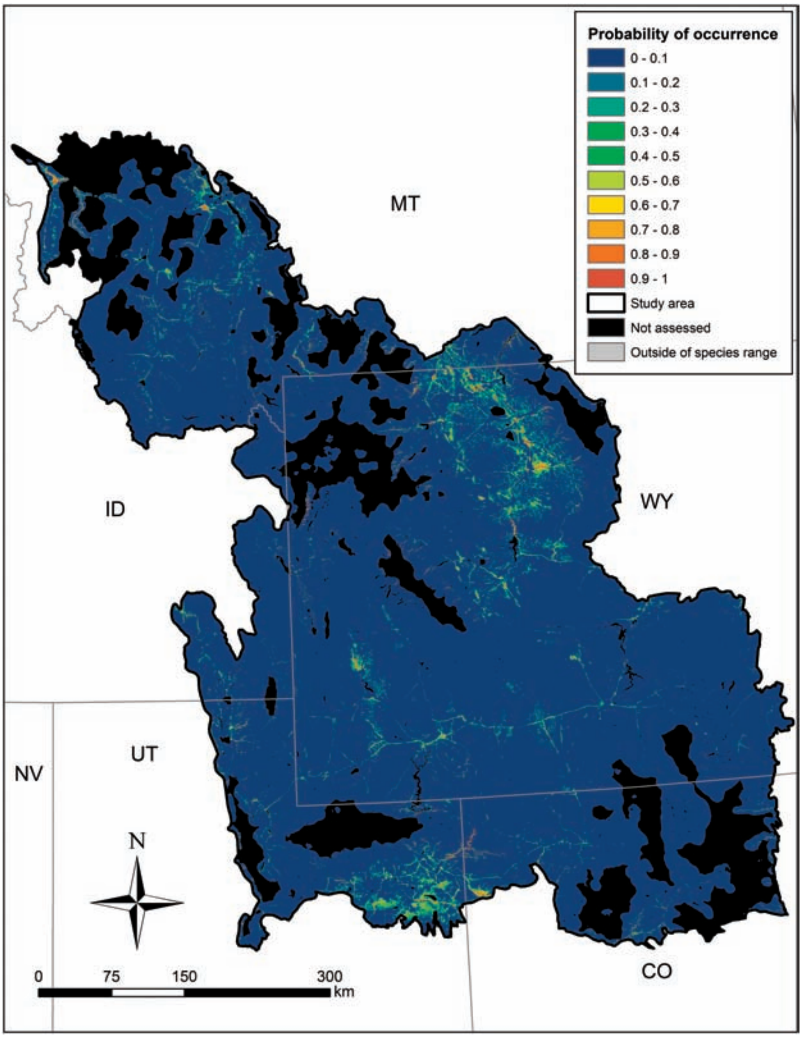

FIG 10.7. Predicted probability of occurrence for Russian thistle in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

and identify areas of sagebrush habitat relatively free from invasive species problems for conservation purposes. Future research should evaluate establishment rates around energy wells and new roads for common invasive plants in the WBEA area, with sites sampled (stratified) by age of disturbance. Such information could be used to predict future threats (growth) associated with energy development within the WBEA area and where invasive species control measures may be most needed.

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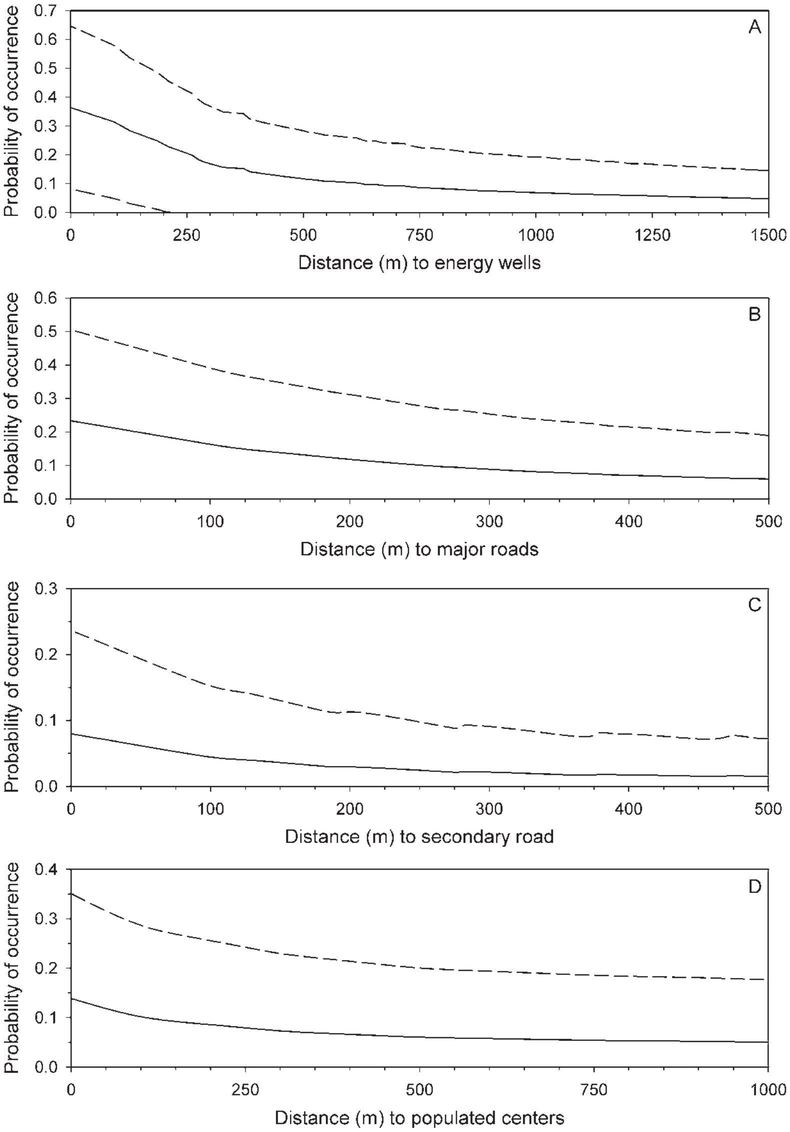

FIG. 10.8. Dose-response curves illustrating mean predicted probability of occurrence of Russian thistle across the Wyoming Basins Ecoregional Assessment area as a function of distance from anthropogenic feature. Dose-response curves illustrating mean predicted probability of occurrence (±1 SD) of Russian thistle across the Wyoming Basins as a function of distance from anthropogenic feature types of energy wells (A), major roads (B), secondary roads (C), and populated centers (D).

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APPENDIX 10.1. Variable descriptions and summary statistics from field plots in the Wyoming Basins Ecoregional Assessment area.

Variable			*Summary statistics*			
Group	Code	Description	x̄	SD	Min	Max
A. Habitat and survey design factors						
	NDVI	Maximum Natural Difference Vegetation Index (vegetation productivity) from MODIS sensor (Carroll et al. 2006)	0.13	0.22	-0.26	1.10
	SAGE	Sagebrush presence/absence	0.79	0.41	0.0	1.0
B. Abiotic factors						
	TRI	Terrain Ruggedness Index (Riley et al. 1999)	20.7	21.1	0.0	154.0

APPENDIX 10.1 Continued

Variable			*Summary statistics*			
Group	Code	Description	$\bar{x}$	SD	Min	Max
	TRMI	Topographic Relative Moisture Index (Manis et al. 2001)	15.1	5.6	1.0	27.0
	SOLR[a]	Solar radiation (WH/m^2, May - August) estimated from a DEM	849.2	30.5	733.6	950.7
	Tmin	Mean minimum temperature (°C) of coldest month	-2.9	1.9	-7.4	0.9
	SAND	Percent sand in soils (Miller and White 1998)	39.2	14.7	0.0	88.3
	CLAY	Percent clay in soils (Miller and White 1998)	16.6	7.1	0.0	47.0
	AWC	Available water content (Miller and White 1998)	5.2	1.7	1.5	9.2
	SALIN	Salinity of soils (Miller and White 1998)	2.3	1.6	0.0	9.5
	$SOIL_{cm}$	Soil depth (cm) (Miller and White 1998)	101	29	38	152
	pH2Od	Distance (m) to perennial water source	3,913	3,683	0	20,390
C. Anthropogenic factors						
	RD	Any road type (distance in meters)	481	529	0	3,711
	MjRD	Major roads (distance in meters)	9,048	9,862	0	43,926
	2RD	Secondary roads (distance in meters)	521	546	0	3,711
	RAIL	Railroad (distance in meters)	38,944	24,850	485	107,281
	WELL	Energy well (distance in meters)	10,591	8,647	0	41,180
	TOWER	Tower (distance in meters)	16,124	9,654	371	46,584
	POWER	Power line (distance in meters)	11,316	14,466	0	70,495
	PIPE	Pipeline (distance in meters)	10,856	11,682	0	53,224
	POP	Populated place (distance in meters)	17,320	10,293	180	50,766
	AG	Agriculture (distance in meters)	6,337	6,091	90	29,158

[a] Units are multiplied by 10^{-2}

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Chapter 11: Management Considerations

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Abstract. We conducted an ecoregional assessment of sagebrush (*Artemisia* spp.) ecosystems in the Wyoming Basins and surrounding regions (WBEA) to determine broad-scale species-environmental relationships. Our goal was to assess the potential influence from threats to the sagebrush ecosystem on associated wildlife through the use of spatially explicit occurrence and abundance models. These models were developed using information from field surveys conducted along gradients of vegetation productivity and human disturbance integrated with spatial datasets delineating land cover, topography, and human land use in the WBEA area. Our evaluation included all sagebrush-associated wildlife species across multiple taxa whose habitat requirements and distributions were appropriate for modeling and interpretation at the broad scales of this assessment. Dominant land uses were included in delineating the human footprint. Although overall levels of the cumulative human footprint were generally low across the WBEA area, oil and gas activities have decreased the amount of shrubland habitats and increased fragmentation within development regions over the last century. At the scale of this assessment, the influence of humans was primarily expressed as an indirect function through actions that altered or reduced available habitat. We identified 65 plant species of conservation concern; 28 of 40 vertebrate species associated with sagebrush were species of concern in at least one state. We modeled environmental relationships for 15 wildlife species from data collected from surveys conducted in 2005 and 2006 designed to sample multiple species and taxa along land cover and land use gradients across the WBEA area. Occurrence of 3 species was negatively influenced by human features; anthropogenic features were a positive influence for 3 species, 8 had a mixed response, and 1 had no measureable relationship. Sagebrush land cover, considered in all wildlife models, was important to most species but differed among species in the proportion of sagebrush required and at what spatial extent. For most species examined, the spatial extent at which sagebrush cover influenced the probability of occupancy was much larger than an individual's home range size. Exotic plants were strongly associated with human features, particularly roads, which may function as linear vectors to facilitate spread of exotic plants across the WBEA area. We used coarse-grained spatial and thematic data because of the large spatial extent (350,000 km^2) of the WBEA area and the need for a consistent land cover map for the region. Distributions of species occurrence or abundance mapped in this assessment need to be corroborated with information on population demographics. In addition, our results should be interpreted relative to assumptions inherent in broad-scale ecoregional assessments. Our assessment provides managers with extensive and detailed maps of occurrence and abundance, allowing for status assessments of native species, diversity and richness, natural communities, and ecological systems present within the Wyoming Basins.

Key words: ecoregional assessment, land use, management considerations, sagebrush, species habitat models, Wyoming Basins.

The Wyoming Basins Ecoregional Assessment (WBEA) area encompasses one of the most expansive regions of sagebrush (*Artemisia* spp.) habitats remaining in western North America. Two-thirds of the WBEA area and half of the 131,000 km^2 covered by sagebrush is public land managed for multiple use (Ch. 1). Thus, some of the largest extant populations of sagebrush-obligate species, such as greater sage-grouse (*Centrocercus urophasianus*), Brewer's sparrows (*Spizella breweri*), pygmy rabbit (*Brachylagus idahoensis*), and pronghorn (*Antilocapra americana*), co-occur in areas that also are important for energy development and transmission, livestock grazing, and recreation. As such, management strategies and land use activities within the WBEA area have a substantial effect on a large portion of the range-wide distribution of sagebrush and persistence of many species that depend on these habitats. The WBEA area contains some of the most significant onshore energy resources in the United States (U.S. Departments of the Interior, Agriculture, and Energy 2006, 2008). Oil and natural gas reserves coupled with the potential for wind energy within this region can supply much of the nation's increasing demand for energy (Doherty et al. 2011). Effects of energy development often are quantified for the area immediately surrounding the physical structures associated with development. Individual and combined effects of different disturbance types and intensities on plants and wildlife, cumulatively defined as the human footprint, often are difficult to quantify for a single region. The broad-scale effects created by multiple developments with accompanying infrastructure for energy transmission across large spatial extents are even more difficult to assess. Yet understanding these broad-scale impacts is an important aspect of conservation because of their potential to influence species at a population or range-wide scale (Leu et al. 2008).

Ecoregional assessments consist of a series of spatial analyses conducted in a Geographic Information Systems (GIS) to identify relationships among species distributions and environmental and human features over broad spatial extents spanning regions to continents (Table 11.1). The information derived from these analyses can help address large-scale, range-wide factors likely to affect the well-being of species of concern, guide the development of management plans to reduce further loss or degradation of their habitats, and establish a basis for restoring habitats in the most time- and cost-effective manner possible (Ricketts et al. 1999, Noss et al. 2001, Jones et al. 2004, Wisdom et al. 2005a).

We conducted an ecoregional assessment of the Wyoming Basins and surrounding regions to provide a regional

TABLE 11.1. Primary steps in an ecoregional assessment (Wisdom et al. 2005a).

1. Identify the ecoregion and spatial extent to be included in the analysis
2. Identify the species of conservation concern
3. Determine habitat associations of species
4. Delineate boundaries of the species range and map distribution within the range
5. Identify natural disturbances and human activities
6. Identify potential risks to species or its habitat
7. Map the extent of individual and cumulative risk factors
8. Identify and develop management actions

broad-scale understanding from which local conservation and restoration actions can be designed. Broad-scale information can provide significant regional perspectives to management by land and wildlife agencies. When integrated with an understanding of patterns and processes from other scales of an ecological system's organization, managers have a powerful array of information from which to understand habitat relationships for species of concern and to develop or adapt land use actions that enhance their conservation. Our objectives were to: (1) identify the primary land uses and their potential influence on sagebrush habitats; (2) identify plant and wildlife species of concern; (3) delineate the distribution of sagebrush habitats and environmental and anthropogenic features from existing and updated GIS coverages; (4) conduct field surveys to determine distribution and abundance of wildlife species and invasive plants; (5) integrate field and GIS-based information to determine habitat relationships using spatially explicit models; and (6) apply spatially explicit models of habitat relationships to delineate species occurrence and abundance. Results of our regional assessment thus provide an increased understanding of the dominant distributional patterns and an enhanced insight into the underlying ecological processes that shape sagebrush ecosystems across the WBEA area.

OBJECTIVES

1. Identify the Primary Land Uses and Their Potential Influence on Sagebrush Habitats

The primary threats to the sagebrush steppe ecosystem were: (1) weather, climatic changes, and catastrophes; (2) highways, secondary roads, and trails/two-tracks; (3) improper livestock grazing practices; and (4) oil and natural gas field development (Ch. 1). Sagebrush areas in the Wyoming Basins represent a stronghold compared to current status and predicted changes from land use or climate change for other ecoregions (Aldridge et al. 2008, Knick and Hanser 2011, Wisdom et al. 2011). However, the synergistic effect of human land use and other disturbances, such as invasion of exotic plants, may offset this relative stability. In addition, the overarching long-term impact of climate change further increases the concern for long-term conservation in the WBEA area.

Roads and trails were dominant features in the Wyoming Basins. Secondary roads (21% of the study area using maximum effect zone) and agriculture (7%) were major land-use features covering the WBEA area (Ch. 1, 3). Roads and other anthropogenic features were associated with the presence of four common invasive plant species (Ch. 10). In particular, cheatgrass (*Bromus tectorum*), crested wheatgrass (*Agropyrum cristatum*), and Russian thistle (*Salsola* spp.) were strongly associated with roads and energy well sites. Russian thistle was likely to occur within 0.55 km of interstates and highways, and 1.3 km of oil and gas wells. Crested wheatgrass, a species commonly planted by land management agencies, was likely to occur within 852 m of interstates and highways and 270 m of oil and gas wells (Ch. 10). Roads can function as a conduit for spreading these exotic plants, which increases the effective area of disturbance in addition to the physical habitat displaced by the road surface (Gelbard and Belnap 2003). Cheatgrass invasion and dominance in the sagebrush understory is of particular concern, especially in lower-elevation xeric landscapes, because it increases the probability of large-scale stand-replacing fires that ultimately affect ecosystem composition, structure, and function (Billings 1990, Brooks et al. 1994, Baker 2006, Miller et al. 2011).

Livestock grazing is a dominant land use throughout the WBEA area. Although local influences of livestock grazing have been described (Beck and Mitchell 2000, Jones 2000, Freilich et al. 2003), we lacked suitable information on livestock numbers and distribution to spatially model impacts of grazing on sagebrush landscapes. In the initial phase of this assessment, we contacted all Forest Service and Bureau of Land Management administrative units to obtain spatial data on livestock grazing. No consistent data were available at any jurisdictional level of either agency. Consequently, we could not assess the potential relations of livestock grazing with habitats or occurrence of the species of conservation concern.

Oil and gas extraction influence the landscape and wildlife but is restricted primarily to the Powder River Basin in northeastern Wyoming and southern Montana (outside the boundaries of our assessment), and the Upper Green River Basin in southern and western Wyoming (Ch. 3). Almost 34,000 oil and gas wells have been drilled and 110,000 km of service roads have been constructed in the WBEA area from 1900 to 2009; in designated fields in Wyoming, well pads and associated roads have eliminated an estimated area >200 km^2 of shrubland habitats since 1900 (Ch. 3). In the WBEA area, oil and gas development removed approximately 1,703 km^2 of sagebrush and other native habitats owing to construction of well pads and supporting infrastructure, such as roads, power lines, and pipelines. Shrubland and grassland land cover were most affected; only 3% of land cover conversions were in riparian or forest land cover. Landscapes have become increasingly fragmented due to decreased patch size of sagebrush and increased number of habitat edges associated with the networks of road, power, and transmission infrastructure. The spatially pervasive pattern of oil and gas wells, the substantial loss in habitat resulting from their development, and their effects on adjacent areas indicate that management and mitigation of this land use will have substantial influence on persistence of the suite of species of concern in the WBEA area (Walston et al. 2009, Naugle 2011, Naugle et al. 2011).

The WBEA area had relatively low influence from human activities when mapped at broad spatial scales compared to other western U.S. regions (Leu et al. 2008). Across the western United States, human footprint intensity increased at lower elevations and in regions containing deeper soils (Leu et al. 2008). Areas surrounding cities received the greatest influence from humans; national parks were least influenced. Although most of the WBEA area (81%, including all habitats) had relatively low influence, high footprint scores (indicating localized, high intensity disturbance) were mapped in 5% of the WBEA area.

2. Identify Plant and Wildlife Species of Conservation Concern

Multi-species evaluations, such as those presented in this assessment, are effective in that management activities or conservation reserves may be designed to benefit several species at once, with costs often little more than those associated with managing for single species (Block et al. 1995, Jennings 2000). Management of sagebrush habitats currently is directed towards benefitting greater sage-grouse (Dobkin 1995, Rowland et al. 2006, Doherty et al. 2011, Hanser and Knick 2011). However, an increasing number of sagebrush-obligate species also are experiencing population declines (Dobkin and Sauder 2004). Therefore, a coarse-filter approach, such as used in this assessment, may be required to manage an appropriate amount and arrangement of all representative land areas and habitats that will provide for the needs of the suite of associated species (Groves et al. 2000, Wisdom et al. 2005a). Understanding the range of sagebrush characteristics required by this suite of species is important if this approach is to be successful and to conserve these ecosystems within the WBEA area.

We identified plant and animal species of concern within the WBEA area by reviewing existing literature and state lists of species of concern, and consulting with experts (Ch. 2). Primary criteria for species selection were a strong association with sagebrush ecosystems and a recognized status of conservation concern due to habitat loss or declining populations. We filtered this list by including species having relatively widespread distribution and whose habitats can be mapped accurately at regional scales. Species lists were reviewed by agency and non-governmental biologists. Of 65 plant species of concern, 59 were found in Wyoming, 40 in Colorado, 43 in Utah, 28 in Montana, and 15 in Idaho. We listed 40 species of vertebrate animals that depend on sagebrush habitats for some or all of their annual life cycle, including 1 amphibian, 4 reptiles, 18 birds, and 17 mammals. Twenty-eight of the 40 vertebrate species were listed as a species of concern by at least one state in the WBEA area. The large number of species of concern, and the diverse taxonomic groups represented, suggest that no single species or environmental characteristic can be used to manage lands effectively for all species of concern in the Wyoming Basins. Instead, our results suggest that more comprehensive multi-species approaches will be required for management planning.

Our assessment has improved understanding of environmental relationships for many species across a range of taxa in the WBEA area. Habitat requirements of commodity species (game or furbearer species, such as greater sage-grouse) and species listed under the Endangered Species Act are well understood in comparison to species that have neither commodity nor TE status (Wisdom et al. 2002). Also, our understanding of habitat requirements is better for birds than for mammals and for mammals than reptiles and amphibians (Bonnet et al. 2002, Wisdom et al. 2002, Dobkin and Sauder 2004). Even for birds, the WBEA area is among the areas least consistently sampled among all physiographic provinces (Dobkin and Sauder 2004). Therefore, our spatially explicit models provide new information on habitat relationships and distribution for species of conservation concern within the WBEA area.

3. Delineate the Distribution of Sagebrush Habitats and Environmental and Anthropogenic Features from Existing and Updated GIS Coverages

We used the Existing Vegetation Type map (Landfire 2007) to delineate land cover in the WBEA area. Although we focused on sagebrush, we also included grassland, coniferous forest, mixed shrubland, riparian, and salt-desert shrub land covers. In addition, our set of environmental variables included metrics for vegetation productivity, soil characteristics, terrain-derived variables, distance to water, and climate.

Eleven anthropogenic features were used to model the human footprint in the WBEA area (Ch. 4). A relative ranking based on a linear summation of features was used to delineate the distribution and cumulative intensity of human disturbance. The footprint score summarized the number of human disturbance types but did not account for potential synergistic or threshold effects. We also estimated the distance to anthropogenic features.

Each land cover type, two environmental variables (topographic ruggedness and vegetation productivity), and density of roads, were averaged within a circular window that varied in size corresponding to 7 representative species home ranges (Ch. 4). We calculated landscape metrics (contagion, patch size, edge density) for sagebrush at 3 representative circular window sizes (McGarigal et al. 2002). We also derived non-linear proximity metrics for six anthropogenic features using an exponential decay equation at 5 different distance parameters (Ch. 4, 10). In all, we used 154 predictor variables to develop species-environmental relationships. Consequently, our assessment represented a comprehensive evaluation of the land-cover and land-use variables that influence a broad suite of species associated with sagebrush in the WBEA area.

4. Conduct Field Surveys to Determine Distribution and Abundance of Wildlife Species and Invasive Plants

Ecoregional assessments based on existing data are increasingly used as a cost- and time-effective alternative in conservation and management planning. However, extrapolating statistical functions developed from other regions can limit the effectiveness of this approach because modeled relationships may not be directly transferable and are rarely evaluated with field data collected within the assessment area. Therefore, we conducted field surveys within the WBEA area during 2005 and 2006 to determine species-environmental relationships (Ch. 4). Many of the species-environment associations developed for the WBEA area differed from other regions and emphasized the importance of including field surveys in developing ecoregional assessments. For example, our field surveys documented new occurrences of pygmy rabbits more than 100 km outside their previously known distribution. Species-specific responses to individual environmental variables and maps of occurrence and abundance derived from those relationships would have differed greatly if based on information derived from other regions. Our study presents some of the first empirically-based models of species' relationships to land use measured across a broad spatial extent.

We stratified our field sampling along gradients of NDVI, a productivity index derived from satellite imagery, and human land use (based on a human footprint score) within sagebrush-dominated land cover in the WBEA area. Our survey design addressed multiple criteria:

1. The broad-regional extent of the WBEA encompassed an extremely wide variation in environmental and land use gradients operating at multiple spatial and ecological scales.
2. The list of species of concern included a large number of species and taxa across a broad range of home range sizes and distributions.
3. Survey methods, timing of surveys, and observer ability varied by species.
4. Available funding, personnel, and logistics limited survey effort.

The design was hierarchical and incorporated survey transects and blocks sampled at different spatial scales. Multiple survey methods were employed, and observer expertise was focused to most effectively sample the range of taxa associated with sagebrush habitats. Finally, our design efficiently and effectively focused resources for sampling the WBEA area (Ch. 4).

5. Integrate Field- and GIS-based Information to Determine Habitat Relationships Using Spatially Explicit Models

We determined the habitat associations underlying the mapped distributions of species from field-collected data. We followed a naive approach in the statistical analyses to develop species-environment relationships (Ch. 4). For most species, we lacked knowledge about specific responses to land use or land cover variables and which spatial scales governed the response. We used an Information Theoretic Approach (Burnham and Anderson 2002) to evaluate candidate models in a hierarchical process to identify final models of species-environment relationships having the best fit to the data. We evaluated our results using data available from independent sources, such as Breeding Bird Surveys (Sauer et al. 2008) and lek distributions for greater sage-grouse. Model evaluation is an important step in any model process. However, model evaluation is not often incorporated into ecoregional assessments due to lack of time or independent data. Positive results obtained using independent data strengthens the value of our conclusions. Species responded differently to the broad suite of habitat variables used to develop the models; specific variables and coefficients varied widely among the species.

We constrained the final models to include sagebrush and/or NDVI. Consequently, sagebrush presence within at least one spatial scale of the sampling point was an important factor in predicting presence for most species (Table 11.2). The proportion of the landscape dominated by sagebrush habitats and the spatial scale of the landscape differed among species. The landscape scale that influenced the probability of occurrence was much larger than the size of individual home ranges for all species except pronghorn and greater sage-grouse. For many species, the amount of sagebrush within a 1- and 5-km radius of the survey point had a strong influence on their presence. The landscape surrounding survey points, at the selected scale, had more sagebrush at occurrence locations for all species except deer mouse (*Peromyscus maniculatus*) and least chipmunk (*Tamias minimus*) (Table 11.2). Mean percent sagebrush land cover was >10% higher at occurrence compared to absence sites for 6 of the 15 modeled species. Our modeled outcomes indicate that greater sage-grouse (roost and general use), sage thrasher (*Oreoscoptes montanus*), harvester ant (*Pogonomyrmex* spp.), short-horned lizard (*Phrynosoma hernandesi*), white-tailed jackrabbit (*Lepus townsendii*), cottontail rabbit (*Sylvilagus* spp.), least chipmunk, and pronghorn were likely to occur in landscapes in which >50% of the land cover was dominated by sagebrush (Table 11.2). Therefore, managing to maintain sagebrush as the dominant land cover at large spatial scales (5-km radius = 79 km^2; 18-km radius = 1,018 km^2) will be important to conserving many of these species. Loss of sagebrush habitats below thresholds identified by the dose-response curves because of natural or human-related disturbance likely will have a negative effect on a species.

Response to human features varied by species and spatial scale (Table 11.3). Greater sage-grouse, a candidate species for protection under the Endangered Species Act (U.S. Department of the Interior 2010), was most consistent among species in a negative response to presence of oil and gas wells, interstates/major highways, and power lines (Ch. 5). The proximity to interstates and major highways consistently had an influence at the largest decay distance tested, and five of the six species that responded were negatively affected by these features. Similarly, sage-grouse lek trends across the species range show a negative association with proximity to these features (Johnson et al. 2011). Long-term conservation will require off-site mitigation or offsets if current levels of energy and infrastructure development continue (Kiesecker et al. 2009, Doherty et al. 2011).

Other wildlife species had either mixed or positive responses (Table 11.3), which illustrates the complexity of managing habitats for multiple species. However some of these responses, or lack of response, may have been an artifact of our sampling. A survey design less widely dispersed may be more appropriate for identifying direct influences of human activities that create localized disturbance patterns. At the broad-scale of an ecoregional assessment, changes resulting from human land use may be expressed as altered occupancy/abundance patterns due to habitat loss or altered habitat conditions rather than a specific identified predictor variable. This may be particularly true across the WBEA area, where multiple land uses contribute to a larger cumulative human footprint. Thus, species models to predict occupancy or abundance may reflect measured habitat variables rather than the underlying driver of habitat characteristics.

TABLE 11.2. Summary of sagebrush habitat, scale of influence, and proportion of sagebrush habitat required to support occurrence or abundance of 15 modeled sagebrush associated species. Differences between present/absent survey block locations are shown for each key sagebrush variable. All models also contained other habitat and/or abiotic variables, which are not presented here (see Chapter 5-9). Predicted area in the Wyoming Basins Ecoregional Assessment (WBEA) area indicated the area where a given species is predicted to be present (occurrence models) or be present at the lowest recorded density, based on model defined thresholds.

			Sagebrush					NDVI		Sagebrush/ NDVI interaction
Species	Model type	Predicted area in WBEA km^2 (%)	Variable	Response[a]	Radius km	Threshold proportion needed for occurrence	Difference between presence and absence survey locations %	Response[a]	Radius km	Response
Greater sage-grouse	Roost occurrence	52,979 (32.4)	All sagebrush[b]	+	1	0.88	14.6			
	General use occurrence	63,784 (39.2)	All big sagebrush[c]	+	1	0.81	13.2			
Brewer's sparrow	Abundance	302,891 (87.7)	All big sagebrush	+	1	0	9.3	+/-[d]	0.27	
Green-tailed towhee	Occurrence	230,078 (67.5)	Mountain sagebrush[e]	+	5	0	15.4	+	5	
Lark sparrow	Occurrence/ abundance	209,010 (60.5)	All big sagebrush	-/+	18	0	2.8	+/-	18	
Sage sparrow	Occurrence/ abundance	169,300 (49.0)	All sagebrush	-/-	18	0	6.1	-/+,+/-[d]	18	
Sage thrasher	Occurrence/ abundance	109,054 (31.6)	All big sagebrush	+/+	0.27	0.5	15.8	-/+, -/+[d]	18	
Vesper sparrow	Occurrence/ abundance	292,896 (74.8)	Big sagebrush	+/-	18	0	5.9	+/+	3	-/+
Harvester ant	Occurrence	99,555 (34.4)	All big sagebrush	-	5	>0.63 and <0.75	4.5	-	1	
Thatch ant	Occurrence	201,031 (58.2)	All sagebrush	+	3	0	5.9	+	5	
Short-horned lizard	Occurrence	46,648 (20.6)	All big sagebrush	+	5	0.81	10.7	-	18	

TABLE 11.2. Continued

			Sagebrush					NDVI		Sagebrush/ NDVI interaction
Species	Model type	Predicted area in WBEA km^2 (%)	Variable	Response[a]	Radius km	Threshold proportion needed for occurrence	Difference be- tween presence and absence survey locations %	Response[a]	Radius km	Response
White-tailed jackrabbit	Occurrence	63,890 (22.1)	Big sagebrush[f]	+	0.27	0.82	13.6			
Cottontail rabbit	Occurrence	121,131 (41.9)	All sagebrush	+/-[d]	5	>0.60 and <0.75	1.6	-	5	
Least chipmunk	Occurrence	153,437 (44.4)	Big sagebrush	-	5	<0.60 or >0.91	-9.7			
Pronghorn	Occurrence	9,439 (13.3)	All sagebrush	+	0.27	<0.07 or >0.76	13.3	+	0.27	-
Deer mouse	Occurrence	180,321 (52.5)	All big sagebrush	-	0.27	0.41	-3.5	+/-[d]	270	

[a] Response is dependent on model type: occurrence or abundance models have a single response; occurrence/abundance models have a response for both occurrence and abundance (occurrence/abundance)

[b] All sagebrush: *Artemisia* spp.

[c] All big sagebrush: *A. tridentata* ssp. *tridentata*, *A. t.* ssp. *wyomingensis*, *A. t.* ssp. *vaseyana*

[d] Quadratic form (variable + variable^2): response listed includes both the single and squared term (single/squared)

[e] Mountain big sagebrush: *A. t.* ssp. *vaseyana*

[f] Big sagebrush: *A. t.* ssp. *tridentata*, *A. t.* ssp. *wyomingensis*

TABLE 11.3. Anthropogenic features that influenced species occurrence/abundance for 15 wildlife species modeled within the Wyoming Basins Ecoregional Assessment area and the relationship (+/-) and spatial extent (km) of measured response[a] (Ch. 5-9).

		Anthropogenic features						
		Proximity (km)[b]						Density[c]
Species		Agricultural land	Oil/gas wells	Pipelines	Power lines	Interstate/highways	Secondary roads	All roads
Greater sage-grouse	Roost occurrence		-1		-0.5	-1		
	General use occurrence		-1		-0.5	-1		
Brewer's sparrow	Abundance	+0.25						+18
Green-tailed towhee	Occurrence					-1		
Lark sparrow	Occurrence/abundance	-1/+1	+1/-1					
Sage sparrow	Occurrence/abundance		+0.25/+0.25					+18/-18
Sage thrasher	Occurrence/abundance						-1/+1	
Vesper sparrow	Occurrence/abundance			-1/-1				+3/+3
Harvester ant	Occurrence	+1	-0.25	+1				
Thatch ant	Occurrence	+1	-1		+1	-1		+18km
Short-horned lizard	Occurrence							
White-tailed jackrabbit	Occurrence			+0.5	-0.5	-1		-3
Cottontail rabbit	Occurrence				+1			
Least chipmunk	Occurrence		+0.5	-0.25	+1	+1		
Pronghorn	Occurrence				+1			+5
Deer mouse	Occurrence			-1				

[a] Response is dependent on model type: occurrence or abundance models have a single response; occurrence/abundance models have a response for both occurrence and abundance (occurrence/abundance)

[b] Proximity metrics were calculated as distance decay functions (value = $e^{(\text{Euclidean distance from feature (km)/-distance parameter})}$) using 3 distance parameters (0.25, 0.5, and 1 km). Distance parameters correspond to asymptotic values of 1.2, 2.4, 4.5 km, respectively.

[c] Road density was calculated using 6 moving window radii (0.27, 0.54, 1, 3, 5, 18 km) to model spatial extent

Invasive plant species all had positive relationships with proximity to human features (Table 11.4). The response to human features varied substantially among species and disturbance types. In general, roads and oil/gas wells had local to mid-scale effect zones; railroads, agriculture, and populated areas had large effect zones, possibly as a result of the development history within the WBEA area. Railroads, agriculture, and population centers have been a part of the landscape in the Wyoming Basins since the development of the transcontinental railroad in the late 1800s (Flores 2001), resulting in greater opportunity for establishment and invasion of exotic plants in association with these features. The profusion of secondary roads and oil/gas wells is a result of the recent rapid expansion of energy development in the Wyoming Basins, for which large-scale effects may be seen in the future.

TABLE 11.4. Anthropogenic features that influenced invasive plant occurrence in the Wyoming Basins Ecoregional Assessment area (Ch. 10)

	Proximity[a] (threshold distance[b])								
Species	Agricultural land	Oil/gas wells	Pipelines	Powerlines	Interstate/highways	Secondary roads	Railways	Populated areas	Communication towers
Crested wheatgrass	-Dist (100 m)	+0.05 km (270 m)			+1 km (825 m)	+0.05 km	+5 km (2.5 km)	-Dist (1.6 km)	
Cheatgrass		+0.05 km			+0.05 km		-Dist	+1 km	
Halogeton	-Dist	+0.05 km		+0.05 km		+1 km	-Dist		+0.5 km
Russian thistle	-Dist	+1 km (1.3 km)	+0.25 km (1 km)		+0.5 km (550 m)	+0.25 km (90 m)		-Dist (700 m)	

[a] Proximity metrics were calculated as Euclidean distances (Dist) and distance decay functions (value = $e^{(\text{Euclidean distance from feature (km)}/\text{-distance parameter})}$) using 5 distance parameters (0.05, 0.25, 0.5, 1, and 5 km). Distance parameters correspond to asymptotic values of 1.2, 2.4, 4.5 km, respectively. Species positively associated with a particular feature type have a negative response to the Euclidean distance metric and positive response to distance decay values.

[b] Species are likely to occur at distances below the threshold distance. In cases without a threshold distance value, the species either did not have a strong response or were likely to occur across the entire range of potential distance values.

6. Apply Spatially Explicit Models of Habitat Relationships to Delineate Species Occurrence and Abundance

We mapped the probability of occurrence or abundance for 15 vertebrate and 4 plant species within the WBEA based on environmental relationships determined from the spatially explicit empirical models. Coupling occurrence and abundance values across the landscape with an occurrence threshold allowed us to delineate areas where each species was likely to occur. Only six of the 15 wildlife species were predicted to likely occur in more than 50% of the region, and three species (pronghorn, short-horned lizard, and white-tailed jackrabbit) were likely in less than 30% (Table 11.2).

Our models for exotic plants emphasized the role of disturbance from anthropogenic features in facilitating invasion and establishment. Crested wheatgrass (*Agropyron cristatum*) was predicted to occur along roads and energy well pads throughout the WBEA area. Cheatgrass

(*Bromus tectorum*) and halogeton (*Halogeton glomeratus*) were predicted to occur in similar regions of the WBEA, especially the Wind River/Bighorn Basin, although their distribution was more limited by climatic factors. Nevertheless, local effects from roads and especially energy wells were noticeable in the species models, and spatial delineations illustrated the strong association with these disturbances (Ch. 10). Finally, the distribution of Russian thistle (*Salsola* spp.) was predicted to be common along Interstate 80 and other major highways, as well as across large areas of the Wind River/Bighorn Basin, and the area south of the Uinta Mountains of Utah.

The response curves developed for each of the modeled species in the WBEA represented the changes in the probability of a species presence or species abundance relative to changes in environmental variables in the context of all other variables influencing the species distribution. The threshold value identified a single or range of values required for presence to occur (Table 11.2). Thus, by using maps of predicted habitat change coupled with knowledge of the species response, managers can establish habitat protection and restoration plans that promote effective use of available and projected resources.

Our broad-scale maps depicting distributions for species of concern in sagebrush ecosystems can help to prioritize regions and guide selection of individual land treatments when restoring habitats (Wisdom et al. 2005b, Meinke et al. 2009). Similarly, maps delineating strongholds for individual or multiple species can be important for identification of specific locations for conservation, as well as for evaluating impacts of potential land cover changes. As such, this ecoregional assessment forms one part of an integrated multi-scale approach to developing management and conservation strategies.

Maps developed at the ecoregional scale can help inform management decisions from regional level down to the local level (Example 11.1). Knowledge of the locations across the ecoregion where species are likely to occur or have higher densities can be used to conserve important habitat in these areas and identify areas where restoration or mitigation may be most effective. These datasets are building blocks for future regional assessments and with the appropriate field validation the underlying equations can be used to create future predictions when updated GIS data on habitat and disturbance variables become available.

ASSUMPTIONS AND LIMITATIONS

All ecological assessments, regardless of the series of process steps or the scale at which they are conducted, require an explicit listing of assumptions and limitations for appropriate management use (Wisdom et al. 2005a). These assumptions and limitations are applicable to any regional assessment that uses remotely-sensed imagery to evaluate habitats, effects of anthropogenic disturbance, and environmental conditions for species of concern across large areas such as an ecoregion (Wisdom et al. 2005a). Thus, we list the primary caveats and guidance for appropriate use and interpretation of our results from the WBEA.

Species Selection and Range Mapping

The number and type of species of conservation concern selected for regional assessments will vary according to the criteria and methods used to develop the list. We used criteria and methods that were inclusive because (1) this ensured that all, or nearly all, potential species of concern were identified; and (2) a more comprehensive set of species of concern ensured that a wide range of associated habitats and anthropogenic effects can be assessed and considered in management (Ch. 2). The conservation status of many species is not clearly understood because a relatively large number of taxa are not yet ranked or have rankings that are inexact or uncertain (NatureServe 2001).

Several species of conservation concern in the WBEA area, such as rare plants, depend on fine-scale or micro-site environmental features that could not be mapped with the spatial layers available for our assessment. Ultimately, their distributions and environmental requirements may be too fine-scale and should not be included in a regional assessment.

We did not evaluate species of concern that occur in riparian zones or other localized habitat types within the sagebrush matrix. Linear habitats, such as narrow riparian corridors, could not be mapped at the spatial resolution of the available vegetation layer used in our assessment. Many of these species, such as MacGillivray's warbler (*Oporornis tolmiei*), have declining trends within shrub steppe landscapes (Dobkin and Sauder 2004, Rich et al. 2005) and should be considered when classified land cover data at finer thematic and spatial resolution are available. Despite these limitations, estimates of the common land

EXAMPLE 11.1

Application: Greater Sage-Grouse and The Human Footprint Across Spatial Scales and Organizational Structure

Land management agencies such as the U.S. Bureau of Land Management address issues at multiple scales simultaneously while allocating resources to the various levels of the organization (Fig. 11.1). We outline a process for conducting a multi-scale analysis using the greater sage-grouse general probability of occurrence model as a case study (Ch. 5). This example is intended to outline a potential application of spatial data to assess species distributions and threats to those species. The number of potential overlays that can be conducted is numerous, and these types of analyses should be question driven. At a national level (National) greater sage-grouse is listed as a candidate species under the Endangered Species Act (U.S. Department of the Interior 2010). Knowledge of a species range can help to identify zones, states, or regions that are important for addressing conservation concerns for a species (Stiver et al. 2006, Aldridge et al. 2008). However, sagebrush landscapes vary across the range of species in factors such as precipitation, temperature, soils, topographic position, elevation, and disturbance gradients (Miller et al. 2011). This makes it necessary to partition species ranges into manageable but ecologically similar analysis units. This is the organizational level at which the Wyoming Basins Ecoregional Assessment was conducted. Probability of occurrence was modeled and thresholds applied to depict areas of potential habitat (Regional). Assessment of threats to habitats and species is also appropriate at this scale. The human footprint is a cumulative assessment of human disturbance factors and can be used as an independent analysis or as an overlay to examine individual species responses. These maps can provide tools useful for directing resources to individual field offices. Further analysis can be used to assist in identifying high priority field offices through summary analyses (Subregional). Work within a field office may be conducted within discreet units such as range allotments or pastures. Summaries of conditions within these units can help identify potential areas where restoration may reconnect habitat patches or depict those areas of high habitat quality where steps should be taken to conserve current conditions (Local).

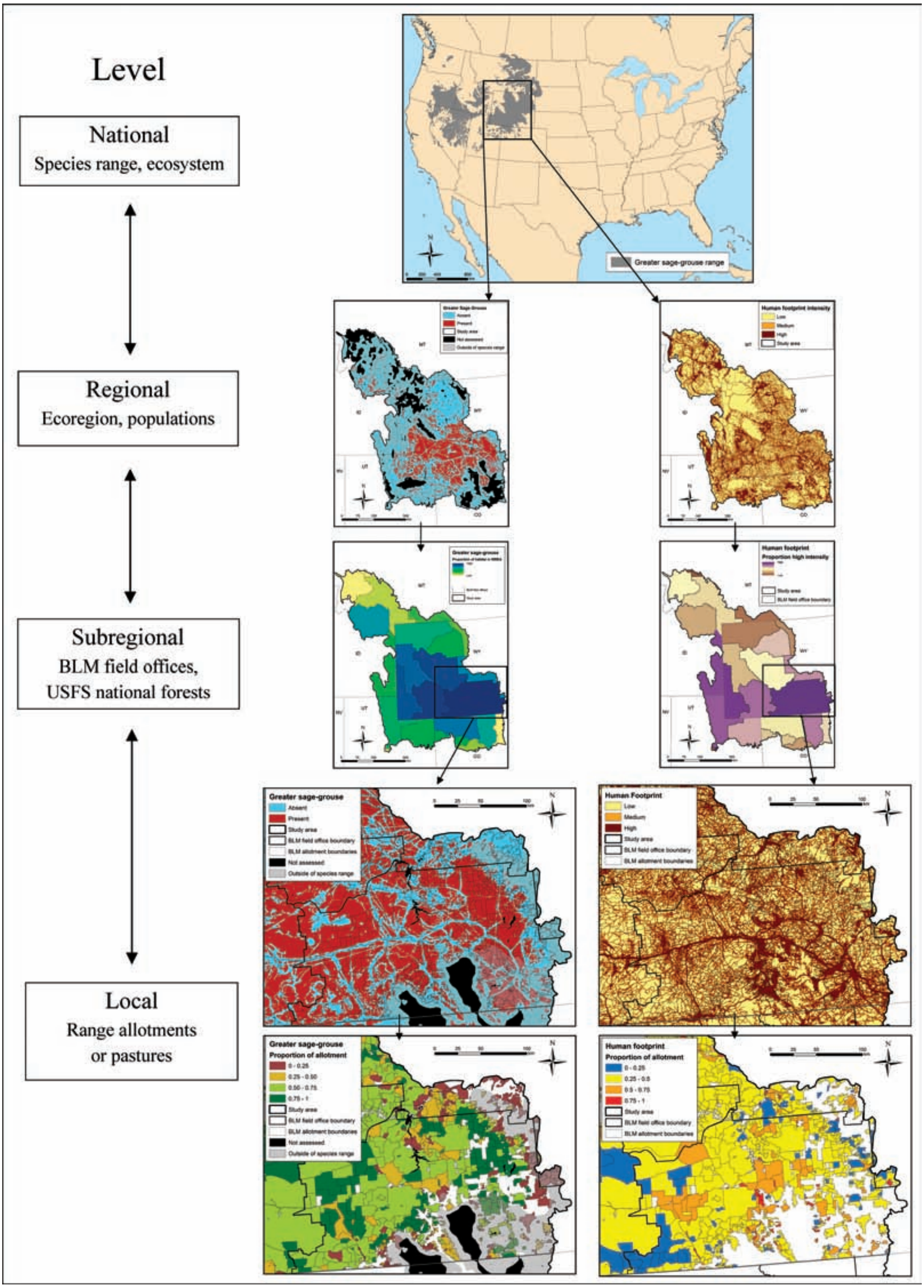

FIG. 11.1. Spatial scales and application of results from the Wyoming Basins Ecoregional Assessment using the greater sage-grouse general probability of occurrence model and an assessment of the human footprint.

cover types that are distributed over large spatial extents, such as the region covered by a BLM Field Office or the extent of our assessment area, can be accurately delineated and quantified for analysis in broad-scale ecoregional assessments (Hann et al. 1997, Wisdom et al. 2000).

Spatial Data and Land Cover Maps

Broad-scale assessments conducted for conservation and land-use planning, such as the Wyoming Basins Ecoregional Assessment, both assemble and incorporate a broad variety of types and sources of spatial data. Levels of accuracy and applicability vary according to the problems and questions addressed in the assessment. Thus, the quality of an ecoregional assessment depends largely on the availability of accurate spatial data. Many data coverages already exist and can be downloaded from websites such as the USGS SAGEMAP site (U.S. Geological Survey 2001). However, developing and obtaining accurate datasets in rapidly changing regions, such as areas of energy development, remains a continuing challenge. Building new or updating existing data sets that span one or more ecoregions will require reliance on large programs such as the U.S. Departments of the Agriculture and Interior LANDFIRE project (www.landfire.gov), the U.S. Geological Survey Gap Analysis Program (www.gapanalysis.usgs.gov), and the series of Rapid Ecoregional Assessments currently being conducted for the BLM.

Availability of accurate spatial data across our assessment area was a primary limitation in model development. These data gaps may result in models that excluded some of the most important drivers of animal distribution. We also assumed that variables included in each species model operate at the scale at which the model was developed and applied (Wiens 1989). In spite of these limitations, development of landscape models and their subsequent evaluation with empirical data are necessary steps for increasing our understanding of large-scale landscape processes influencing species, such as greater sage-grouse and Brewer's sparrow, that show declining population trends (Dobkin 1995, Rotenberry and Knick 1999, Knick and Rotenberry 2002).

Habitat variables used in our models also may not include information that may be important to determine occurrence or abundance of a species. For many bird species, breeding locations are selected based on a hierarchical process to first evaluate broad-scale features followed by successively finer features in the environment (Wiens 1989, Kristan 2006). Thus, areas dominated by sagebrush can be mapped and appear suitable to many species in a broad-scale assessment. However, sagebrush communities vary widely in composition and quantity of understory vegetation. The quantity of understory vegetation can range from high abundance of grasses and forbs to virtual absence of any understory in more xeric environments; composition can vary from all native species to complete dominance by exotic species (West and Young 2000). Because land cover maps identify dominant cover types but not the characteristics of understory vegetation, the amount of habitat for some sagebrush-associated species may be overestimated. For example, greater sage-grouse depend on an understory of native grasses and forbs for nesting and brood-rearing (Schroeder et al. 1999, Connelly et al. 2011). We caution that some areas identified as habitats for sage-grouse from a land cover model may be unsuitable due to lack of native understory plants, either naturally occurring or due to displacement by exotic grasses and forbs; we could not quantify this in our landscape models.

Models of Predicted Occurrence and Abundance

Our spatial models based on species-environmental relationships delineated probability of occurrence, or categorical ordinal estimates of relative abundance, or densities. Probability of occurrence is the statistical likelihood that a species will be present at that location. Although a higher probability of occurrence may be correlated with population density, the extent of that correlation is uncertain and likely varies by species and the effects of extrinsic factors not included in our models. In addition, time lags in species response to habitat loss and anthropogenic effects may not be seen for a number of years, suggesting that observations of species under varying environmental conditions at any one time may not always correlate well with previous habitat loss (Wiens et al. 1986, Knick and Rotenberry 2000).

The response curves developed from our species models are best viewed as a set of hypotheses about the rate at which species distributions can change relative to changes in habitat components. These changes have seldom been demonstrated with empirical data through time. Rather, these estimates of change are developed from differences in species abundance or occurrence relative to habitat characteristics at points distributed in space. Although there is support in the literature for the importance of various life history traits with regard to abundance and extinction risk and thus, presumably, response to disturbance (Purvis et al. 2000, Zuckerberg et al. 2009), information about many of these relations for the Wyoming Basins species of concern is limited. Our abundance models provide additional insights that may help future interpretation of population trends, fitness, and probability of displacement by disturbance.

Analysis of Human Disturbance

Many anthropogenic features that influence species occurrence, particularly linear features such as roads and power lines, were substantially under-estimated in our assessment. For example, roads were under-estimated in existing maps by at least 30% (Ch. 3). Consequently, our analysis of the human footprint under-estimated the presence of anthropogenic impacts in the Wyoming Basins and under-estimated their potential influence. Updated spatial layers that represent a current census of all anthropogenic infrastructure (especially roads, power lines and fence lines) are a large investment but will be necessary to correct this data deficiency.

Global climate change may result in the elimination of up to 80% of the remaining sagebrush in large areas of the sagebrush ecosystem (Neilson et al. 2005, Miller et al. 2011), potentially overwhelming the effects of other anthropogenic disturbances. Many of these effects are complex and difficult to model, and others require substantial effort and investment to collect accurate and up-to-date data.

Regionally consistent spatial data were unavailable for assessment of several impacts that may affect sagebrush-associated species and their habitats. Off-road vehicles and associated human impacts are believed to pose threats to sagebrush-associated species (Barton and Holmes 2007, Tull and Brussard 2007) but data on levels of off-road vehicle use (particularly on BLM lands where access by such vehicles is readily gained) are not widely available for modeling. Off-road vehicle use may affect wildlife through harassment or increases in poaching rates (Gaines et al. 2003, Ouren et al. 2007). Because we did not include off-road vehicle use in our model of the human footprint, our estimates of human impacts likely underestimate the true effects of anthropogenic features and processes on sagebrush ecosystems.

We also could not evaluate the potential effects of livestock grazing – the most pervasive land use in the sagebrush ecosystems in the Wyoming Basins (Ch. 1) – because of the lack of area-wide spatial data on animal unit months, stocking rates, grazing systems, and allotments for public lands managed by BLM, U.S. Forest Service, and other state and federal agencies

(Knick et al. 2011). Moreover, some of the available data pertaining to livestock grazing are inconsistent across administrative units, thus precluding their use in our assessment. Consequently, the potential influences of livestock grazing were not evaluated in our human footprint analysis or our species models despite the ubiquitous nature and recognized significance of grazing on ecosystem patterns and functions (Freilich et al. 2003, Knick et al. 2011).

Scales of Assessment

Regional assessments have been criticized as being "too coarse" or "too broad" to reflect ecological patterns and processes that affect species of conservation concern or dismissed as not useful for planning at local management levels. Most problems result from incorrect application of results or mismatch of the objectives relative to the intended scale of an assessment (Thompson et al. 2000). Thus, deficiencies can be present in assessments conducted at any scale. Most ecological processes that influence broad-scale patterns operate at large spatial and temporal scales (Urban et al. 1987, Shugart 1998). Therefore, the appropriate objectives of an ecoregional assessment are to develop an understanding of species distributions, habitat requirements, and habitat characteristics throughout an entire ecoregion.

The large number of plant species of conservation concern whose distributions are largely driven by micro-site variables not examined in our broad-scale assessment, emphasize the need for local assessments to estimate and monitor the status of these species' habitats and populations. How well our estimates of sagebrush fragmentation and spatial patterns of human footprint impacts relate to the needs and responses of plant species of concern is unknown. This uncertainty justifies the additional (and considerable) effort to conduct local assessments for the plants of conservation concern to complement our regional assessment.

The concepts of thematic and spatial resolution in data often are intermixed. Coarse-grained thematic land cover data sets are developed using plant species assemblages to define dominant land cover types. In the WBEA, accurate delineation of the sagebrush subspecies was not possible; different combinations of subspecies were grouped because of limitations in satellite imagery and availability of vegetation mapping efforts. Therefore, many of our land cover types are coarse and include multiple species or subspecies of sagebrush within a given thematic category or land cover type. Although the properties of thematic and spatial resolution are often linked, coarse-grained thematic data can be displayed or measured at relatively fine-grained spatial resolutions (e.g., 27-m pixels in a LANDSAT satellite image). Coarse-grained thematic data, such as dominant land cover, are most commonly used in ecoregional assessments because of availability for the large regions over which the analyses are conducted. With the exception of rare species that occupy localized micro-environments, few management actions are based on very fine-resolution thematic or spatial data. Use of continuous coverage maps of fine-grained spatial data (e.g., 1-m pixels) across an area as large as the Wyoming Basins (350,000 km^2) is impractical owing to limited availability of data at this resolution, the prohibitive cost of acquiring or developing these data, and current limitations on computer capacity and performance to manage such large volumes of data (but see Homer et al. in press). We delineated and summarized data in this assessment using 90-m grid cells.

We used a number of terms to describe the WBEA landscape (Table I.2), derive predictor variables, and quantify species-environment relationships. Understanding the technical aspects of the data and matching the correct characteristics to the ecological scale of interest is an important part of linking landscape patterns to ecological processes driving population and habitat change in space and time (Wiens 1989, Levin 1992). For example, a landcover map having a resolution of 1-km grid cells can adequately delineate most agriculture cropland but will be inadequate for analysis of habitat features, such as narrow riparian zones, that have a smaller ecological scale. Similarly, our results describe the response by species to environmental features as measured across the WBEA area. Local characteristics not measured in our assessment can further influence site-specific responses.

CONCLUSIONS

Our results and spatially explicit models of species relationships with environmental variables and anthropogenic effects complement other assessments completed by The Nature Conservancy for the Wyoming Basins (The Nature Conservancy 2000, Freilich et al. 2001, Neely et al. 2001, Noss et al. 2001). Collectively, these assessments contain extensive and detailed compilations of the diversity, richness, and status of native species, natural communities, and ecological systems present within our assessment area. Thus, a large amount of information, much of it spatially depicted and in a GIS format, now is available for land managers to use in developing integrated, multi-scale approaches to managing natural resources in the Wyoming Basins.

Federal and state land and wildlife management agencies rely on information about species-environmental relationships and spatial distributions in order to make effective management decisions affecting species of concern, to prevent further population declines of these species, and to establish a basis for restoring habitats for these species in the most time- and cost-effective manner possible. The spatial delineations of species occurrence and abundance can help prioritize regions and focus limited resources for restoring habitats (Wisdom et al. 2005b, Aldridge et al. 2008, Meinke et al. 2009). Similarly, maps delineating strongholds for individual or suites of species can be important in assessing future impacts of potential land cover changes within these regions. As such, the results from this ecoregional assessment of the Wyoming Basins form an important contribution to our understanding of impacts from land uses and in developing comprehensive management and conservation strategies to minimize or mitigate these impacts. Results from this assessment can be directly integrated into management planning processes, such as environmental impact statements, environmental assessments, records of decision, travel management planning, and conservation for species of concern. Ultimately, these results can form a baseline accounting system (Aldridge and Boyce 2007) that can be used by agencies to monitor changes in habitat quantity and configuration, as well as distribution of human land use, and how species respond to these changes. Our assessment provides tools and models for use in the development of an integrated approach to conservation and management of the sagebrush ecosystem in the Wyoming Basins.

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