Utah Legacy Raptor Project

GREAT BASIN AVIAN SPECIES-AT-RISK AND INVASIVE SPECIES MANAGEMENT THROUGH MULTI-AGENCY MONITORING AND COORDINATION

Final Report 2012

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RECOMMENDED CITATION

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INTRODUCTION

The invasive winter–annual cheatgrass (*Bromus tectorum*) has degraded military, public and private lands throughout the Western United States, particularly in the Great Basin region of Utah (Knapp 1996). In addition to being a sensitive ecological area, this region, specifically the Utah West Desert, is critical to important military activities associated with Hill Air Force Base (HAFB), Dugway Proving Ground (DPG), Tooele Army Depot (TEAD), Deseret Chemical Depot (DCD), and Camp W.G. Williams (Utah National Guard – UNG). The ecological consequences of cheatgrass invasion have broad–ranging threats to natural floral and faunal communities. Cheatgrass-invaded areas are typically extensive monocultures that are more "flashy" and flammable than native plant cover. This loss of native vegetation, heightened fire risk and decline in biodiversity has potentially severe implications for military Mission, land managers; wildlife and the general public (see reviews in Knapp 1996, Zouhar 2003). Under likely climate change and land use change scenarios, cheatgrass cover may spread even more than the current extent due to the tolerance of cheatgrass to disturbance and drought (Chambers and Pellant 2008).

Invasive species are a world-wide threat to global biodiversity and ecosystem function, second only to habitat loss. In the United States, it is estimated that losses due to invasive species cost upwards of $120 billion dollars per year (Pimental et al 2005). In the Western United States, cheatgrass has become a major invasive plant. In the Great Basin region alone, the Bureau of Land Management (BLM) estimates that cheatgrass has spread to over 1/3 of the total land area, with more and more acres being invaded yearly (BLM Great Basin Research Initiative briefing). While the total cost of cheatgrass invasion is difficult to determine, its contribution to ecosystem degradation, loss of habitat and forage for wild and domestic animals, losses due to cheatgrass-fueled fires coupled with resources spent on habitat restoration and fire suppression has made it clear that it has made a significant impact on the regional as well as national economy and ecology.

The two greatest risks from cheatgrass invasion result from its ability to alter fire regimes and to degrade native shrub and grass cover (Knapp 1996, Brooks and Pyke 2001, Zouhar 2003, Chambers et al. 2008). Cheatgrass can invade an area and quickly establish a monoculture through increased fire frequency caused by increased "flashiness" of the ground cover. Cheatgrass itself is highly flammable, and has the ability to carry low intense fires across the landscapes at increasing frequencies. After fires, since cheatgrass maintains a competitive advantage over native flora in post-fire conditions, the invasive will establish again, and the cycle will perpetuate. Given the potential for loss of native vegetation and heightened fire risk, this invasive species has widespread implications for military installations, land managers, native wildlife, livestock and the general public.

Recent monitoring research in Northwest Utah by HawkWatch International, Inc. (HWI) suggested cheatgrass dominated habitats may act as an ecological "trap" for Burrowing Owls (*Athene cunicularia*) and Ferruginous Hawks (*Buteo regalis*; i.e., an inappropriate attraction to poor quality habitat [Gates and Gysel 1978]) That is, birds may be initially attracted to nesting in cheatgrass dominated areas due to more open foraging habitat, but could possibly use such areas less consistently over the long-term trend or experience lower nest success and productivity due to potential lower prey abundance associated with monoculture cheatgrass (Smith and alter 2010). An abundance of research from southern Idaho suggests cheatgrass vegetation may support lower abundances of prey species such as ground squirrels (Spermophilus spp.), small mammals in general, and black-tailed jackrabbits (*Lepus californicus*; U.S. Department of Interior 1996, Hanser and Huntly 2006, Steenhof et al. 2006). Similarly, research in northern Utah found cheatgrass-dominated areas supported lower small mammal abundance and diversity (Ostoja and Schupp 2009) and fewer snakes, perhaps partly due to reduced prey availability (Hall et al. 2009). If this is indeed true, that areas of cheatgrass support lower abundances of prey diversity, such areas could have potential negative implications for a variety of raptor species that rely on these lands for resources.

The study region is comprised mostly of Department of Defense (DoD) lands; DoD–administered (i.e. restricted and controlled) airspace and public land (BLM). DoD land holdings, by congressional decree, support a wide array of testing and training which are critical to supporting DoD Mission and Readiness objectives. Military installations, such as DPG, HAFB, and the Utah Test and Training Ranges support a wide array of testing and training activities crucial to the DoD Mission. In addition to these installations, the DoD controls a large portion of the operational airspace in the study area, called the Military Operating Area (MOA). Due to the nature of military activities within the MOA, the underlying landscape and management thereof is an important consideration for the DoD. This area is also home to a diverse raptor population, which has been monitored over the past few decades by non-profit organizations (HWI and the Raptor Inventory Nest Survey [RINS]), volunteers, the DoD and BLM. The Utah Legacy Raptor Project (ULRP) partnership, consisting of military (i.e., DPG, HAFB), non-profit (i.e., HWI and RINS), and agency personnel (i.e., BLM, US Fish and Wildlife Service [USFWS], Utah Division of Wildlife Resources [UDWR]) was formed in 2009 to further research this important issue for three focal species: the Golden Eagle (*Aquila chrysaetos*), Ferruginous Hawk, and Burrowing Owl.

The Ferruginous Hawk and Burrowing Owl are open-country raptors adapted to native grasslands, shrubsteppes and deserts of the Western US and currently are Utah State Species of Concern (Haug et al. 1993, Bechard and Schmutz 1995, UDWR 2004). The third study species, the Golden Eagle, is not a species of concern in Utah; but research in Southern Idaho, Northern Nevada, and North Central Utah has suggested populations have declined in the West. All three raptors are protected by the Migratory Bird Treaty Act (MBTA). Additionally, the Golden Eagle is protected under the Bald and Golden Eagle Protection Act (BGEPA), under which regulatory guidelines are being established for multiple agencies, making current research on these birds an integral part to establishing regulatory procedures. Future declines in any of these species could lead to petitions for listing on the Endangered Species Act (ESA). The Ferruginous Hawk has already been petitioned for listing under the ESA in 1991, but based on findings at the time was excluded (Ure et al. 1991, USDI Fish and Wildlife Service 1992). Proactive, cooperative management of species-at-risk such as these three species can prevent the need for ESA listing if sufficient work is being done to effectively understand and manage these species at multiple scales. Because federal agencies are prohibited from authorizing, funding or carrying out actions that jeopardize the continued existence of ESA-listed species and are prohibited from adverse modification of designated critical habitat, such designations could severely restrict activities on military and public lands, thereby potentially posing a threat to the military Mission. All three species could negatively impact DoD Mission sustainability in the Utah West Desert MOA if they are proposed for listing under the ESA.

ACHIEVEMENTS OF THE UTAH LEGACY RAPTOR PARTNERSHIP

Through our cooperative efforts, we were able to achieve the following objectives, many of which comprise firsts for large-scale conservation efforts in the Great Basin region:

- Creation of a partnership comprised of 2 DoD installations (i.e., DPG and HAFB), two raptor-focused not for profit organizations profits (i.e., HWI and RINS), BLM, USFWS and UDWR.
- Compilation of multiple years of nest activity data for each of the focal species into one database, with some records dating back over 30 years and encompassing almost 40,000 square kilometers, the largest geographical long–term dataset compiled for these species.
- Compilation of over 14,000 previously unassembled nesting records (1998–2011), representing over 1,000 nests and 573 "territories" or nest clusters for Golden Eagles, Ferruginous Hawks, and Burrowing Owls for the entire study area. This involved combining historical records, previous reports, and field-based observations to place nests into associated clusters.

- Mapping of the previously mentioned territories, providing a visual representation of where efforts have been undertaken and where birds have been found. Additionally, calculation of landscape metrics for each of the focal species, depicting territory and nest spacing.
- Creation of predictive habitat maps for all three study species for the study area.
- Creation of cheatgrass coverage maps from MODIS remotely sensed images for all years of the study period (1998–2011). Completion of statistical and geospatial analysis of cheatgrass invasion risk, including landscape risk factors and predictive maps of potential risk factors associated with invasion potential.
- Analysis of cheatgrass invasion risk potential associated with currently occupied and predicted habitat. This analysis and resulting maps offers significant management implications for land managers within the study area, highlighting areas of invaded and high future invasion risk relative to raptor habitat.
- Development of standardized protocols that can be used in other regions for organizations and agencies to use to monitor raptor populations. This document includes model data sheets, nest chronology information for our region by species (includes other species besides the ULRP focal species), suggestions for safe field practices, and information on how to complete surveys without disturbing nesting birds.
- Development of protocols for use in engaging citizen scientists in large-scale and long-term monitoring projects for the collection of data valuable to decision makers.
- Development of a listing of management recommendation for use by federal and state managers for each of the focal species.

STUDY AREA

The study area falls within the Great Basin physiographic region, a large semi-arid area that comprises parts of California, Idaho, Oregon, Nevada and Utah. The Great Basin is a cold desert, with variable precipitation, most of which falls as snow during the winter months (Wagner 2003). Geographically, this region is marked by basin and range topography, where small remote mountain ranges are separated by vast, flat valleys. The elevation of our study area ranges from 1,271–3,686m. Approximately 99% of the study area is below 2,500 m, and 84% occurs below 1,800 m. Although only sparsely settled in the early 1900s due to its remoteness and poor resource base, this region is one of the fastest growing population centers in the US, and is host to growing energy and mineral resources development.

The ULRP study area is bounded on the east by the Great Salt Lake and the Salt Lake and Tooele valleys. The western edge is bounded by the state border with Nevada. The northern and southern boundaries of the study area are delineated by the extent of the MOA in the West Desert of Utah (Figure 1). The MOA is largely comprised of public (BLM) land, with DoD inholdings (Appendix 1.) The DoD maintains an interest in the management of the MOA because it administers control of the MOA airspace. The study area was drawn to include gaps in the MOA (mostly surrounding the I-80 corridor) to include the entire bio-geographic region. Total area in the study area is 39,250 km^2, 34,400 km^2 of which are part of the MOA (Table 1). The Department of Defense is a major user and manager of lands in the West Desert of Utah. On Dugway Proving Ground (DPG), a 3,200-km^2 US Army installation, defense and detection systems are tested for biological and chemical weapons, soldiers from guard units and active duty army units (both conventional and special forces) are trained for combat readiness, and both manned and unmanned air systems are evaluated. On the Utah Test and Training Ranges (UTTR), the DoD tests munitions and air-based weapons systems. Combined, the UTTR and DPG installations make up one of the largest contiguous military training spaces in the United States. The desert landscape has proven invaluable to Mission Readiness in the last few decades, as it closely matches the climate and topography of the Middle East and allows the DoD to prepare warfighters for operational theatre. In addition to DoD held lands, the DoD controls the airspace in the MOA so that commercial and private flights are restricted.

Non-DoD lands in this study area are mostly managed by the BLM (Table 1). Even though this region is remote, it hosts many recreational opportunities, frequently in the form of off-road vehicle use (ORV) on public lands. Private lands include some industrial operations as well as ranching operations. The Skull Valley Goshutes Tribal Lands and Goshute Tribal Lands own and manage the 250 km^2 of tribal land within the study area.

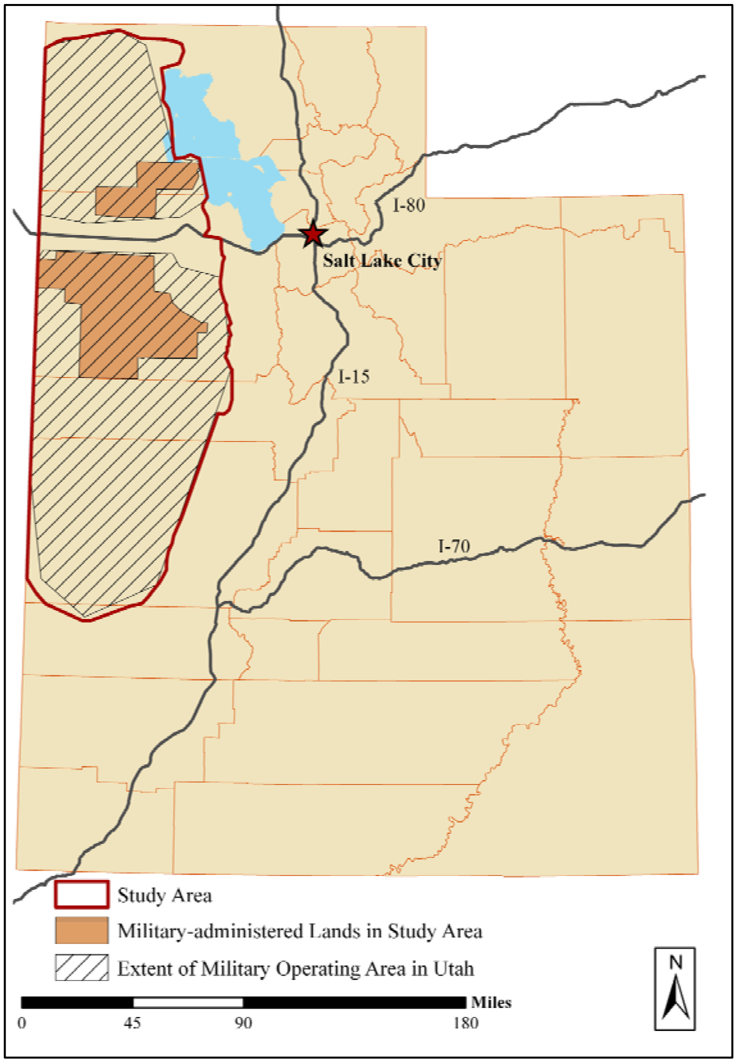


Figure 1. Utah Legacy Raptor Project (ULRP) study area in relation to military lands and the military operating area (MOA) in western Utah.

Table 1. Land ownership within the ULRP study area in the state of Utah.

Category	Agency	Percentage
Federal	BLM	60.1%
Federal	DOD	16.5%
Private	Private	11.6%
State	SITLA	7.1%
Federal	USFS	2.1%
State	DNR	1.8%
Tribal	Tribal	0.6%
Federal	USFWS	0.2%

We used Southwest ReGAP (SWReGAP) data to describe landcover within the study area (USGS 2005). We combined cover types that were similar in order to group SWReGAP types into simplified cover types based on habitat structure and species composition. The majority of the study area is comprised of arid shrub cover types, including sagebrush (*Artemesia* spp.) shrub, salt desert scrub, greasewood (*Sarcobatus vermiculatus*) flats and semi-desert shrublands (Table 2). We divided the arid shrublands into two different categories; those associated with upland shrub cover and a desert shrub cover more associated with lower elevations and valleys. Over one-quarter of the study area is comprised of playa, salt flats or wash, land cover types which support little to no vegetation; classified here as barren. Juniper (*Juniperus* spp.) woodlands make up the largest amount of forested cover type, which was combined with other forest types into a "woodland category". Invasive forbs and grass cover less than 5% of the total range, and were classified into the "grassland category".

Table 2. Landscape composition in the ULRP study area.

Land Cover	Percentage
Upland Shrub	29.3%
Desert Shrub	27.8%
Barren	24.6%
Woodland	11.1%
Grassland	3.8%
Water	1.4%
Human influenced	1.3%
Rock/Cliff	0.9%

Most of the non-vegetated cover types are found in the "basin" regions of the study area; those that are low-lying, relatively flat and occur between mountain ranges (see Appendix 2). There are a few areas of development and agriculture, most notably the town of Delta, as well as developed sections of land on Dugway and the UTTRs (Appendix 2).

HISTORIC STUDY AREA CLIMATE AND FIRE OCCURRENCE

Landscape fires in the Great Basin were historically infrequent during pre-settlement times (Brooks and Pyke 2001). Since settlement (mid to late 1800s), active fire suppression has changed the historical fire regimes and composition and structure in Great Basin habitats (Chambers et al. 2008). In forested habitat types (which are rare in our study area) a decrease in fire suppression has caused an increase in vertical structure of forests, more biomass and a corresponding increase in fire severity (Keane et al. 2002.) The decrease in fire frequency in pinyon (*Pinus edulis*) juniper and surrounding habitat in the Great Basin has caused an increase in cover and canopy closure in pinyon juniper forests, therefore increasing the risk of high-severity stand-replacing wildfires within those cover types (Miller et al. 2008). With increased fire suppression, higher intensity fires and the encroachment of pinyon-juniper woodlands, sagebrush communities have declined in the region. This sagebrush decline has also been a result of increased coverage of annual grasses such as cheatgrass, another cause of higher intensity fires, and the central focus to our study. Increased coverage of annual grasses additionally cause an increase in fire intensity and fire frequency, and create a feedback loop that perpetuates invasive grass cover and hinders shrub recruitment and growth.

The BLM closely tracks fire occurrence, severity and size for each recorded fire on Utah BLM lands. During the 12-year study period (1998–2011) the study region saw over 250 fires that burned (Table 3) nearly 2,000 km^2 (of which some was burned multiple times during the study period; see Appendix 3).

Table 3. Fire history in the ULRP study area, provided from BLM file geodatabase. Fires that intersected the study area boundary were also included.

Year	Number of fires	Area (km^2)
1998	14	118.8
1999	22	184.6
2000	20	282.6
2001	27	85.5
2002	5	9.2
2003	10	6.0
2004	8	13.3
2005	19	216.9
2006	35	244.5
2007	25	495.9
2008	14	16.4
2009	9	210.3
2010	8	14.0
2011[a]	45	68.0
TOTAL	261	1,969.8

[a] 2011 data from Utah Fire Information Portal; number of fires may be high due to different data compilation methods (accessed online 1/2/2011).

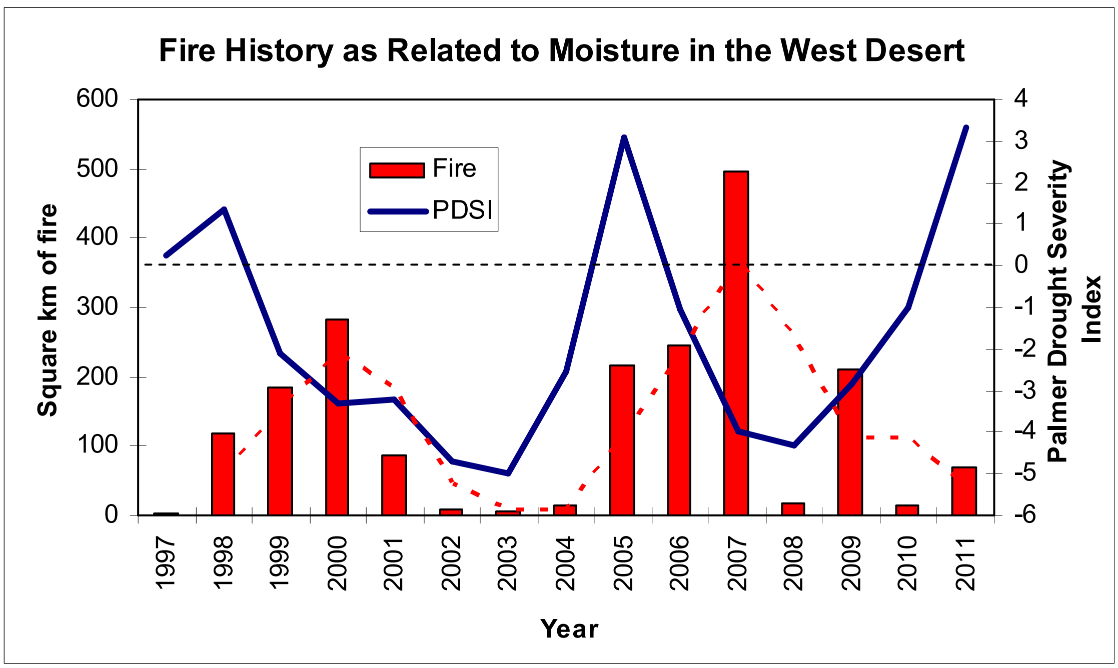


Figure 2. Annual area burned as related to moisture (i.e., Palmer Drought Severity; higher values = wetter conditions) in the ULRP study area. Fires are positively related to moisture, but with a two year lag.

There are two notable spikes in area burned, in 2000 and 2007 that correspond with decreases in the Palmer Drought Severity Index (NOAA 2011; Figure 2). The Palmer Drought Severity Index (PDSI) is a measurement of dryness that combines temperature and moisture measurements to calculate drought intensity (Palmer 1965). High positive values correspond to wetter conditions in the index, while high negative values correspond to drought conditions. 1998 and 2005 were the wettest years during the study, and the increases in fire area came two years after these spikes in moisture. It is likely that an increase in drought severity following these wetter years caused large-scale drying of vegetation that greened up during the increase in precipitation and the corresponding increase in fire in 2000 and 2007.

METHODS

LONG-TERM RAPTOR DATA COLLECTION AND COMPILATION

Focal species raptor data was collected in the study area by project partners on an annual basis between 1998–2011. Survey work typically occurred from mid-March through early August to encompass the majority of the nesting cycles of all focal species. The goal of field visits was to document occupancy (i.e., birds present) or "activity" (i.e., a nest start), hatching and initial brood size, and nesting success and fledgling production. Crews located active nests based on known nest records and by scanning suitable habitat for signs of nesting or adult activity. They recorded various nest and nest-site characteristics at each documented nest. Although the study area survey coverage is undoubtedly biased towards roads, 91% of the study area was within relatively close proximity (2.0 km) of a road, suggesting surveyed areas are likely representative of the study area at large.

Raptor nests were grouped into territories based on their history of use, field knowledge, and inspection of nest spacing and configuration. Because it is virtually impossible to truly determine the size of defended territories from our data, we created artificial boundaries around nests or nests clusters based on scientific knowledge of each species. These were used to define the landscape characteristics and cheatgrass coverage around nests for analysis. Only nests or clusters with at least one record of occupancy during the study period (i.e., 1998–2010) were included in our analyses. We used nest clusters to determine intra-cluster distance and inter-cluster metrics. For Burrowing Owls, we assumed that each separate burrow was its own territory if it had at least one record of occupancy during the study period.

To create spatially delineated territories, we took the grouped nests and created point, lines or minimum convex polygons in ArcGIS 9.3 (Environmental Systems Research Institute, 2008) using Hawth's Tools (Beyer 2004; see Appendix 4). Regionally, Golden Eagle home range sizes have been found to average near 23 km^2 (Kochert et al. 2002), but as large as 83 km^2 (2.7 km–5.1 km radius) (Marzluff et al. 1997). We felt that a 4.0–km radius would likely capture the appropriate home range size for Golden Eagles in our study area. Ferruginous Hawk home range size average 6.0–7.6 km^2 for the region (1.4–1.6 km radius), but can be found as large as 90.3 km^2 (5.4–km radius) (Smith and Murphy 1973, McAnnis 1990, Leary et al. 1998). Consequently, we chose a 2.0–km radius as the home range size for Ferruginous Hawks in this study. We selected a 1.0–km radius for Burrowing Owls based on research from throughout their range that suggests average home range radius is between 0.3–1.3 km (Haug and Oliphant 1990, Sissons et al. 2001, Gervais et al. 2003). We buffered Burrowing Owl territories with a 1.0-km radius buffer, Ferruginous Hawk territories with a 2.0–km radius buffer and Golden Eagle territories with a 4.0–km radius buffer.

FIELD METHODS–2011

We used the preliminary maps of cheatgrass probability during the years 2007–2009 provided by Utah State University (USU) to coarsely assess cheatgrass coverage surrounding known Golden Eagle and Ferruginous Hawk territories and near historic Burrowing Owl concentrations. Active Golden Eagle and Ferruginous Hawk nests were intensively monitored during repeated 2-hr observation sessions beginning April 5 (Golden Eagles) and May 5 (Ferruginous Hawk). We attempted to monitor each active nest every 4–14 days until confirmed nest failure or success (i.e., at least one nestling reaching ≥80% fledge age [Steenhof and Newton 2007]). Nests were monitored during the morning (8–11:00), midday (11:30–15:00), or evening (15:30–19:00m) period, and monitoring order was altered to balance observation of each nest by period while maintaining balanced representation of nests by both period and cheatgrass coverage as the total number of active nests changed throughout the breeding season. During each monitoring period, observers quantified adult nest attendance (total time at nest), number of prey deliveries, hunting attempts, and flushing. Observers also attempted to coarsely identify prey remains (e.g., bird, small mammal, jackrabbit, etc.).

We established Burrowing Owl broadcast/search transects of varying length along roads passing through areas of historic Burrowing Owl activity and additional roads in low or high cheatgrass cover. Stations were established every 800 m (0.5 mile) along transects and each transect contained a minimum of 5 stations. At each station, a pair of observers conducted a 6-minute scan and broadcast survey in all directions. Broadcast surveys were initiated in late April to coincide with the beginning of the nestling period in our study area, the peak period of broadcast effectiveness (Conway et al. 2008). To the degree possible, surveys were suspended during inclement weather (e.g., rain or winds >15 mph). We attempted to video-probe all burrows with adults present or other recent signs of activity (e.g., mutes) to count eggs and nestlings present in active burrows. We modified a Snap-On® BK6000 borescope with a 3.3-m video probe (plus 1-m extendable handle) with electrical conduit and foam and plastic camera casing. The electrical conduit provided needed rigidity and protection for the camera probe and the casing kept the camera lens from becoming obstructed by dirt while being fed down the burrow.

To assess small mammal and invertebrate abundance relative to cheatgrass cover, Brigham Young University (BYU) partners established 29 trapping grids at a subset 100 random points that met our cheatgrass cover and logistical requirements. Random points were established proximate to known nesting concentration (i.e., within 2 km, but >800 m from nest sites to avoid disturbance) in areas spanning a range of cheatgrass cover based on preliminary USU cheatgrass maps. Trapping grids were operated between May 3–June 17, 2011, to overlap the nestling period (peak resource demand) of our three focal raptor species. Each trapping grid included 49 small mammal traps in a 7x7 trap layout with 15 meter spacing between trap stations. At each station, a Sherman livetrap was baited with birdseed for 3 consecutive nights. All small mammals captured were marked with uniquely numbered eartags to monitor individuals.

Invertebrate abundance was sampled with 10 pitfall traps spaced throughout each small-mammal trapping grid. Traps were built from glass test tubes (mouth approx. 2.5-cm diameter) inserted into a PVC pipe of slightly larger diameter (to prevent breaking the test tube), with the entire trap inserted into the ground. Each pit fall trap was open for 3 days and all captured specimens were treated with propylene glycol for preservation. Additionally, at each site we made a single pass of 50 sweeps with a sweep net. This sampling was done from one corner to the opposite corner of the small mammal trapping grid. This was an attempt to capture species that may not normally enter the pitfall traps. Although most ground-dwelling arthropods are included in the Burrowing Owl diet, micro-insects such as ants, springtails and mites are not included, and thus were discarded from the sample. Specimens were identified to lowest level possible. Specimens that were unidentifiable due to poor quality of specimen or immature stages were separated into organizational taxonomic units (OTU's), which is a commonly used method for obtaining expedient species richness data on hyper diverse taxa (Rich 1992, Basset et al. 2004). All specimens were measured for total body length in millimeters to determine size classes of invertebrates appropriate for burrowing owl diet.

Road transects were driven after dark near established prey survey plots in an attempt to index leporid (i.e., rabbit) abundance by cheatgrass cover. Transects were driven 12 nights between May 3 and June 8, 2011, and 16–30 km of road were driven for each transect. All leporids detected with headlights or high-powered spotlights were recorded to species and location relative to survey road.

IDENTIFICATION OF POTENTIAL RAPTOR NESTING HABITAT

Habitat classification is central to understanding the ecology of a species. Accurate habitat models are fundamental for conservation planning purposes. It is essential that conservation practitioners have available the best available science upon which to make decisions for management. In its simplest form, habitat classification involves determining how the environment where species are found differs from the surrounding landscape, where the species is presumably not found.

In order to accurately depict the ecology of the three study species, we decided to model both nesting habitat and foraging/territory habitat. The spatial occurrence data for these species are limited to nesting sites, while foraging/territory habitat is based on both proximity to nesting substrate and surrounding habitat structure. We chose to use Maximum Entropy, or "Maxent", to model nesting habitat. Maxent is a modeling algorithm that allows the user to make predictions or inferences on incomplete data distributions by fitting a distribution to the data that is simultaneously as "loose" as possible to the distribution of the data while fitting as tightly as possible to the observed distribution (Phillips et al. 2006). Maxent is designed to work with presence-only species occurrence data (Philips et al. 2006); ideal in this case since the data lacks known absences due to incomplete survey coverage of the entire study area over the course of the data set. There may be inherent biases in presence-only data, due to the nature of data collection for these types of data sets (Zaniewski et al 2002). As stated in our methods, raptor nesting data might be biased towards roads within the study area, even though 98% of the study area is within 2 km of a navigable road. Despite these biases, presence only models, including Maxent, have been shown to be sufficiently accurate for habitat suitability models when compared with presence-absence methods (Elith et al. 2006)

The model functions by minimizing the relative entropy between two probability densities - one distribution from the sample (in our case, nesting sites) and the other from the landscape at large (Elith 2011). The program fits a distribution of covariates (environmental variables) and creates an output for each pixel in the landscape that represents a logistic prediction of habitat. Values are coded between 0 and 1, with values approaching one indicating a higher probability of suitable habitat (Anderson et al. 2003, Philips et al. 2006).

We started our modeling process using just nest site data within the study area. Our outputs indicated that the models were failing to estimate habitat in the southern part of the study area, possibly due to the fact that there were much fewer nests in the southern portion. To overcome this, we expanded the original Maxent study area - including nests that were not included in our other analyses, and essentially clipping the final output by our original study area. The environmental variables we selected described the nest sites based on topography, elevation, vegetative cover and precipitation (Table 4). We also included a soil depth variable for Burrowing Owls. Initial data exploration showed that there were very few correlations among environmental variables, and so all variables were included for each model.

Table 4. Environmental variables used to model potential Golden Eagle, Ferruginous Hawk, and Burrowing Owl habitat in the ULRP study area.

Variables	Source
Elevation	DEM - from the National Elevation Dataset (NED). Accessed from Utah GIS Portal (http://gis.utah.gov/)
Soil Depth (Burrowing Owl only)	USGS 2004b - derived from STATSGO soils database
Landcover	Derived from SWReGAP (USGS 2005)
Precipitation	Derived from PRISM (PRISM Climate Group 2004)
Slope	DEM - derived in ArcGIS 10 (ESRI 2010)
Aspect	DEM - derived in ArcGIS 10 (ESRI 2010)
Ruggedness	DEM - derived in ArcGIS 10, Ruggedness Tools (Sappington et al. 2007)

Maxent provides HTML outputs that gives the user information regarding variable importance and potential cut-off values for the logistic output. For our purposes, we chose to use the thresholds that provided maximum training sensitivity plus specificity, such that it maximizes true positives (i.e. nests that are correctly classified in the habitat output) while minimizing the overall area predicted to be habitat. Additionally, when inspecting all cut-off values, these thresholds were visually closest to what would be expected for habitat classification for each species according to expert opinion. Output files were converted into rasters in ArcGIS 10.0 (ESRI 2010). A generalize tool was applied to each raster to remove excess single pixels and to smooth boundaries.

To further refine our understanding of potential habitat based on focal species relationships with vegetation variables at known territories, we established random points (number equal to known territories) within the identified potential habitat of each species. Random points were spaced from each other and existing territories based on minimum territory spacing between known territories of each species. Random points were used to create 1, 2, and 4-km radius Burrowing Owl, Ferruginous Hawk, and Golden Eagle "random territories", respectively. Discriminant function analysis was used to distinguish between known and random territories based on coverage of 8 vegetation variables. Jackknife (leave-out-one) correct classification rates were used to assess the performance of the functions (Afifi and Clark 1997, McGarigal et al. 2000). Although vegetation coverage variables used in the discriminant function analysis were not normally distributed, the value of the resultant functions are best judged based on whether they have an ecologically meaningful and consistent interpretation and aid in separation of groups (McGarigal 2000). Additionally, analyses based on larger samples are generally more robust to violations of the assumptions (McGarigal et al. 2000). For all potential habitat of each species, we computed vegetation variable coverages in the appropriate surrounding landscape area and multiplied these values by the discriminant function variable coefficients to identify potential nesting habitat also surrounded by habitat characteristics similar to known territories (i.e., "prime potential habitat").

ASSESSMENT OF CHEATGRASS COVERAGE AND INVASION RISK

The GIS and Remote Sensing Laboratory at Utah State University (USU) performed the remote sensing to determine cheatgrass coverage within the study area. In order to do this, MODIS version 5 data was acquired from the NASA Warehouse Inventory Search Tool for the region and study period. Imagery was processed using ERDAS Imagine 2011. To ensure minimum smoothing and reduce data loss, nearest neighbor resampling was selected for each transformation.

USU used SWReGAP field data containing percent cover and dominant vegetation types (including cheatgrass) were acquired and sorted so that only points containing greater than 10% cheatgrass cover remained. These points were then sampled through the MODIS NDVI layer to identify site greenness phenology. These values were plotted against time to identify green-up, green-peak, green-down and green-trough dates for cheatgrass sites. Temporal periods were identified as showing peak and trough greenness for cheatgrass and were then used to model cheatgrass distribution.

Because of considerable annual variability in annual maps of predicted cheatgrass occurrence, we chose to group annual maps into three 4-year time periods: 2000–2003, 2004–2007, and 2008–2011. For each 4-year period, we considered cheatgrass present if it was present (i.e., ≥0.5 probability) in at least 2 of 4 years. We created a map of long-term cheatgrass presence by summing all three period cheatgrass maps (i.e., 0 = no cheatgrass during any period or 1, 2, and 3 = cheatgrass during 1, 2, or 3 periods, respectively).

We used the map of long-term cheatgrass presence to assess environmental variables (Table 5) associated with invasion risk based on methods used successfully in a similar assessment by Bradley and Mustard (2006). We summarized persistent cheatgrass cover (i.e. present during at least 2 of 3 periods) within "bins" of 9–12 discrete ranges of values for elevation, aspect, and slope (based on 30-m digital elevation model), average precipitation and soil average water capacity, distance to human landscapes (i.e., settlements and agriculture), and distance to human linear features (i.e., roads and powerlines).

This variable set was selected based on their documented importance in previous studies and literature (see Zouhar [2003], Bradley and Mustard [2006]). Percent cheatgrass cover in each bin (e.g., 0–250 m from linear features) was assumed to represent the invasion probability of that bin, using GeoSpatial Modelling Environment software (Beyer 2011). We used multi-criteria evaluation (MCE; Store and Kangas 2001) to assess overall cheatgrass invasion risk in the study area by summing probabilities across bins associated with each environmental variable. Summing probabilities is valid when variables area approximately independent (Store and Kangas 2001); hence slope and precipitation were dropped from this risk summation due to high correlations (>0.6) with elevation. We also created a binary risk map (low = <0.5; high ≥0.5) to allow direct comparison with binary cheatgrass occurrence.

Table 5. Environmental variables used to model cheatgrass invasion risk in the ULRP study area.

Variables	Source
Elevation	DEM - from the National Elevation Dataset (NED). Accessed from Utah GIS Portal (http://gis.utah.gov/)
Aspect	DEM - derived in ArcGIS 10 (ESRI 2010)
Slope	DEM - derived in ArcGIS 10 (ESRI 2010)
Soil water capacity	Derived from STATSGO soil database (USGS 2004a)
Precipitation	Derived from PRISM (PRISM Climate Group 2004)
Distance from linear features	Euclidean distance calculation in ArcGIS 10 (ESRI 2010) from linear features (i.e., roads and powerlines) accessed from Utah GIS Portal
Distance from human-influenced landscape	Euclidean distance calculation in ArcGIS 10 from human-influenced landscape features (i.e., agriculture and urbanization) from SWReGAP

ANALYSIS OF RAPTOR, PREY, AND CHEATGRASS DATA

To determine inter-nest and inter-cluster spacing, we used the "near" tool in ArcGIS 10 to calculate distances between distinct nests or nest clusters (i.e., territory spacing) and between nests within nest clusters (i.e., within territory nest spacing). We then removed 2.5% of the distance on upper and lower tails of the data distribution to remove outliers (e.g., huge distances due to unsurveyed area between nests), so that 95% of the data remained. For average intra-cluster nest spacing, we used the same ArcGIS tool. We did not perform the analysis on Burrowing Owls, as there was only one nest per territory and therefore unnecessary. We also excluded territories that contained only one nest for Golden Eagles and Ferruginous Hawks.

Raptor territories, random territories, and prey survey plots were classified as within low, medium, or high cheatgrass based on percent mapped cheatgrass cover within each sampling unit as determined with ArcGIS (primary method) or field surveys (prey sampling only). Cheatgrass cover intervals were assigned to each coverage class based on natural breaks that achieved relatively equitable sample sizes in each class. Coverage intervals varied to some degree for each species and in relation to the scale of the sampling unit (i.e., smaller plots were necessarily more likely to cover a broader range of coverage than larger plots). The coverage intervals assigned to low, medium or high cover classes are defined for each analysis in the results.

We used general linear models (GLM) to assess the potential influence of cheatgrass cover (low, medium, or high), and nesting period (incubation, early nestling, or late nestling), and their first-order interactions on total adult nest attendance per observation time. We also assessed the influence of cheatgrass cover on prey abundance GLM. When the analysis revealed a significant main effect, we used plots and post-hoc univariate t-tests to further elucidate differences among categories of that main effect.

Because estimates of "apparent nest success" (i.e., the proportion of observed nests that are successful) often are positively biased by less than complete observation of all nests throughout the entire nesting period (Mayfield 1961, 1975), we used the "logistic-exposure" modeling technique (Shaffer 2004) to estimate nest survival and investigate relevant influences of landscape and climatic variables. Specifically, we produced multiple logistic regression models relating the binomial response variable, nest fate (0 = failed, 1 = successful), to variable nest-observation intervals with a modified logit link function (Shaffer 2004). The modified logit link function took the form g(θ)=loge(θ1/t/[1 - θ1/t]), where θ is the interval survival rate and t is the interval length in days. This method treats observation intervals as sample units and assumes that survival and predictor variables are constant within intervals (T. Shaffer, USGS Northern Prairie Wildlife Research Center, personal communication). We also related nest fate to cheatgrass cover surrounding active nests of Ferruginous Hawks (2-km radius) and Golden Eagles (4-km radius) to assess its influence on nest survival in 2011. Daily and full nest period survival rates were calculated from significant model coefficients (i.e., daily survival rate [DSR] = [e ^(Bo + B1x)]/[1 + e ^(Bo + B1x)]; period survival =DSR^period length).

RESULTS

GENERAL RAPTOR TERRITORY CHARACTERISTICS AND LONG-TERM HISTORY

We compiled data for 167 Golden Eagle, 124 Ferruginous Hawk, and 282 Burrowing Owl territories present and occupied at least once between 2000–2011 (see Appendix 4). The average Golden Eagle territory spacing was 4,499 m. For Ferruginous Hawks, this distance was 3,322 m. Distance between individual Burrowing Owl nests was 1,307 m. For Golden Eagles, with a sample of 108 clusters with more than one nest, the average intra-nest distance within a cluster was 1,031 m; there were 80 Ferruginous Hawk territories with more than one nest and the average intra-nest distance was 659 m.

Peak survey effort for the three focal occurred between 2002–2007. During this period, surveys located 49–63 (mean 55.0) active Golden Eagle breeding pairs per year, 20–41 (mean 32.8) active Ferruginous Hawk breeding pairs, and 43–54 (mean 48.7) occupied Burrowing Owl burrows. We multiplied the average activity per surveyed territory during this period by total concurrently known territories for each species to estimate that these territories may have supported an average of 90 Golden Eagle breeding pairs, 44 Ferruginous Hawk breeding pairs, and 56 occupied Burrowing Owl burrows over this time period.

Golden Eagle nest activity declined from ~50% (1998–2007) to 25% (2008–2011) in conjunction with a number of large wildfires that occurred in the MOA in 2007 (Figure 3). Ferruginous Hawk occupancy and activity rates averaged 43% and 36%, respectively, over the study period and appeared to roughly track drought and moisture conditions (Figure 4).

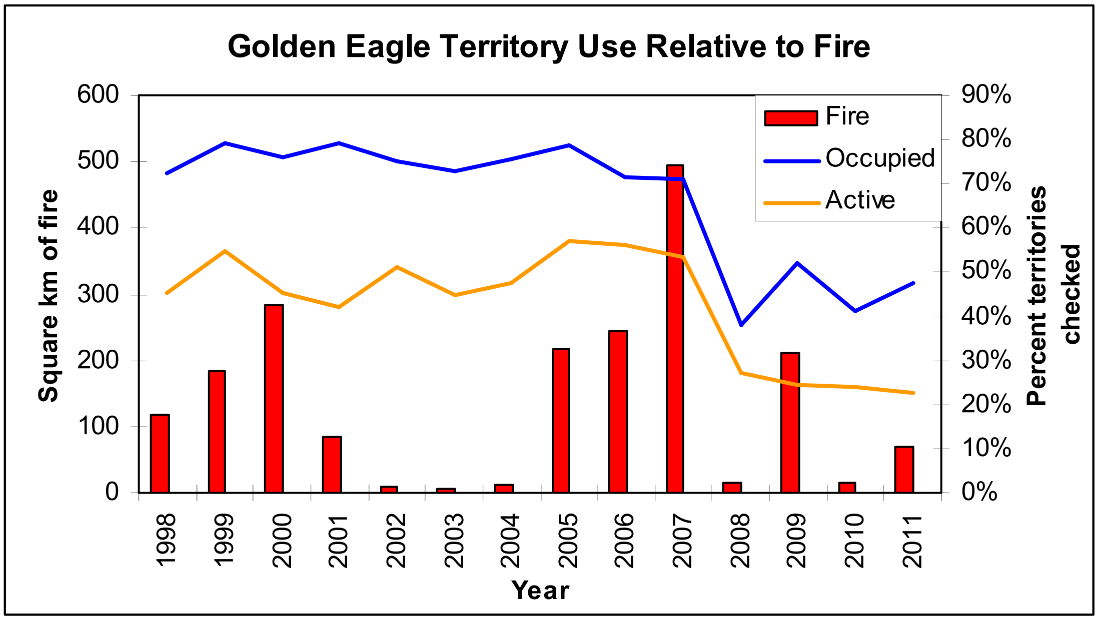


Figure 3. Annual Golden Eagle territory occupancy (i.e., birds present during the breeding season) or activity (i.e., eggs laid) relative to area burned. Occupancy and activity have declined since large areas burned in 2007.

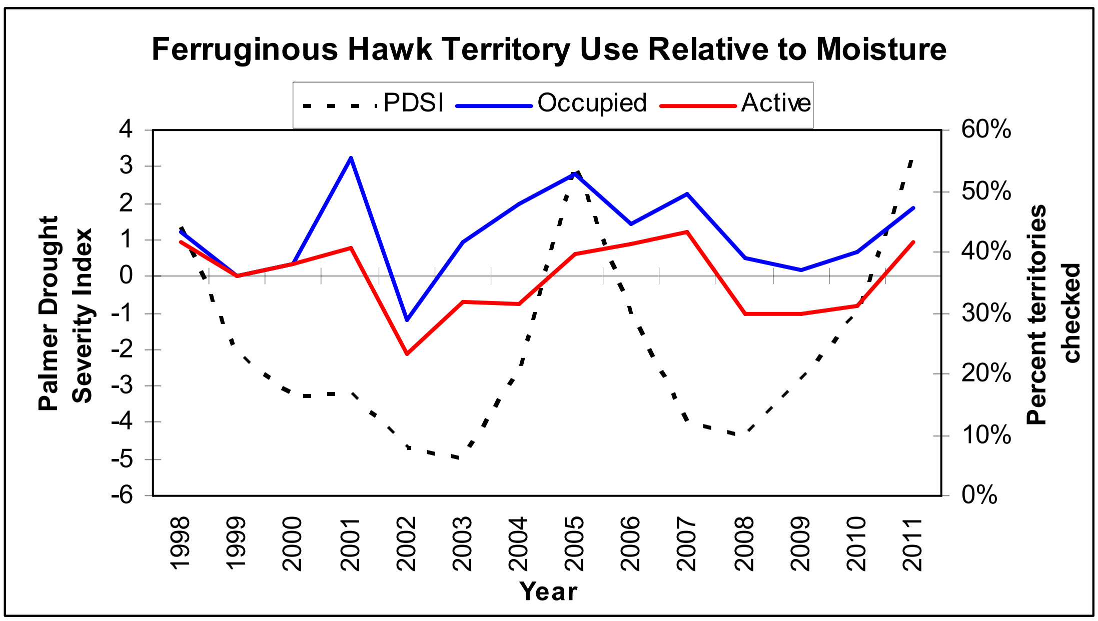


Figure 4. Annual Ferruginous Hawk territory occupancy (i.e., birds present during the breeding season) or activity (i.e., eggs laid) relative to moisture (Palmer Drought Severity Index; higher values = wetter conditions).

Unfortunately, Burrowing Owl annual occupancy and activity trend data cannot be presented in a manner comparable to that for Golden Eagles and Ferruginous Hawks due to biases and changes in survey methods for this species across study years. During early years of the study, active or occupied burrows were located opportunistically while surveying for other raptor species. Additionally, as the number of known burrows increased over time, more time was spent revisiting these known locations, biasing surveys toward a suite of burrows that would necessarily experience a perceived decline in activity, simply due to burrow collapse over time. However, during 2010 and 2011, we employed more intense survey methods for Burrowing Owls, including actively searching specifically for this species from roadways, limited walking transects in previously occupied habitat, and road-based broadcast surveys. Despite this intense effort, only 10–11 occupied territories were located during the last two years, compared to 43–54 located between 2002–2007. Previous and intervening years received reduced survey effort (e.g., HawkWatch did not receive funding to monitor Burrowing Owls in 2008 or 2009) and are not directly comparable. NOTE: we only report on occupancy (i.e., birds present) for Burrowing Owls, as activity (i.e., eggs laid) is difficult to confirm for this subterranean nesting species.

POTENTIAL RAPTOR HABITAT

Golden Eagle Model

The final Golden Eagle Maxent model had an AUC (area under curve) of 0.92 (Table 6). Values approaching 1 for AUC are desirable as a measure of model success, as values closer to 0.5 indicates model performance based on random chance. The model correctly classified 338 of 372 nests, for a misclassification rate of 9% within the study area landscape. The model seemed to fail most in the northwestern portion of the study area (Appendix 5), where the geography and vegetation structure is more similar to the Snake River physiographic region than the Great Basin, which is more typical of the rest of the study area. Other failures occurred where nests were geographically close predicted habitat, or where artificial nest structures were utilized.

Table 6. Maxent modeling results for Golden Eagles, Ferruginous Hawks, and Burrowing Owl nesting habitat in the ULRP study area.

	Maxent		Predicted nesting habitat in study area	
Species	AUC	Threshold	Total	Prime
Golden Eagle	0.92	0.25	10.9%	24.1%
Ferruginous Hawk	0.86	0.31	21.8%	12.1%
Burrowing Owl	0.91	0.31	16.7%	98.7%

The variables that contributed the most to the fitting of the model were slope, ruggedness and elevation (Table 7). Slope is also the variable that has the highest gain when used in isolation, meaning that it contains the most useful information for the model by itself. It also is the variable that decreases the overall gain in the model when omitted, meaning that it has the most information that is not present in the other variables for the overall model (Figure 5).

Table 7. Variable contributions in Maxent models of Golden Eagle nesting habitat in the ULRP study area.

Variable	Percent contribution
Slope	55.1
Ruggedness	24.1
Elevation	18.6
Precipitation	1.4
Aspect	0.7
Landcover	0.2

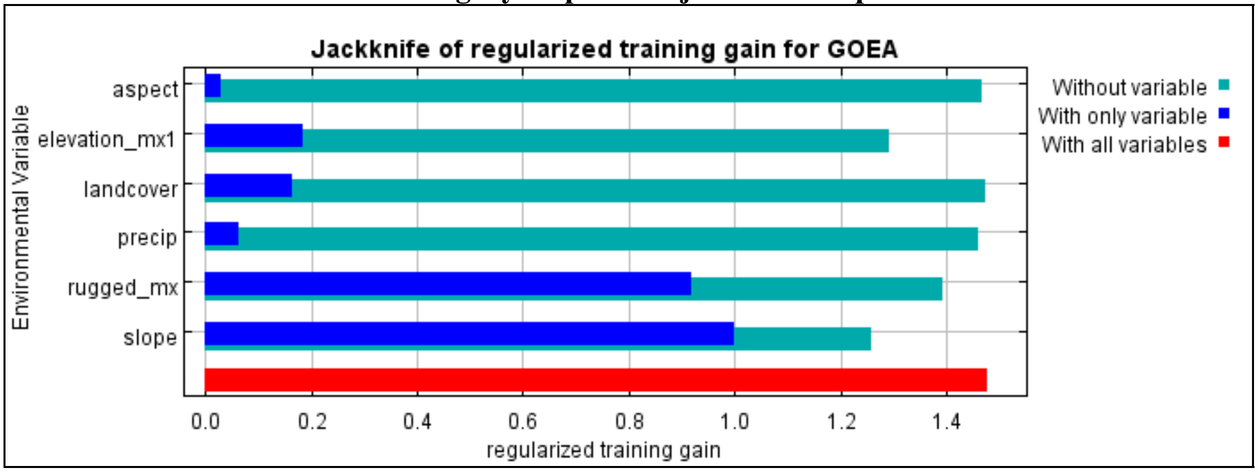


Figure 5. Variable importance in the Golden Eagle nest habitat model. Blue bars indicate model performance with only that variable considered in the overall model. Green indicates gain when the variable is omitted.

Marginal response curves for each variable were generated, depicting the logistic output or probability of presence for the entire range of values for each variable while holding all other variables constant. We report only those variables who contributed the most to the overall model; in the case of Golden Eagles, those are elevation, ruggedness and slope. Probability of presence for Golden Eagle nesting habitat occurs roughly between elevations of 1,000–2,500 m, peaking at around 1,300 m (Figure 6). There may be an elevation bias in our nesting habitat model based on a survey access bias toward lower elevation sites. However, very little (1%) of the study area actually occurred above 2500 m and our results are meant to be applied primarily to similar "desert" eagles that are most common in the study area .

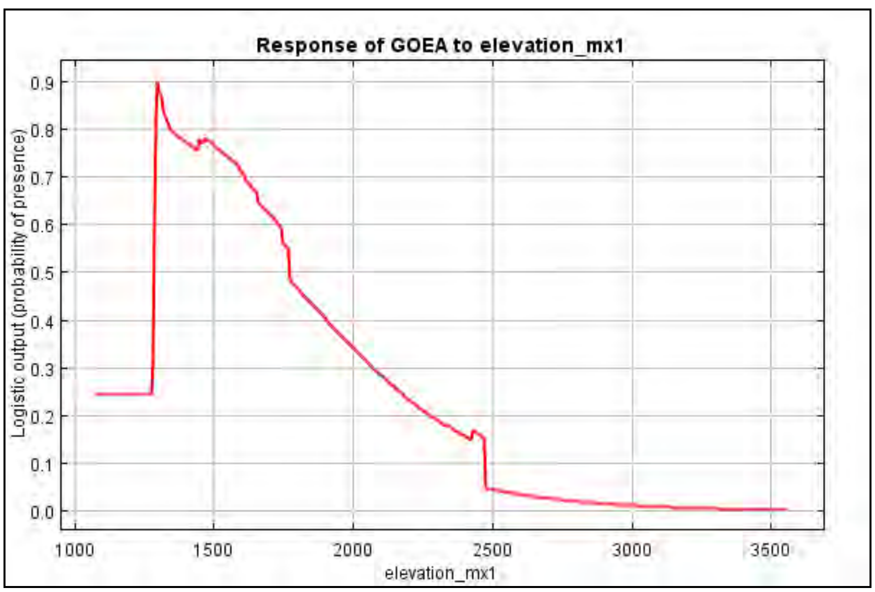


Figure 6. Probability of Golden Eagle nesting habitat in response to elevation in the ULRP study area, with all other variables held constant.

The probability of presence graphs for ruggedness and slope were roughly the same shape (Figures 7A and 7B). As ruggedness and slope increase, so does the likelihood of presence of Golden Eagle nesting habitat.

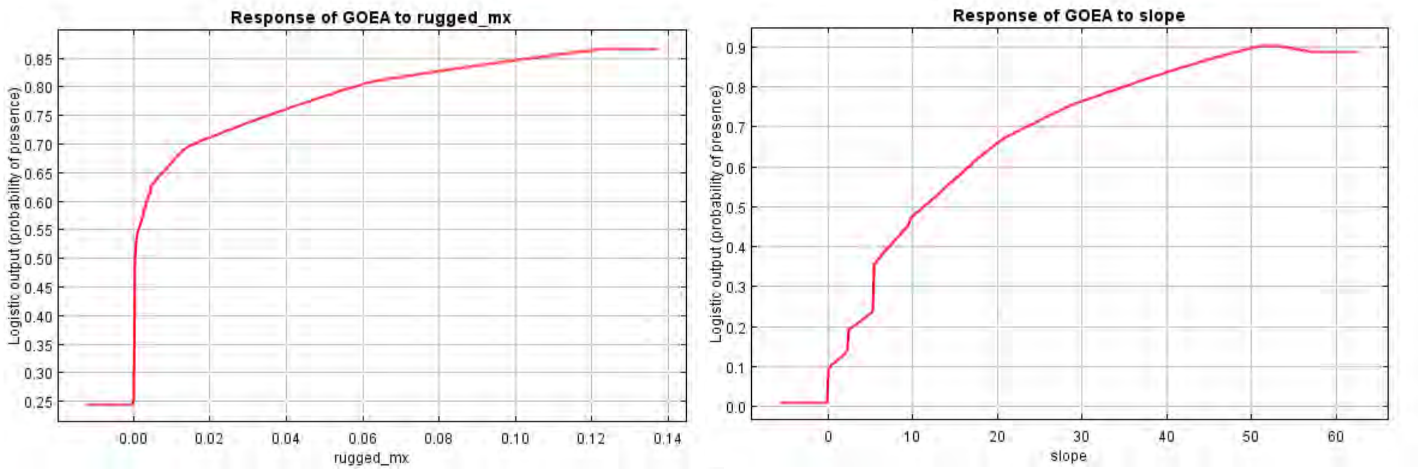


Figure 7A and 7B. Probability of Golden Eagle nesting habitat in response to ruggedness (left) and slope (right) in the ULRP study area, with all other variables held constant.

Ferruginous Hawk Model

The final full model for Ferruginous Hawks had an AUC of 0.86, which was the lowest of all three of our species (Table 6). The threshold rate selected for the model was 0.31. At this threshold, the model correctly classified 308 of the 356 Ferruginous Hawk nests within the study area, for a misclassification rate of 13% (Appendix 6). Elevation and slope were the variables that contributed the most overall to the model fitting (Table 8). Landcover and precipitation each contributed roughly half of what elevation and slope provided in the model. The variable with the highest gain (performance) when used by itself was elevation (Figure 8). This was also the variable that when removed from the overall model, caused the largest decrease in gain for the overall model success.

Table 8. Variable contributions in Maxent models of Ferruginous Hawk nesting habitat in the ULRP study area.

Variable	Percent contribution
Elevation	34.6
Slope	31.8
Landcover	16.6
Precipitation	13
Ruggedness	2.8
Aspect	1.2

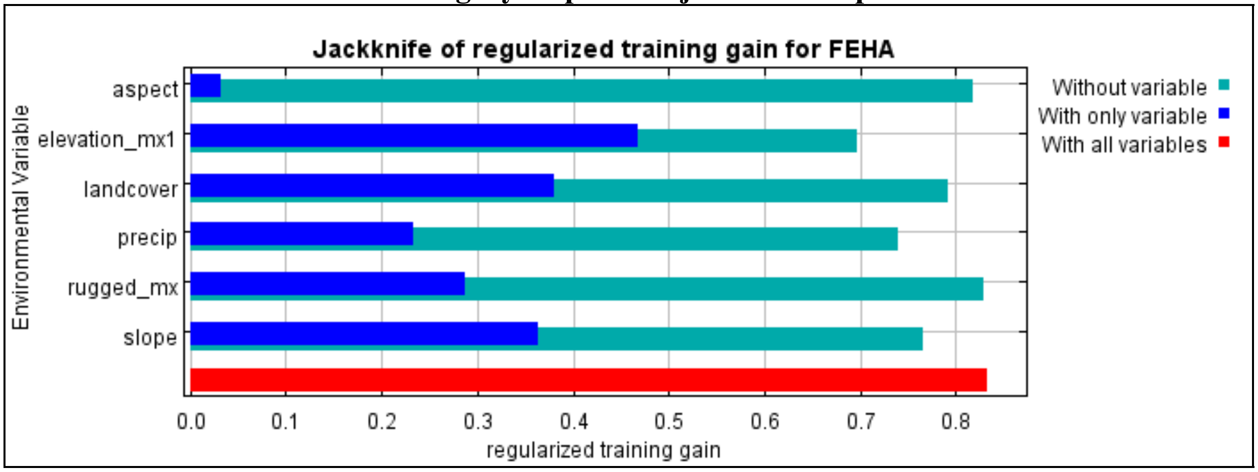


Figure 8. Variable importance in Ferruginous Hawk nest habitat model. Blue bars indicate model performance with only that variable considered in the overall model. Green indicates gain when the variable is omitted.

The likelihood of Ferruginous Hawk nesting habitat presence increases between elevations of about 1,300-1,700 m, at which the likelihood declines until it levels off after 2,000 m in elevation (Figure 9). For slope, the likelihood of habitat presence increases dramatically in flat areas (roughly 0 to 5) and declines with greater slopes (Figure 10). The landcover types that have increased probability of habitat presence are upland shrub, desert shrub and grassland (Figure 11).

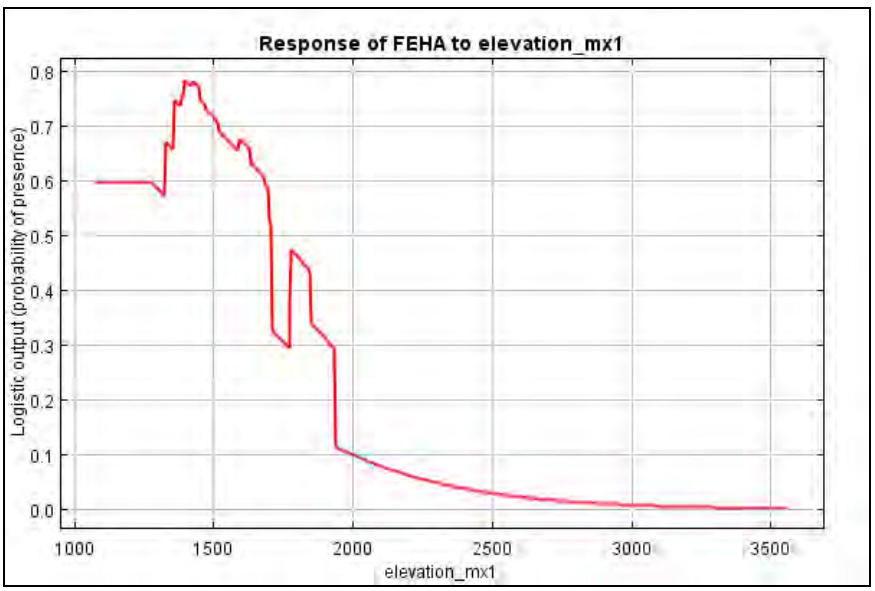


Figure 9. Probability of Ferruginous Hawk nesting habitat in response to elevation in the ULRP study area, with all other variables held constant.

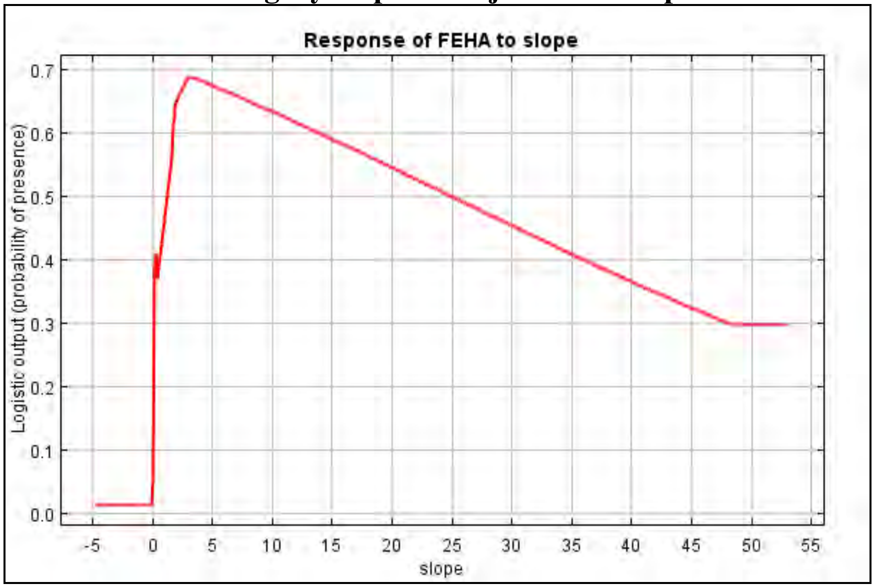


Figure 10. Probability of Ferruginous Hawk nesting habitat in response to slope in the ULRP study area, with all other variables held constant.

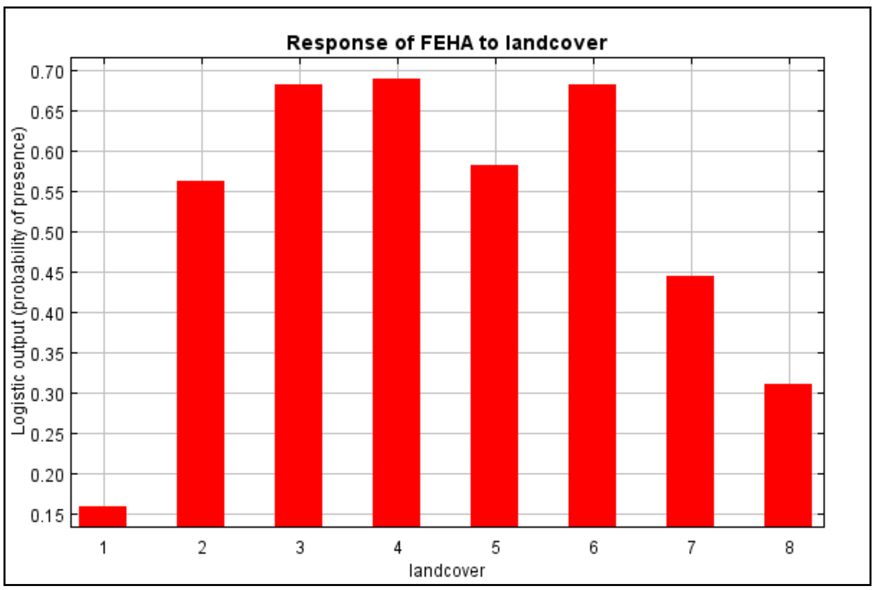


Figure 11. Probability of Ferruginous Hawk nesting habitat in response to landcover type (1-Barren; 2-Cliff and Rock; 3-Upland Shrub; 4-Grassland; 5-Human landscape; 6-Desert Shrub; 7-Water; 8-Woodland) in the ULRP study area.

Burrowing Owl Model

The Maxent output for Burrowing Owls had an AUC of 0.91 (Table 6). The model had the highest rate of misclassification of the three species, with a rate of 17% (correctly classifying 227 out of 272 nests; Appendix 7). Elevation and landcover were roughly equal in contribution to the overall final model (Table 9). The variable that had the highest gain in a model when used by itself was landcover. The variable that caused the largest decrease in overall model gain when omitted from the entire model was elevation, meaning that it contains the most information not present in other variables in the overall model (Figure 12).

Table 9. Variable contributions in Maxent models of Burrowing Owl nesting habitat in the ULRP study area.

Variable	Percent contribution
Elevation	39.3
Landcover	32.5
Soil Depth	9.4
Precipitation	9.3
Slope	4.9
Aspect	1.9
Ruggedness	2.7

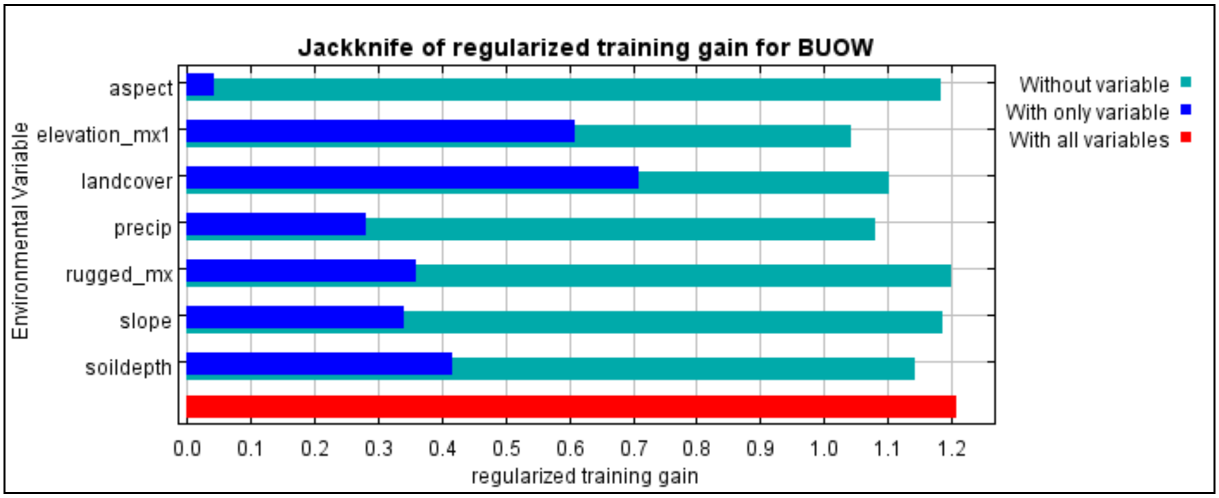


Figure 12. Variable importance in the Burrowing Owl nest habitat model. Blue bars indicate model performance with only that variable considered in the overall model. Green indicates gain when the variable is omitted.

Probability of presence of burrowing owl habitat increased for elevation values between about 1,300–1,700 m, peaking between 1,300–1,400m (Figure 13). Likelihood of habitat presence decreased and approached zero over elevations of about 1,700 m. The landcover type most associated with high likelihood of presence for burrowing owl habitat was grassland (Figure 14). Mid ranges of values for soil depth were more associated with presence of habitat than shallower soils (Figure 14). The poorer performance of the Burrowing Owl model is likely due to our inability to locate a study area-wide soil type map or to account for the presence or absence of burrowing mammals in the landscape (since Burrowing Owls do not excavate their own burrows, their presence is completely dependent on the burrowing mammal activity).

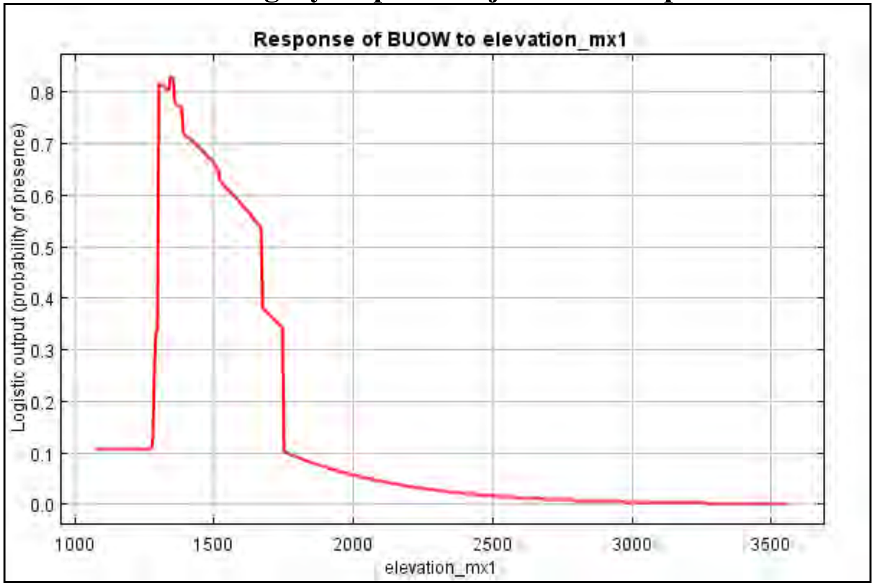


Figure 13. Probability of Burrowing Owl nesting habitat in response to elevation in the ULRP study area, with all other variables held constant.

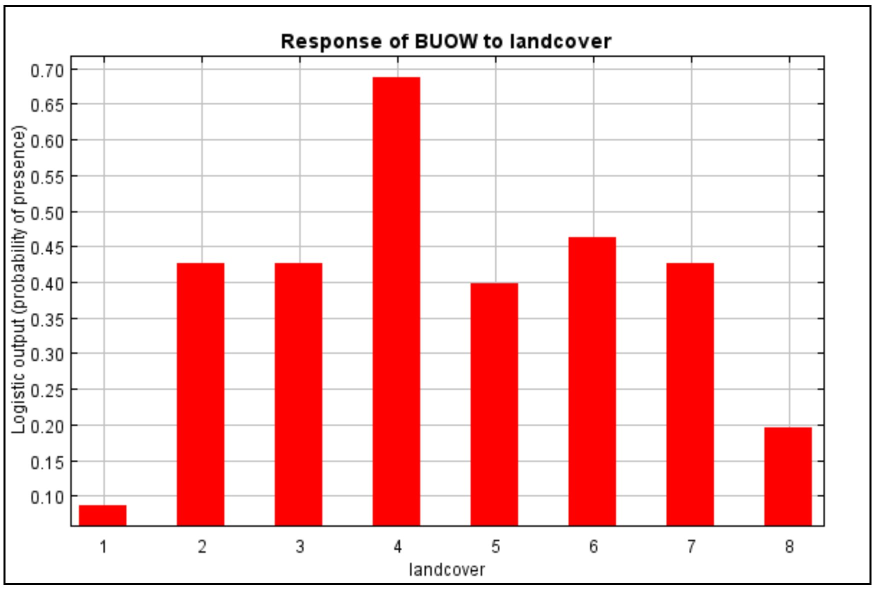


Figure 14. Probability of Burrowing Owl nesting habitat in response to landcover type (1-Barren; 2-Cliff and Rock; 3-Upland Shrub; 4-Grassland; 5-Human landscape; 6-Desert Shrub; 7-Waterl; 8-Woodland) in the ULRP study area.

Primary Potential Habitat of Focal Species

We used discriminant function analysis to distinguish between known territories and random territories created within potential nesting habitat identified by Maxent (previous section) based on 8 simplified study area vegetation variables (see methods). Discriminant functions were able to correctly distinguish between 72%, 68%, and 62% of known and random Golden Eagle, Ferruginous Hawk, and Burrowing Owl territories, respectively. The discriminant functions suggested all three species were positively association with grasslands and (Table 10). Golden Eagles were also positively associated with desert shrub and barren lands. Grasslands and human landscapes were most important for Ferruginous Hawk. Grassland cover was of disproportionate importance to Burrowing Owls, but this species was also positively related to desert shrub and human lands, and negatively related to water (Table 10).

Table 10. Standardized discriminant function scores for variables used to distinguish known and random territories in the ULRP study area. Bolded values are >0.3 (i.e., important to function interpretation).

	Golden Eagle	Ferruginous Hawk	Burrowing Owl
Grassland	**0.75**	**0.62**	**1.17**
Human	0.22	**0.77**	**0.34**
Barren	**0.41**	-0.22	-0.23
Desert shrub	**0.62**	0.12	**0.38**
Water	0.09	-0.07	**-0.33**
Cliff and rock	-0.10	-0.28	-0.12
Upland shrub	0.17	-0.11	0.17
Woodland	0.00	0.00	0.00

Potential Golden Eagle, Ferruginous Hawk, and Burrowing Owl nesting habitat is present within 11%, 22%, and 17% of the study area, respectively (Table 11). When potential habitat is filtered by landscape context (i.e., "primary potential habitat"; see methods), the amount of area is reduced to approximately 3% for both Golden Eagles and Ferruginous Hawks, but remains unchanged for Burrowing Owls, likely due to the limited ability of discriminant analysis to distinguish between known and random territories within potential habitat for this species. Known Golden Eagle territories occupy 61% of prime habitat, compared to 27% for Ferruginous Hawks, and 4% for Burrowing Owls (Table 11). The small percentage of potential nesting habitat occupied by known Burrowing Owl territories is likely due to the poorer performance of these for reasons previously discussed. Most importantly, our models may predict considerable amounts of attractive nesting habitat for this species in the study area, but nest site and landscape characteristics are irrelevant if no burrows are available in an area. See Appendices 8–10 for visual displays of all and primary potential nesting habitat for each species within the study area.

Table 11. Potential nesting habitat by species in ULRP study area and relative to known territories. Excludes barren and water cover (i.e., unavailable areas).

Species	Variable	Proportion of study area	Proportion of potential habitat occupied by known territories
Golden Eagle	Potential nesting habitat	10.9%	32.1%
	Primary potential habitat	2.6%	61.0%
Ferruginous Hawk	Potential nesting habitat	21.8%	11.6%
	Primary potential habitat	2.6%	26.7%
Burrowing Owl	Potential nesting habitat	16.7%	4.4%
	Primary potential habitat	16.5%	4.4%

For DoD lands within the study area, 4.4% is considered potential nesting habitat for Golden Eagles, while 2.8% of DoD lands contain potential nesting habitat surrounded by landscapes similar to known eagle territories (i.e., prime potential habitat; Table 12). Overall, it appears that DoD lands support lower proportions of potential habitat of all three focal species relative to the study area at large, although Golden Eagle primary potential habitat is similar (see Table 11 and 12). Ferruginous Hawk potential habitat in particular is less common on DoD lands, and it also appears this species may be under-surveyed there, given the difference between the proportion of potential habitat occupied by known territories on DoD lands (2–6%) compared to the study area in general (12–27%).

Table 12. Potential nesting habitat by species in DoD controlled lands within the ULRP study area and relative to known territories. INCLUDES barren and water cover.

Species	Variable	Proportion of DoD land	Proportion of potential habitat occupied by known territories on DoD land
Golden Eagle	Potential nesting habitat	4.4%	41.7%
	Primary potential habitat	2.8%	43.4%
Ferruginous Hawk	Potential nesting habitat	6.8%	1.9%
	Primary potential habitat	1.1%	6.3%
Burrowing Owl	Potential nesting habitat	8.7%	2.4%
	Primary potential habitat	8.5%	2.5%

Most potential prime nesting habitat not contained within currently known territories occurs in under-surveyed areas and we assume these areas may support similar territory densities and nest activity rates as the known study area. Given this assumption, we can estimate that the overall study area may support an estimated 274 Golden Eagle, 464 Ferruginous Hawk and 2955 Burrowing Owl territories (i.e., total # known territories/potential prime nesting habitat occupied by known territories). Multiplying these total territory estimates by average territory activity during the peak survey period (2002–2007; see long-term history discussion) suggests the area may have supported an estimated 148 Golden Eagle and 165 Ferruginous Hawk active breeding pairs and 1,262 occupied Burrowing Owl burrows during this time. We have very little confidence in the Burrowing Owl territory and occupancy estimates due to the poor performance of the combined Maxent and discriminant function models and their dependency on burrowing mammals. It is also important to note that Golden Eagle territory activity has declined approximately 50% since this period and Burrowing Owl occupancy is also perceived to have declined.

CHEATGRASS OCCURRENCE AND INVASION RISK

The final products from the USU effort were 12 annual cheatgrass presence probability maps for the course of the study (2000-2011; 250-m resolution.) Each annual probability map was converted to a binary presence (i.e., ≥0.5 probability)/absence map to assess trends in coverage during the study. Cheatgrass cover ranged between 6.4–9.3% on an annual basis between 2000 and 2011 and appeared to vary in direct response to moisture conditions (Figure 15). Cheatgrass cover in 2011 was below that expected, perhaps due to below average temperatures during the spring.

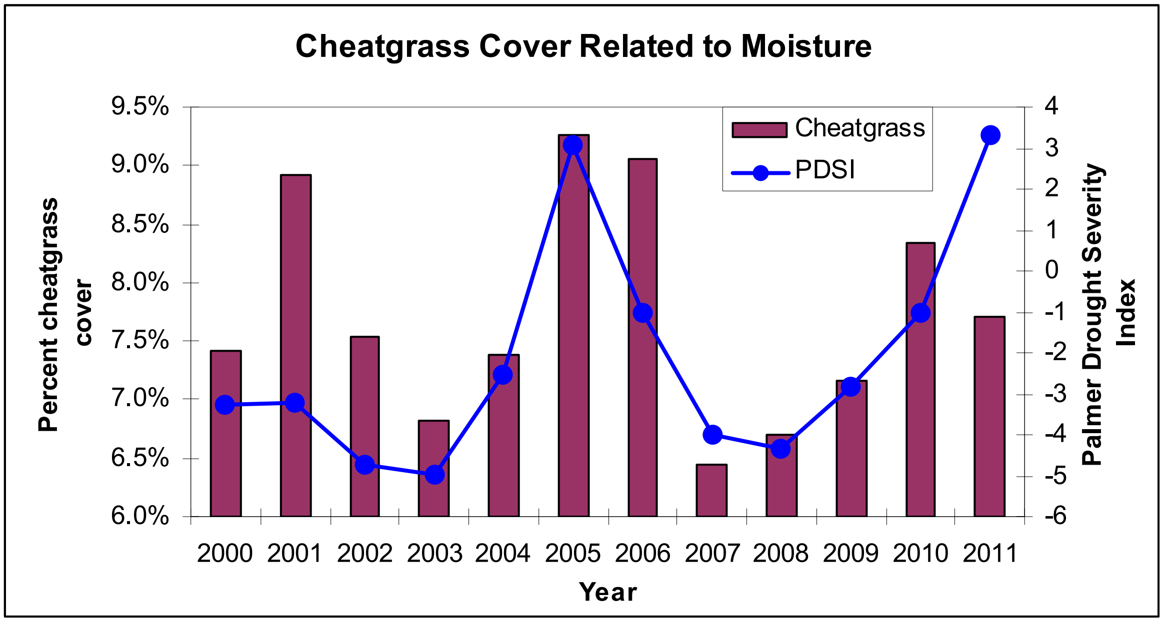
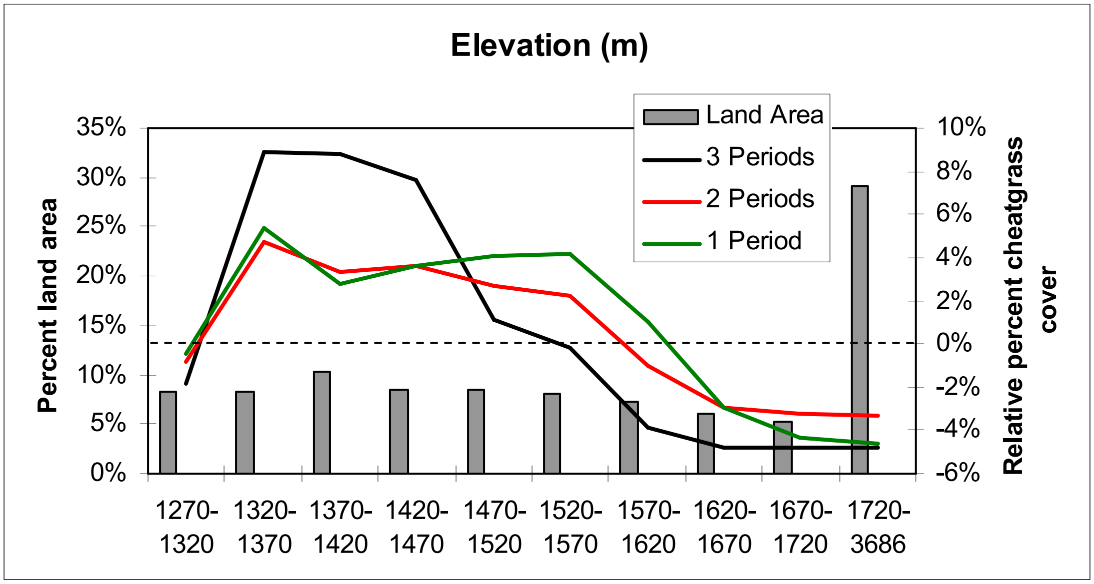


Figure 15. Cheatgrass coverage in the ULRP study area related to moisture (Palmer Drought Severity Index).

Cheatgrass cover was present in 4.7%, 3.3%, and 4.8% of the study area during 1, 2, and 3 of the study time periods, respectively (see Appendix 8). Not surprisingly, areas with cheatgrass present during only 1 or 2 time period, were on the fringes of areas with long-term cheatgrass presence. It is likely that cheatgrass spreads and contracts into these neighboring areas during wet and dry years, as suggested by Figure 15.

Comparing study area-wide cheatgrass presence and absence to environmental variables with MCE (see methods) revealed that cheatgrass was more common between 1,320–1,520 m, slightly more common on west-to-northwest, and east-to-northeast aspects, and more common on slopes between 1–11º (Figure 16A). Cheatgrass was also more common in areas averaging 24–34 cm of annual precipitation and in areas with higher soil water capacity (i.e., 5–12; Figure 16B). Cheatgrass was more common proximate to human landscapes (i.e., agriculture and urbanization), gradually declining through 6 km, beyond which cheatgrass became less common (Figure 16C). Similarly, cheatgrass was more common near linear features (i.e., roads and powerlines) through 1 km, beyond which it became less common (Figure 16C; note the sharp increase in the last distance band is likely a spurious result driven the fact that <1% of study area occurred in this band).

We created an invasion risk map based on the relative probabilities of cheatgrass presence associated with study area elevation, aspect, soil water capacity, and distance to linear and human (Appendix 9). The risk map, combined with actual cheatgrass occurrence, suggests that 8.2% of the study area is currently invaded by cheatgrass, 17.8% is at considerable risk (≥0.5 probability) of future invasion, while 74.1% is at low risk. Cheatgrass occurrence is most prevalent in the north and central eastern portion of the study area, while future invasion risk is most pronounced in the western and southern portions (Appendix 10). We suggest these patterns are likely driven by proximity to human population. That is, the current highly invaded areas are closer to major population concentrations, while those at high risk, but currently un-invaded are further away.



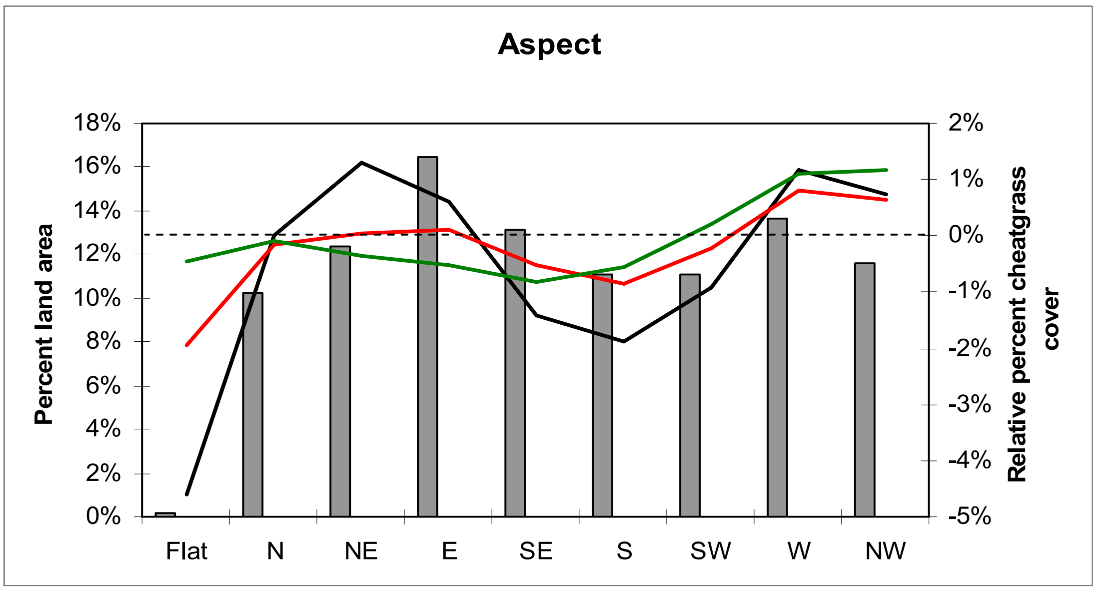


Figure 16A. Cheatgrass association with elevation and aspect relative to cheatgrass in the ULRP study area overall.

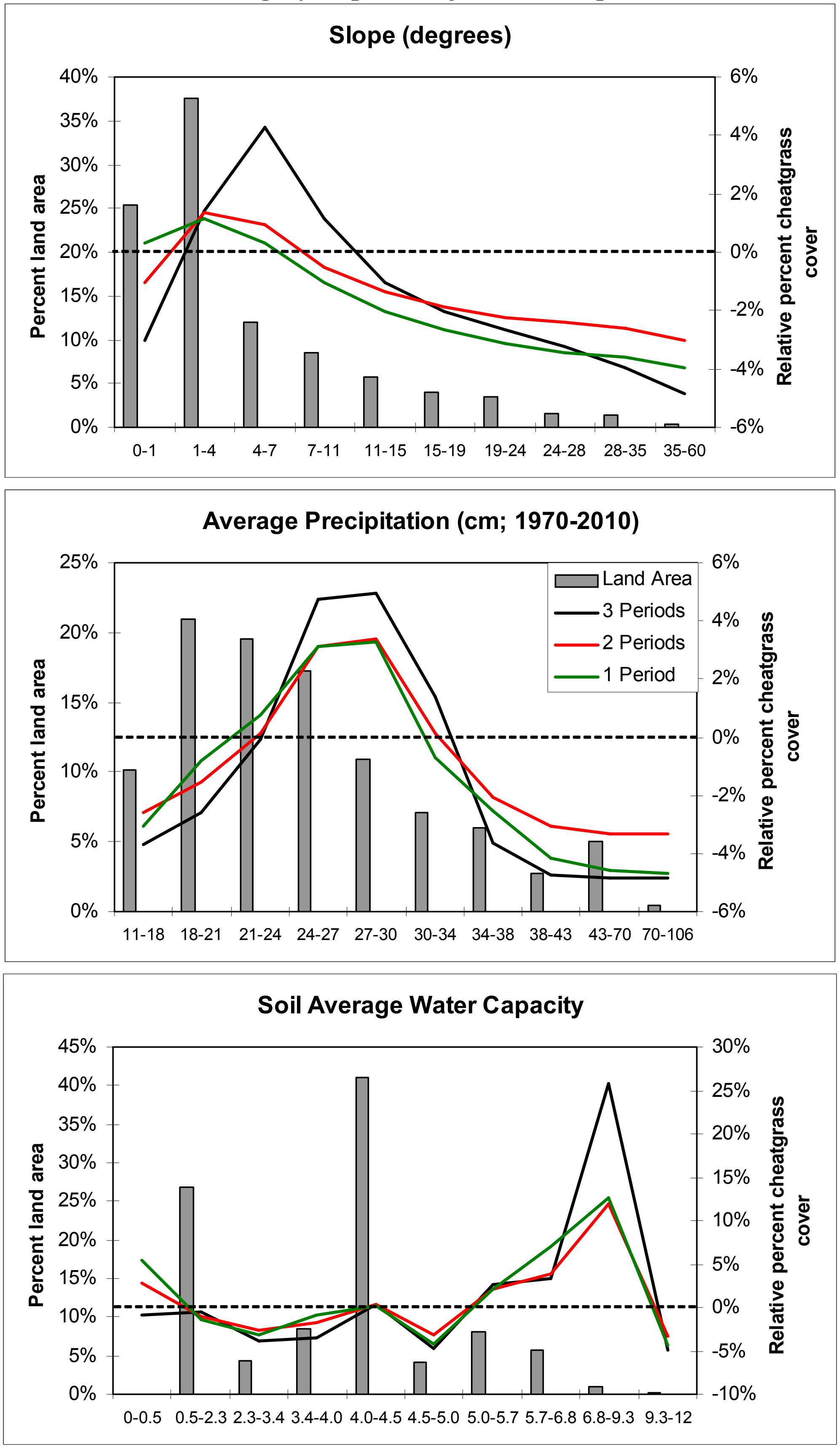


Figure 16B. Cheatgrass association with slope, average precipitation, and soil water capacity relative to cheatgrass in the ULRP study area overall.

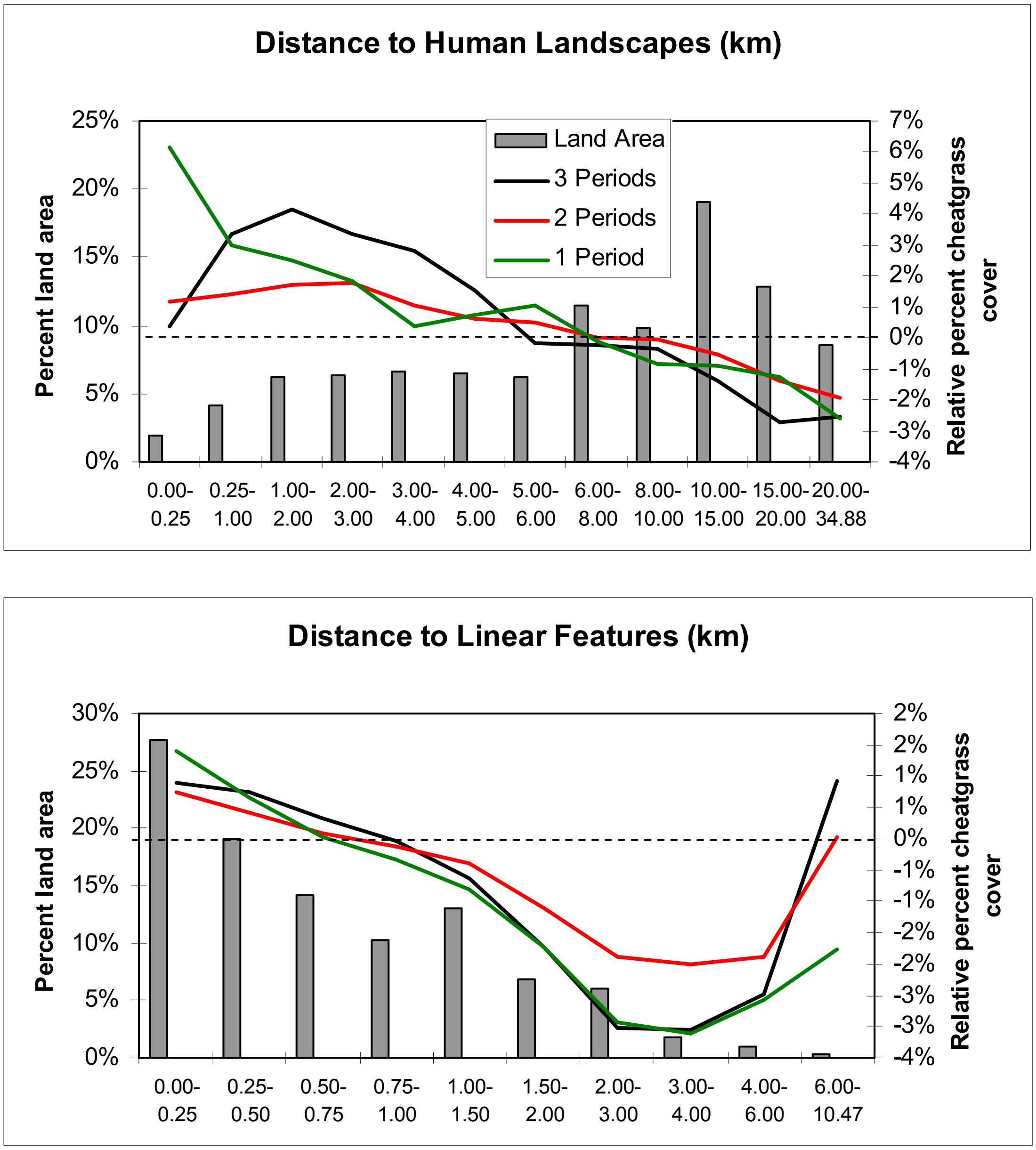


Figure 16C. Cheatgrass association with distance to human landscapes and linear features relative to cheatgrass in the ULRP study area overall.

RAPTORS, PREY, AND CHEATGRASS

Cheatgrass is present within 8.2% of the study area, but is more common at Golden Eagle (24.1%), Ferruginous Hawk (33.1%), and Burrowing Owl territories (40.4%). The area surrounding potential prime nesting habitat for each focal species also contains higher amounts of cheatgrass than the study area in general (Table 12). These areas are at very similar risk for future cheatgrass invasion as known territories, with 18–20% of Golden Eagle, 27–29% of Ferruginous Hawk, and 34–35% of Burrowing Owl known and potential habitat at future risk (Table 12).

Table 13. Cheatgrass presence and invasion risk in known raptor territories and surrounding potential prime nesting habitat within the ULRP study area. Potential prime habitat was buffered by the same spatial extent as known territories for this comparison.

Area	Cheatgrass present	No cheatgrass, high risk	No cheatgrass, low risk
Study area	8.2%	17.8%	74.1%
Golden Eagle territories	24.1%	18.1%	57.8%
Potential prime Golden Eagle nesting habitat	28.3%	20.1%	51.5%
Ferruginous Hawk territories	33.1%	27.0%	39.9%
Potential prime Ferruginous Hawk nesting habitat	41.5%	28.8%	29.6.3%
Burrowing Owl territories	40.4%	33.5%	26.1%
Potential prime Burrowing Owl nesting habitat	24.9%	34.8%	40.3%

[a] Potential Cheatgrass cover was significantly higher at known territories relative to "random territories" in potential nesting habitat for Golden Eagles ($t = -6.04$, $df = 332$, $P < 0.001$), Ferruginous Hawks ($t = -3.663$, $df = 246$, $P < 0.001$), and Burrowing Owls ($t = -5.791$, $df = 562$, $P < 0.001$; Table 13; Figure 17).

DoD lands overall are more invaded (15.8%) by cheatgrass compared to the study area at large (8.2%) and contain a greater percentage of lands at future risk of invasion (Table 14). However, for Burrowing Owls and Golden Eagles, known territories and potential prime habitat is currently less invaded by cheatgrass compared to the study area (see Tables 13 and 14). In contrast, Ferruginous Hawk territories are more invaded (47%) compared to all study area territories (33%). For all three focal species, there is a higher percentage of known territories and potential prime habitat on DoD lands that are considered at "high risk" for cheatgrass invasion compared to the study area overall (see Tables 13 and 14).

Table 14. Cheatgrass presence and invasion risk in known raptor territories and surrounding potential prime nesting habitat within DoD–managed lands in the ULRP study area.

Area	Cheatgrass Present	No cheatgrass, high risk	No Cheatgrass, Low risk
DoD-managed lands	15.8%	26.0%	58.2%
Golden Eagle territories	22.1%	32.6%	41.4%
Potential prime Golden Eagle nesting habitat	10.1%	27.9%	53.3%
Ferruginous Hawk territories	47.2%	40.1%	10.9%
Potential prime Ferruginous Hawk nesting habitat	40.2%	39.5%	17.2%
Burrowing Owl territories	21.4%	41.8%	35.2%
Potential prime Burrowing Owl nesting habitat	19.6%	35.7%	42.2%

Table 15. Cheatgrass cover at known raptor territories compared to random territories in potential habitat.

Species	Comparison	*n*	Cheatgrass cover	S.E.
Golden Eagle	Known Territory	167	24.1% A	1.6%
	Random Territory	167	10.9% B	1.5%
Ferruginous Hawk	Known Territory	124	33.1% A	2.7%
	Random Territory	124	19.7% B	2.4%
Burrowing Owl	Known Territory	282	40.4% A	1.9%
	Random Territory	282	24.8% B	1.9%

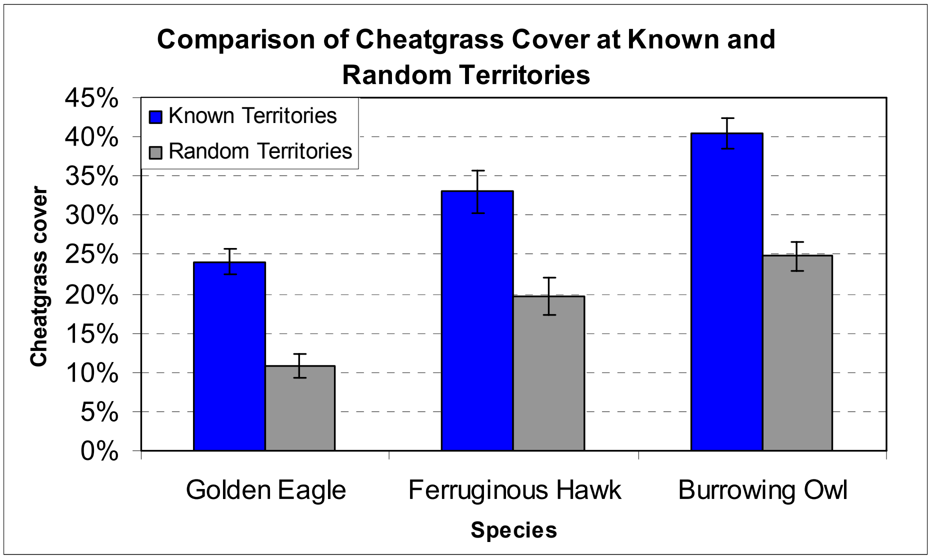


Figure 17. Cheatgrass cover at known and random raptor territories in the ULRP study area.

We also compared the performance of three correlated variables, cheatgrass cover, risk of cheatgrass invasion, and grassland cover, in individual logistic regression models to determine their relative importance in distinguishing between random and known raptor territories. Cheatgrass cover itself was not considered competitive with models that included invasion risk or grassland cover in its place (Table 14). This suggests the higher cover of cheatgrass at known territories may be spurious and due to its correlation with these other factors.

Table 16. Relative importance of logistic regression models distinguishing between known and random raptor territories. Bolded models are considered of top importance (i.e., <ΔAIC<2.0).

Species	Model	AIC	ΔAIC	w_i
Golden Eagle	**Invasion risk**	426.98	0.00	0.89
(*n* = 334)	Cheatgrass cover	432.36	5.38	0.06
	Grassland cover	432.67	5.69	0.05
Ferruginous	**Invasion risk**	332.39	0.00	0.55
Hawk	**Grassland cover**	333.68	1.29	0.29
(*n* = 248)	Cheatgrass cover	334.76	2.37	0.17
Burrowing	**Grassland cover**	742.85	0.00	0.99
Owl	Cheatgrass cover	753.64	10.79	<0.01
(*n* = 564)	Invasion risk	779.78	36.93	<0.01

Note: AIC = Akaike's Information Criterion; w_i = Akaike's weight, indicating probability of the model, given the data (Burnham and Anderson 2002).

Cheatgrass cover varied at focal species territories, perceivably in response to moisture conditions (see Figure 4). However, there was minimal (<5%) net increase in cheatgrass cover from the early period (2000–2003) to late period (2008–2011). As a result, we were unable to assess breeding response to changes in cheatgrass cover. In general, cheatgrass cover class (i.e., low, medium, high), study period (i.e., 2000–2003, 2004–2007, 2008–2011), or their interactions were not significant ($P > 0.05$) predictors of territory activity, nest success, or productivity per successful nest for our focal species. The exceptions were the Ferruginous Hawk, for which territory activity differed significantly ($F = 5.05$, df = 2, $P = 0.008$) in relation to cheatgrass cover, and the Golden Eagle, for which territory activity differed ($F = 20.96$, df = 2, $P < 0.001$) by study period. Univariate tests revealed Ferruginous Hawk territory activity was lower in medium cover, relative to low (t = 3.07, df = 80, *P* = 0.003) or high cheatgrass cover (t = 2.58, df = 70, *P* = 0.012; Table 15).

Table 17. Ferruginous Hawk territory activity relative to cheatgrass cover class.

Comparison	Category	*n*	Territory activity	S.E.
Cheatgrass cover	Low (0–10%)	52	44.0% A	4.5%
	Medium (11–50%)	30	23.3% B	4.1%
	High (>50%)	42	38.9% A	4.2%

[a]Variables that differ significantly (*P*<0.05) based on univariate post-hoc tests are denoted with different letters (within comparison only).

Golden Eagle territory activity was low during 2008–2011 compared to the 2000–2003 (t = 4.93, df = 150, *P* <0.001) and 2004–2007 periods (t = 6.27, df = 150, *P* <0.001; Table 16), as was also previously visible in Figure 3.

Table 18. Golden Eagle territory activity relative to study period (NOTE: this analysis was restricted to territories surveyed at least twice during each 4-year period).

Comparison	Category	*n*	Territory activity[a]	S.E.
Study period	Years 2000–2003	76	48.9% A	3.7%
	Years 2004–2007	76	58.1% A	4.2%
	Years 2008–2011	76	24.0% B	3.3%

[a]Variables that differ significantly (*P*<0.05) based on univariate post-hoc tests are denoted with different letters (within comparison only).

Although only the Ferruginous Hawk differed significantly in activity by cheatgrass cover (previous discussion; see Table 15), territory activity was highest in low cheatgrass for all three species (Table 17). Similarly, nest success was highest in low cheatgrass for Golden Eagles and Burrowing Owls, and highest in medium cover for Ferruginous Hawks. Productivity per successful nest was also highest in low cheatgrass for Burrowing Owls and similarly high in low and medium cheatgrass for Golden Eagles. In contrast, Ferruginous Hawk productivity increased across cheatgrass cover (Table 17). As a result, total output (chicks per known territory) is highest for Golden Eagles and Burrowing Owls in low cheatgrass. Ferruginous Hawk output is similar in high and low, but depressed in medium cover, driven by the significantly lower territory there (Table 17).

Table 19. Focal species territory activity, nest success, and productivity by cheatgrass cover class in the ULRP study area, 2000–2011. The highest values in each comparison are bolded.

Species	Cheatgrass Cover	*n*	Territory activity	*n*	Nest success	*n*	Prod.[a]	Output[b]
Golden Eagle	Low (0–10%)	62	**46.7%**	50	**65.9%**	44	1.33	**0.41**
	Medium (11–40%)	67	44.2%	44	60.7%	36	**1.35**	0.36
	High (>50%)	38	40.7%	31	56.4%	25	1.22	0.28
Ferruginous Hawk	Low (0–10%)	52	**44.0%**	40	74.4%	35	2.08	0.68
	Medium (11–50%)	30	23.3%	20	**79.6%**	18	2.20	0.41
	High (>50%)	42	38.9%	37	75.7%	33	**2.33**	**0.69**
Burrowing Owl	Low (0–10%)	81	**55.8%**	24	**62.5%**	16	**4.81**	**1.68**
	Medium (11–50%)	77	53.2%	23	47.8%	11	2.85	0.73
	High (>50%)	124	54.7%	32	60.9%	20	3.88	1.29

[a] Productivity (number of chicks reaching ≥80% fledge age) per successful nest.
[b] Chicks produced per known territory (i.e., product of activity, nest success, and productivity).

We considered the possibility that areas of medium/high cheatgrass invasion risk were inherently more productive/attractive raptor habitat in general, thereby potentially confounding the negative impact of cheatgrass presence on raptor activity. To explore this theory, we selected all medium and high risk cheatgrass areas and classified them as at/above their cheatgrass potential (i.e., mapped cover class equal or greater than risk) or below risk potential (e.g., medium or high risk, but low cover). We then tested whether areas of similar cheatgrass risk, but of lower actual cheatgrass cover received higher raptor activity than those at or above their cheatgrass potential. There was no significant difference between the groups ($P > 0.1$ for all results) for all three focal species despite reasonable sample sizes (i.e., $n > 45$ for all species/category combinations).

Results from the 2011 Field Season

In 2011, we surveyed 84 Golden Eagle and 53 Ferruginous Hawk territories. Overall, Golden Eagle territory occupancy and activity were low at 48% and 23%, respectively, compared to the 1998–2007 averages of 75% and 50%, but values were similar to the 2008–2010 averages of 44% and 25% (see Figure 3). This suggests that the marked decline in occupancy and nest activity for Golden Eagles following major fires in 2007 continues in the study area. Ferruginous Hawk occupancy and activity were 47% and 42%, respectively, and were above the long-term (1998–2010) averages of 43% and 35% (see Figure 4).

Logistic-exposure modeling (Shaffer 2004) of 2011 Ferruginous Hawk nest observation interval data (n = 90; 22 active nests) produced a daily nest survival estimate of 99.4% and full nesting period (76 days) nest survival rate of 65.4%. Golden Eagle daily nest survival was 98.2% (n = 64 observation intervals; 19 active nests), equating to a full nesting period (106 days) nest survival rate of 13.8%. Cheatgrass cover surrounding Ferruginous Hawk nests did not have a significant influence ($z = -0.58$, $df = 89$, $P = 0.56$) on nest survival rates in 2011. Similarly, Golden Eagle nest survival in 2011 did not differ significantly ($z = 0.50$, $df = 63$, $P = 0.62$) in relation to cheatgrass cover within 4 km of nests. The number of chicks fledged per active nest also did not differ by categorical cheatgrass cover (i.e., low = <25%; high ≥25%) surrounding nests of Ferruginous Hawks ($t = -0.28$, $df = 20$, $P = 0.78$) or Golden Eagles ($t = -0.11$, $df = 17$, $P = 0.91$). Table 18 summarizes breeding season activity of the two species during 2011.

Table 20. Nesting season activity in the ULRP study area in 2011 relative to low (<25%) or high (≥25%) cheatgrass cover (cover classes were simplified for this analysis due to low sample sizes).

	Ferruginous Hawk		Golden Eagle	
	Low cheatgrass	High cheatgrass	Low cheatgrass	High cheatgrass
Territories surveyed	31	22	40	44
Territories occupied (%)	12 (39%)	13 (59%)	18 (45%)	22 (50%)
Territories active (%)	11 (35%)	11 (50%)	9 (23%)	10 (23%)
Period nest survival[a]	70%	62%	11%	17%
Chicks/active nest (S.D.)	2.18 (1.47)	2.00 (1.55)	0.22 (0.44)	0.20 (0.42)

[a]Cheatgrass cover was a continuous variable in the survival modeling; therefore, we substituted low (10%) and high (40%) cover values to calculate period survival

Golden Eagle and Ferruginous Hawk nests found to be active were monitored for 143.5 and 191.9 hours, respectively, during the 2011 intensive 2-hr monitoring sessions (excludes observation time during first visits to determine nest status). For Golden Eagles, nest attendance (i.e., ratio of total adult time at nest/total survey time) was significantly ($F = 22.01$, $df = 2$, $P < 0.001$) related to nest period stage (i.e., incubation, early nestling [0–30 days], late nestling [31–64 days]), and univariate post-hoc tests revealed attendance declined significantly each period (Table 19). Cheatgrass cover ($F = 2.90$, $df = 2$, $P = 0.066$) approached significance, but its interaction with stage did not ($F = 1.14$, $df = 4$, $P = 0.353$). Univariate tests suggested attendance was significantly lower (t = -2.25, df =31, P = 0.032) in areas of high cheatgrass cover compared to areas of low cover (Table 19).

Table 21. Golden Eagle nest attendance relative to nest stage and cheatgrass cover in the ULRP study area, 2011.

Comparison	Category	*n*	Nest attendance[a]	S.E.
Nesting period stage	Incubation	25	0.96 A	0.05
	Early nestling (0–30 days)	13	0.65 B	0.13
	Late nestling (31–64 days)	12	0.04 C	0.02
Cheatgrass cover	Low (0–8%)	8	0.91 A	0.11
	Medium (19–34%)	17	0.78 AB	0.11
	High (41–52%)	25	0.49 B	0.10

[a]Variables that differ significantly (P<0.05) based on univariate post-hoc tests are denoted with different letters (within comparison only).

For Ferruginous Hawks, nest attendance differed significantly by nesting stage (F = 47.38, df = 2, P<0.001), with attendance also declining from incubation through early nestling (i.e., 0–21 days) and late nestling (22–44 days; Table 20). Adult attendance did not differ by cheatgrass cover group (F = 0.87, df = 2, P = 0.423), but its interaction with stage approached significance (F = 2.01, df = 4, P = 0.100). Univariate tests revealed attendance overall was significantly lower (t = -2.73, df = 26, P = 0.011) in medium cheatgrass cover compared to areas of low cover during the early nestling period (Table 20). Changes in nest attendance by stage were nearly identical for both species (Figure 18).

Table 22. Ferruginous Hawk nest attendance relative to nest stage and cheatgrass cover during the early nesting stage in the ULRP study area, 2011.

Comparison	Category	*n*	Nest attendance[a]	S.E.
Nesting stage	Incubation	11	0.97 A	0.03
	Early nestling (0–21 days)	37	0.61 B	0.07
	Late nestling (22–44 days)	44	0.09 C	0.03
Cheatgrass cover in early nesting stage	Low (0–6%)	20	0.75 A	0.07
	Medium (30–48%)	8	0.33 B	0.16
	High (56–78%)	9	0.56 AB	0.15

[a]Variables that differ significantly (P<0.05) based on univariate post-hoc tests are denoted with different letters (within comparison only).

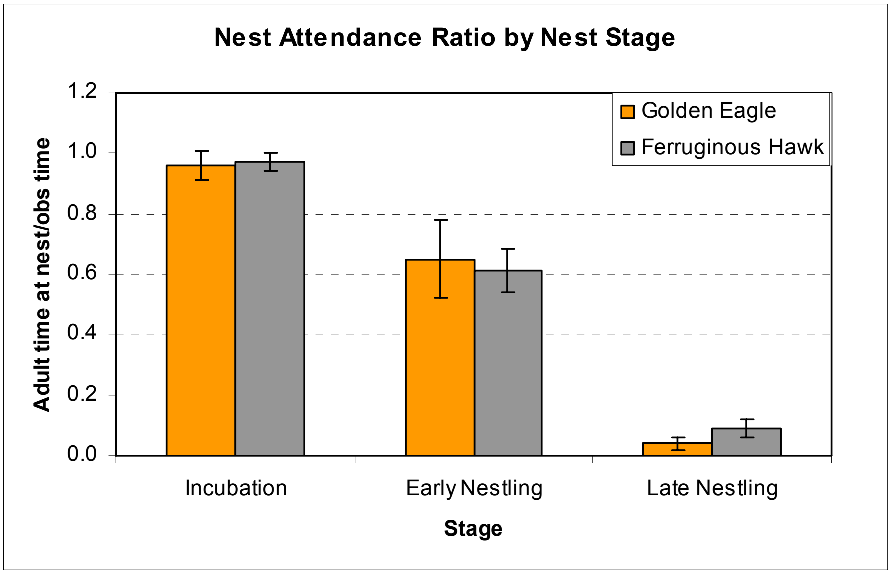


Figure 18. Adult nest attendance per observation time at Golden Eagle and Ferruginous Hawk nests during the incubation, early nestling, and late nestling stage in the ULRP study area, 2011.

Few observations of prey deliveries for either species (i.e., 4 Golden Eagle and 15 Ferruginous Hawk deliveries) and difficulty determining identity of prey items precluded analysis of this data.

During 2011, we completed broadcast surveys for Burrowing Owls at 197 points at 800 m intervals along 20 transect routes (141.6-km total) during late April with only two detections of occupied burrows. Due to this poor success, we modified our survey technique in early May to concentrate visual searches and broadcasts near mounds or near previous burrow concentrations. This resulted in the detection of 9 additional occupied burrows (11 total). Despite revisiting all occupied burrows 3–7 times each between June 1–July 12, 2011, we only confirmed nestlings at two burrows. Each occupied burrow was probed at least once, but we discontinued probing after a complete failure to detect eggs or young with our probing camera equipment. We suggest the poor success of our probing attempts may be related to the perceived greater complexity and length of burrows created by a variety of burrowing mammals in our study area relative to those created primarily by prairie dogs (*Cynomys* spp.), in which burrow scopes are typically utilized.

Total small mammal abundance varied significantly ($F = 4.51$, df = 2, $P = 0.021$) in relation to cheatgrass cover class (i.e., low [0–5%], medium [6-33%], high [42–94%]) at the trapping site. Post-hoc univariate tests suggested small mammal abundance was significantly lower in high cheatgrass cover relative to low ($t = 2.49$, df = 17, $P = 0.024$) or medium cover ($t = 2.80$, df = 16, $P = 0.013$; Table 21). Species diversity also differed by cheatgrass cover ($F = 6.77$, df = 2, $P = 0.004$), with diversity also reduced in high cheatgrass cover relative to low ($t = 2.71$, df =17, $P = 0.015$) or medium cover ($t = 3.71$, df = 16, $P = 0.002$; Table 21).

Table 23 Comparison of small mammal abundance and diversity by cheatgrass cover class at trapping sites in the ULRP study area, 2011.

Comparison	Cheatgrass cover	*n*	Abundance[a]	S.E.
Total small mammals per plot	Low (0-5%)	11	4.73 A	1.20
	Medium (6-33%)	10	7.60 A	2.03
	High (42–94%)	8	1.23 B	0.35
Species diversity per plot	Low (0-5%)	11	1.91 A	0.34
	Medium (6-33%)	10	2.70 A	0.45
	High (42–94%)	8	0.75 B	0.16

[a]Variables that differ significantly ($P<0.05$) based on univariate post-hoc tests are denoted with different letters (within comparison only).

Overall, total small mammal abundance and diversity increased from low to medium cheatgrass cover, but declined significantly in high cover. The abundance pattern was driven by an increase in mice abundance in areas of medium cover, and a reduced abundance of both mice and kangaroo rats in high cheatgrass cover (Figure 19). Note the larger standard errors associated with small mammal abundance in low and medium cover, suggesting greater variability in abundance in these areas, in contrast to consistently low abundance in high cheatgrass (Figure 19).

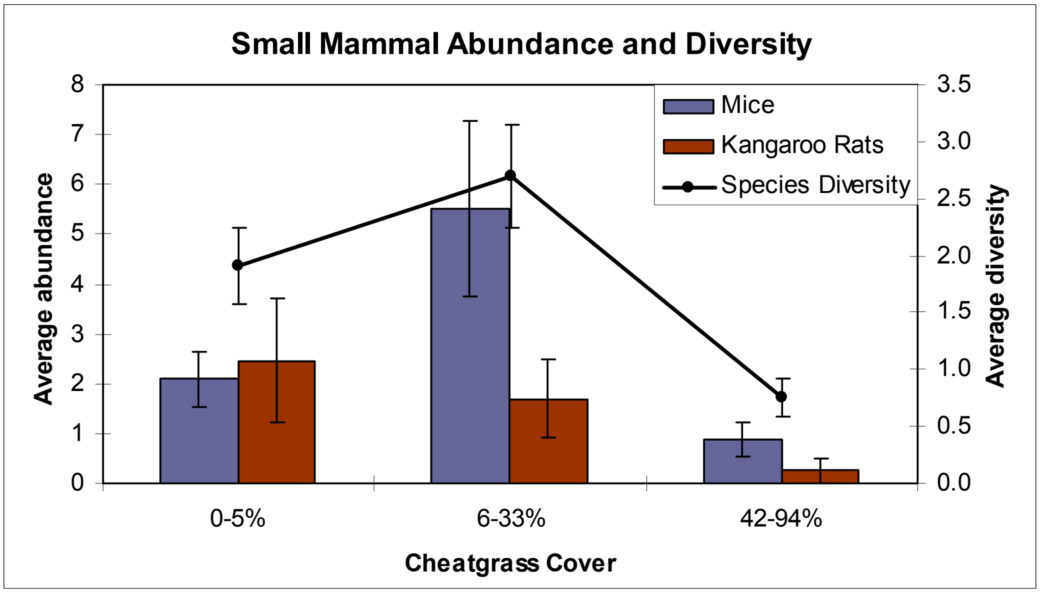


Figure 19. Small mammal abundance and diversity relative to cheatgrass cover classes at trap sites in the ULRP study area, 2011.

Invertebrate abundance differed significantly (F = 3.66, df = 2, P = 0.040) by cheatgrass cover at trap sites. As with small mammal abundance and diversity, univariate post-hoc tests revealed that invertebrate abundance was lower in high cheatgrass cover compared to low (t = 2.20, df = 17, P = 0.042) or medium cover (t = 2.15, df = 16, P = 0.047; Table 22). Average abundance declined across cheatgrass cover classes and areas of low cover had considerable variability in abundance (Figure 20).

Table 24. Comparison of invertebrate abundance by cheatgrass cover class at trapping sites in the ULRP study area, 2011.

Comparison	Cheatgrass cover	*n*	Abundance[a]	S.E.
Invertebrate	Low (0-5%)	11	7.27 A	2.32
abundance per	Medium (6-33%)	10	3.30 A	0.78
plot	High (42–94%)	8	1.13 B	0.58

[a]Variables that differ significantly (P<0.05) based on univariate post-hoc tests are denoted with different letters (within comparison only).

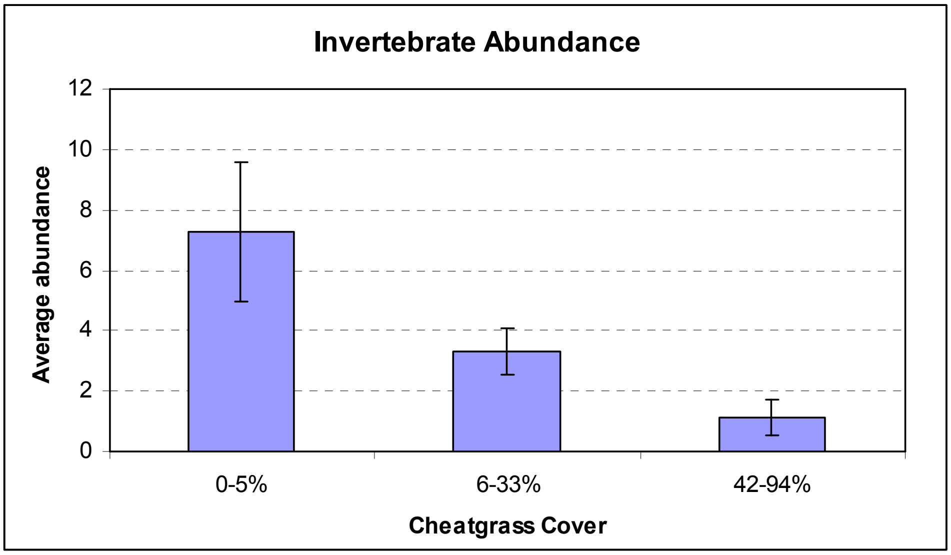


Figure 20. Invertebrate abundance relative to cheatgrass cover classes at trap sites in the ULRP study area, 2011.

Field technicians drove 238 km of road transects on 12 nights between May 3–June 8, 2011, in an attempt to index leporid abundance near established small mammal and insect survey plots. A total of 24 black-tailed jackrabbits, 8 cottontails (*Sylvilagus* spp.), and 1 unknown rabbit were observed. Due to biases in sight-ability by habitat structure (i.e., rabbits are more easily detected in open habitats) we were unable to relate abundance to habitat or cheatgrass cover. We suggest future work to assess leporid abundance relative to cheatgrass utilize pellet transects (surveyed on foot) transecting variable cheatgrass cover and different habitat types. For example, a transect passing through both shrub cover and cheatgrass cover would allow assessment of changes in abundance as distance to security cover (i.e., shrubs) increased. This type of data could potentially shed light on rabbit threshold responses to shrub loss.

CONCLUSIONS: CHEATGRASS, PREY, AND RAPTORS IN THE ULRP STUDY AREA

Cheatgrass is an invasive grass that is becoming increasingly ubiquitous in western landscapes. The Great Basin region has borne perhaps the largest impacts of cheatgrass invasion, where estimates indicate that roughly 1/3 of the land area has been invaded. Cheatgrass is detrimental to landscapes. Where cheatgrass establishes itself, it develops large monocultures, which can alter fire regimes due to its inherent flammability. This loss of native vegetation, heightened fire risk and decline in biodiversity has implications for military mission, land managers, wildlife and the general public.

This study investigated the landscape effects of cheatgrass coverage and invasion risk on three focal raptors species (Golden Eagles, Ferruginous Hawks and Burrowing Owls) in the West Desert of Utah. Both Ferruginous Hawks and Burrowing Owls are species of concern within the state, and Golden Eagles have shown declines across their range, making all three important conservation targets at the state and federal levels. After completion of their report following a 10-year monitoring effort, HawkWatch International noted possible declines in nesting starts and productivity in these focal species. HWI hypothesized these declines were possibly associated with an increase in cheatgrass coverage in territories; that cheatgrass monocultures might create an ecological trap, or an inappropriate attraction to poor-quality habitat. This report represents the culmination of our efforts to analyze this trend.

While there is indeed an association between higher cheatgrass and lower activity for the focal species, the ecology behind the association is likely much more nuanced than the stated hypotheses. What we believe is likely occurring is a decline in prey base availability due to loss of native shrub cover. Golden Eagles are the species most affected by this, showing an extreme decline in territory activity and occupancy following an intense fire year in 2007. Because Golden Eagles typically rely on a prey base that is comprised of at least two reliable mammal species populations, (usually black-tailed jack rabbits and one other substantial population) loss of shrub cover due to fires and eventual transition into cheatgrass monoculture could potentially prevent the establishment of a proper prey structure for these species, and therefore contribute to the overall decline in nesting activity and success. For example, previous studies have clearly demonstrated the influence jackrabbit abundance can exert on eagle nest activity (Bates and Moretti 1994, Steenhof et al. 1997). Although cheatgrass cover has not changed substantially at known eagle territories, fires have occurred more frequently in the areas of long-term and substantial cheatgrass coverage (compare Appendix 3 [fire occurrence in study area] and Appendix 8 [cheatgrass coverage]), likely contributing to substantial shrub loss over the study period in such areas. Jackrabbits will not venture far from the security of shrub cover, and widespread loss of shrubs may eventually lead to their extirpation at local scales. Unfortunately, we lack rabbit abundance data for our study period and cannot completely discount the possibility that the recent documented declines in Golden Eagle nest activity were not influenced by natural fluctuations in jackrabbit abundance. However, while nest activity rates (i.e., percentage of pairs laying eggs) may flux over time in response to changing prey resources, territory occupancy rates (i.e., percentage of territories with adults present) should be relatively stable in a healthy population. That is, in a long-lived and territory-focused species such as the Golden Eagle, the number of territories occupied should not change much from year-to-year, unless major habitat changes cause adults to abandon long-term territories completely. As both Golden Eagle territory activity and occupancy have been depressed since 2007 in our study area, we believe the data suggests a more serious concern for this species.

Overall, we found that for known territories for all three species, that the coverage of cheatgrass within the territory was much higher than in random territories generated in the study area. Long-term territory activity was lower for all three species in areas of high cheatgrass cover when compared to areas of low cheatgrass cover (Table 23). Intensive field effort in 2011 to examine nest attendance for active nests also showed lower nest attendance in higher cheatgrass areas (Table 23), despite low sample sizes this year likely due to a wet and cool spring. Overall, there is consistent evidence to suggest Golden Eagles and Burrowing owl breeding season activity and output is negatively related to cheatgrass, perhaps accounting for the long-term declines in these species in the study area (Table 23). There is also some evidence for negative relationships with cheatgrass for Ferruginous Hawks, but less consistently, perhaps accounting for the lack of a long-term decline in activity for this species (Table 23). Additionally, we found a significant decline in small mammal abundance and diversity and invertebrate abundance in high cheatgrass cover when compared to low cheatgrass cover.

In addition to these relationships, our efforts produced important land management implications and products. Through modeling of cheatgrass invasion risk and associated landscape variables, we were able to create maps of known cheatgrass coverage and potential invasion areas. In our study area, currently invaded areas are closer to population centers (northeastern and north-central portion of the study area), while remaining high-risk invasion sites were located in areas located further away in the southern and western part of the ULRP study area. Through habitat modeling and analyzing current known territories, we were able identify potential nesting habitat that does not currently contain known nests, likely due to lower survey effort, also in the southern part of the study area. The intersection of these two areas of high risk for cheatgrass invasion and under-surveyed potential nesting habitat effort present a possible conservation target for land managers within this region. Overall in the study area, approximately 18% of Golden Eagle, 28% of Ferruginous Hawk, and 34% of Burrowing Owl known territories and potential habitat at risk of future cheatgrass invasion, and these areas also represent areas that need to be managed carefully to reduce the risk of additional cheatgrass spread.

We suggest areas within the ULRP study area with few known territories and little current cheatgrass invasion (but high risk), are correlated. That is, areas further from humans are both least likely to be invaded and to receive survey attention. Similarly, the fact that we detected little change in cheatgrass cover at known territories is likely due to the fact that most of these territories are closer to human populations, and as a result, most proximate areas at risk for invasion were likely heavily invaded prior to the start of our study period. The lack of detected cheatgrass change at known territories should not be interpreted to mean the threat of cheatgrass impacts to nesting raptors in the study area is past.

Period	Investigated trend or relationship	Golden Eagle	Ferruginous Hawk	Burrowing Owl
Long-term (1998-2011)	Decline in study area territory activity	Yes	No	Yes
	Apparent negative response to fire occurrence in study area	Yes	No	NA
Long-term (2000-2011; shortened to correspond to cheatgrass mapping period)	Cheatgrass cover significantly higher at known raptor territories	Yes	Yes	Yes
	Invasion risk or grassland cover better predictor of known territories than cheatgrass cover	Yes	Yes	Yes
	Activity higher in territories with lowest cheatgrass cover	Yes	Yes	Yes
	Nest success higher in territories with lowest cheatgrass cover	Yes	No	Yes
	Productivity/successful nest higher in territories with lowest cheatgrass cover	Yes	No	Yes
2011	Nest attendance higher in territories with lowest cheatgrass cover	Yes	Yes[a]	NA

Table 25. Summary of major trends and relationships of interest for ULRP study area focal species.
[a] Early nestling period only.

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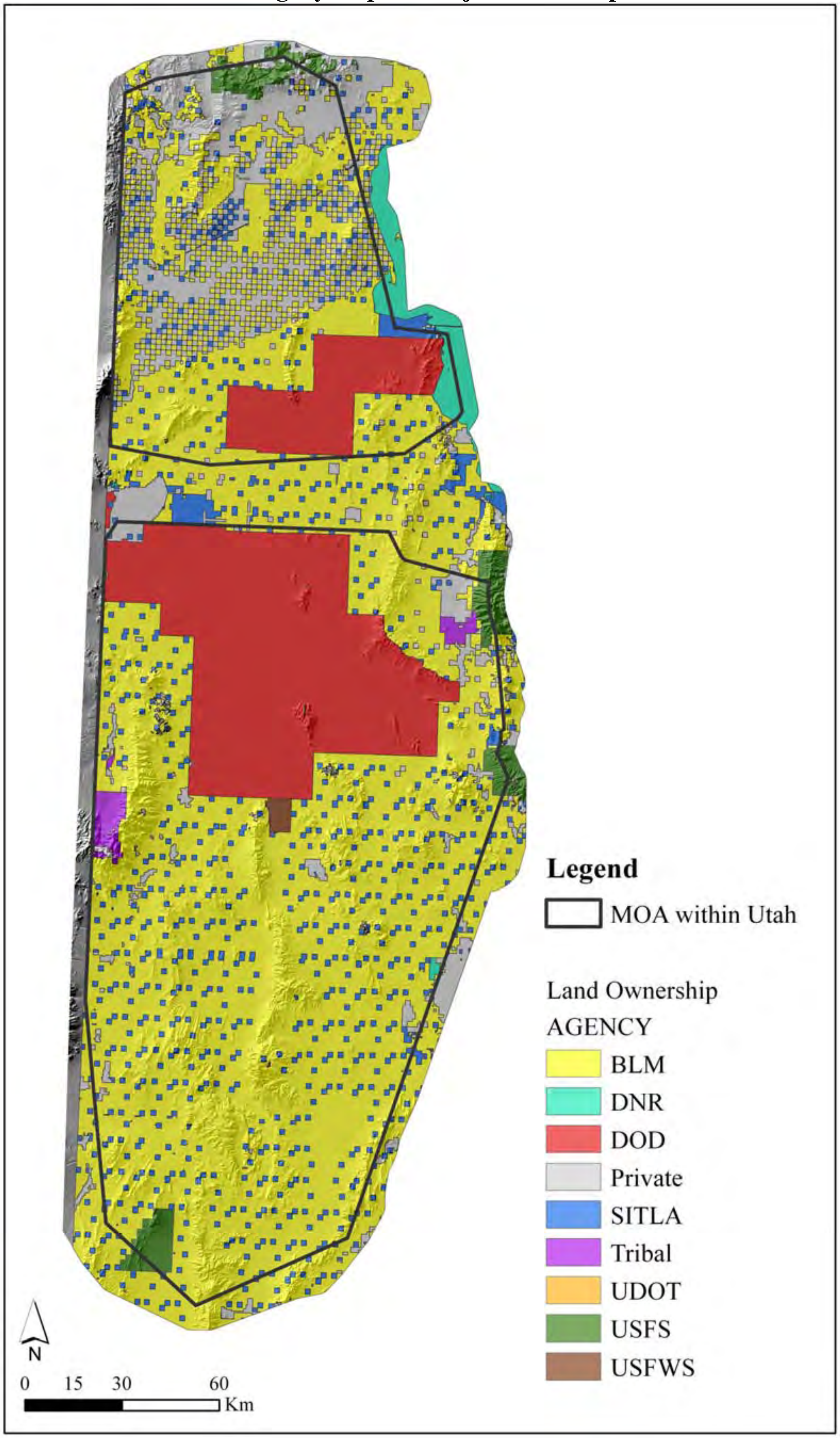
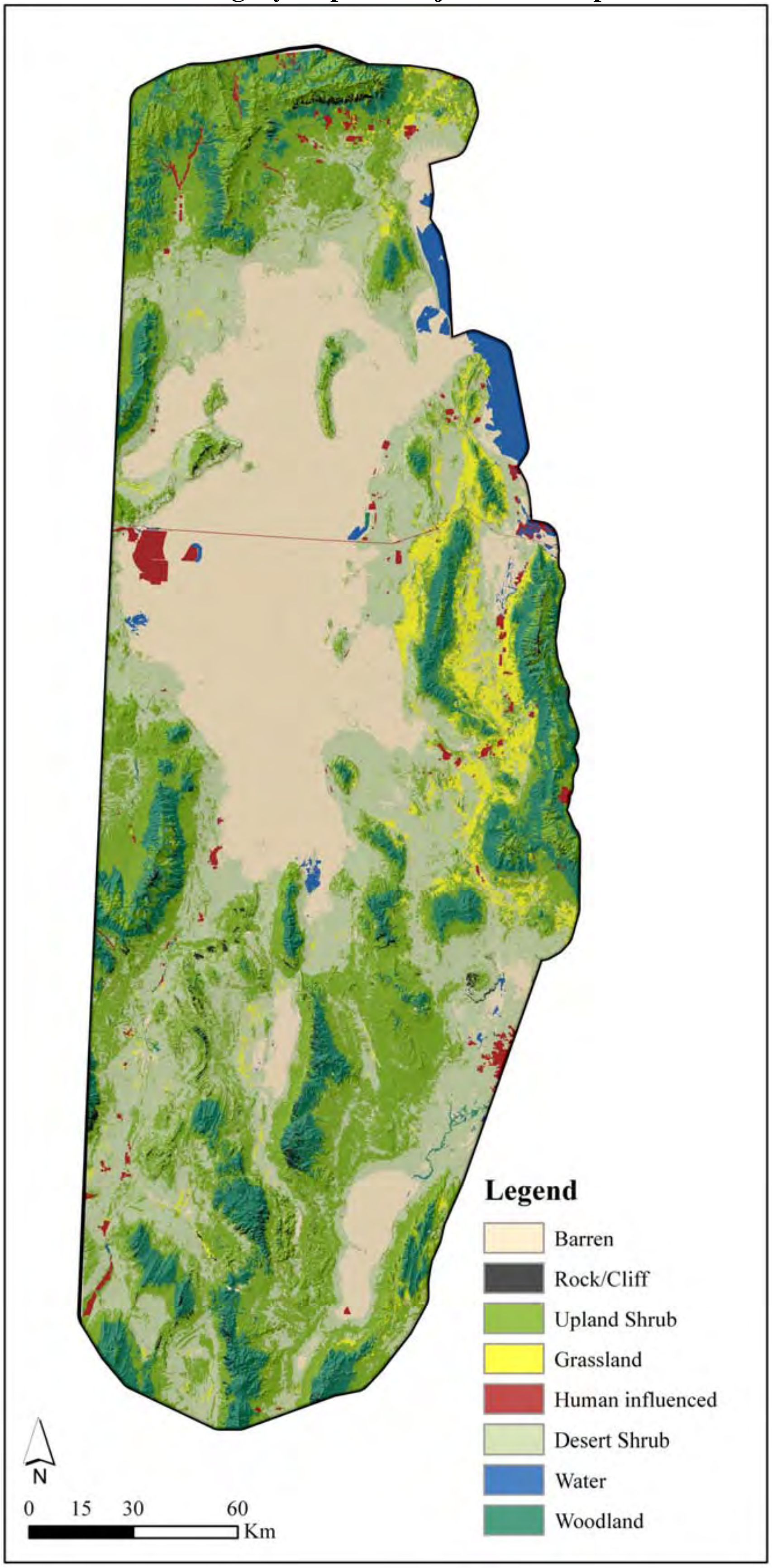
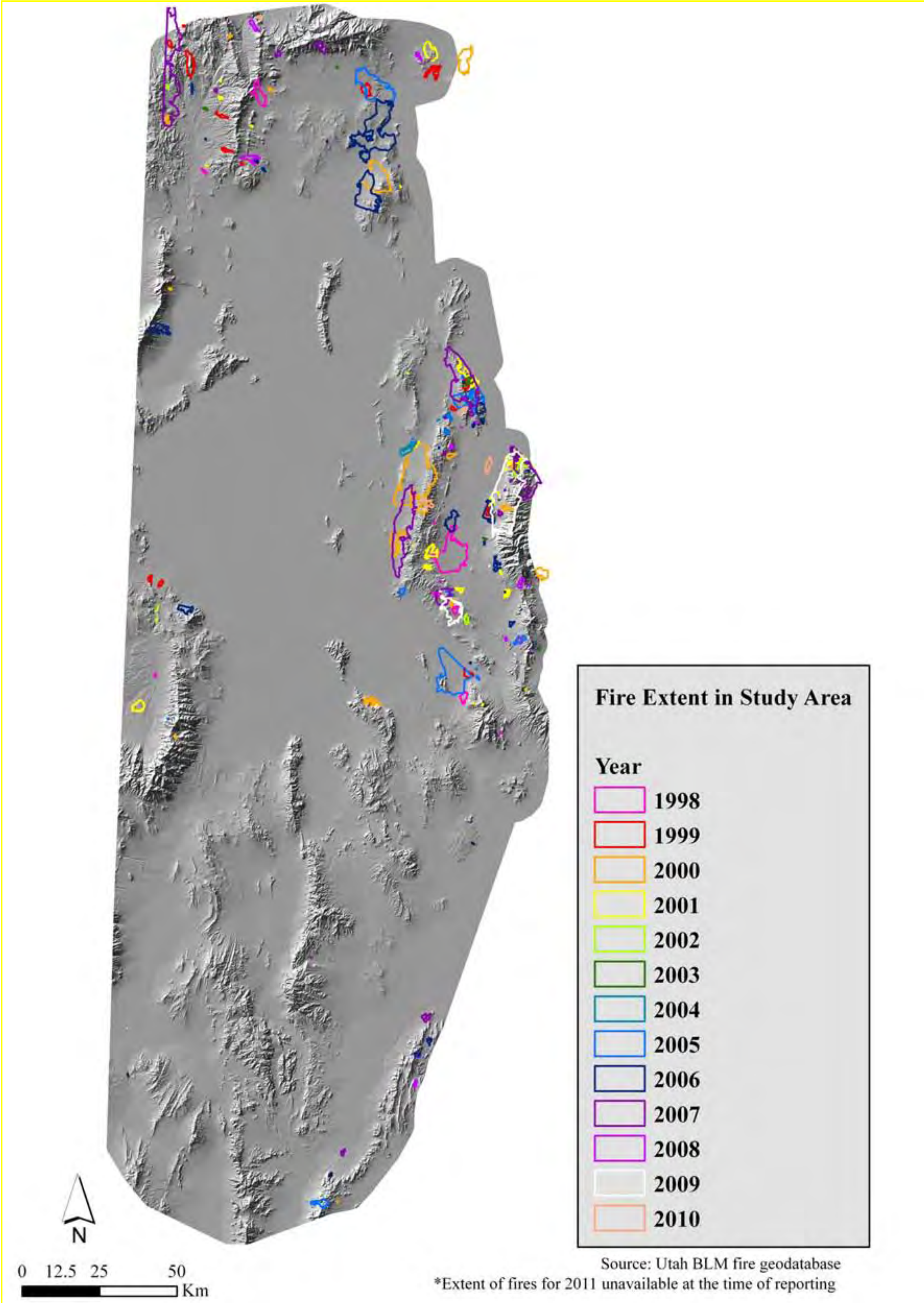
APPENDICES (BEGIN ON NEXT PAGE)



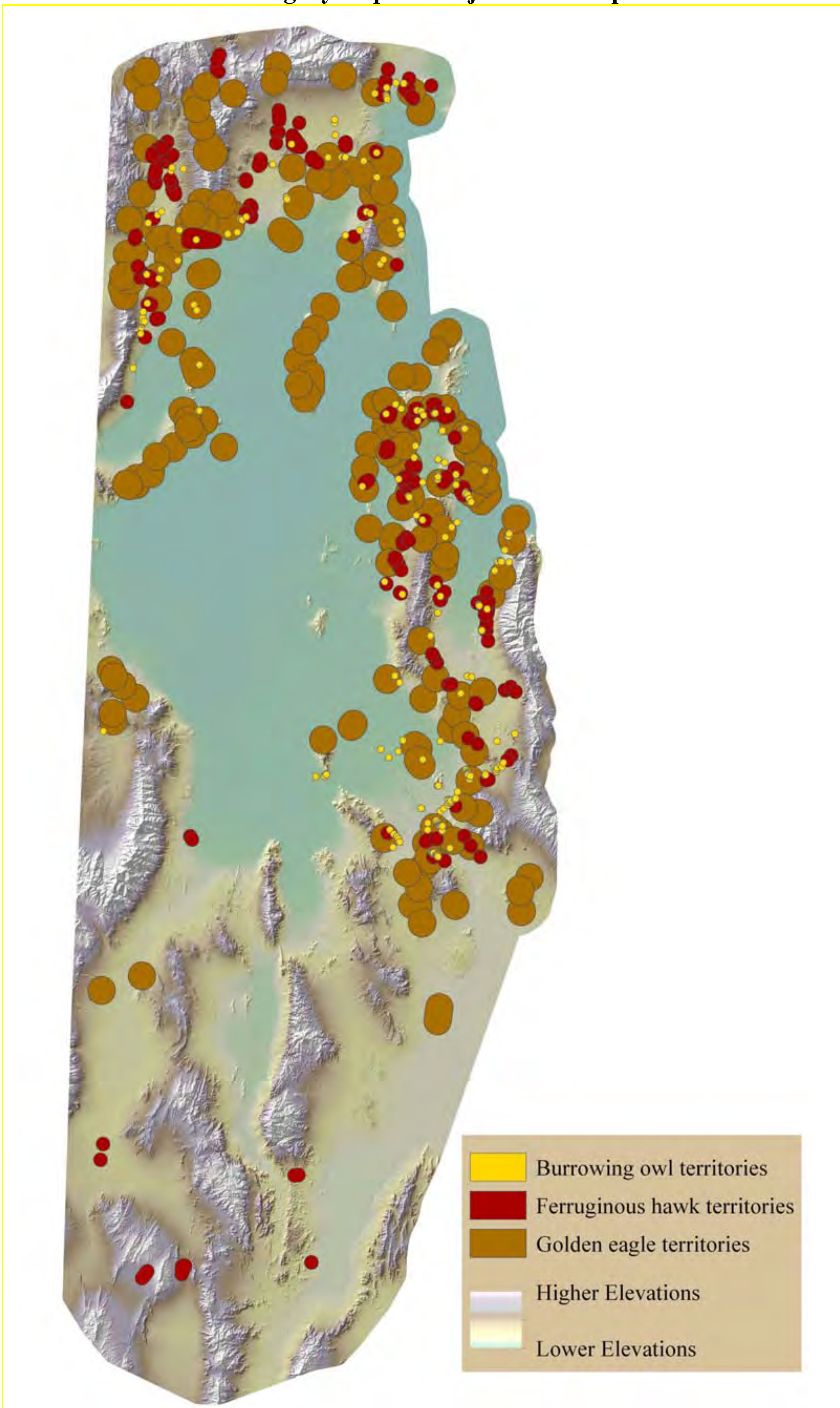
Appendix 1. Land ownership within the ULRP study area.



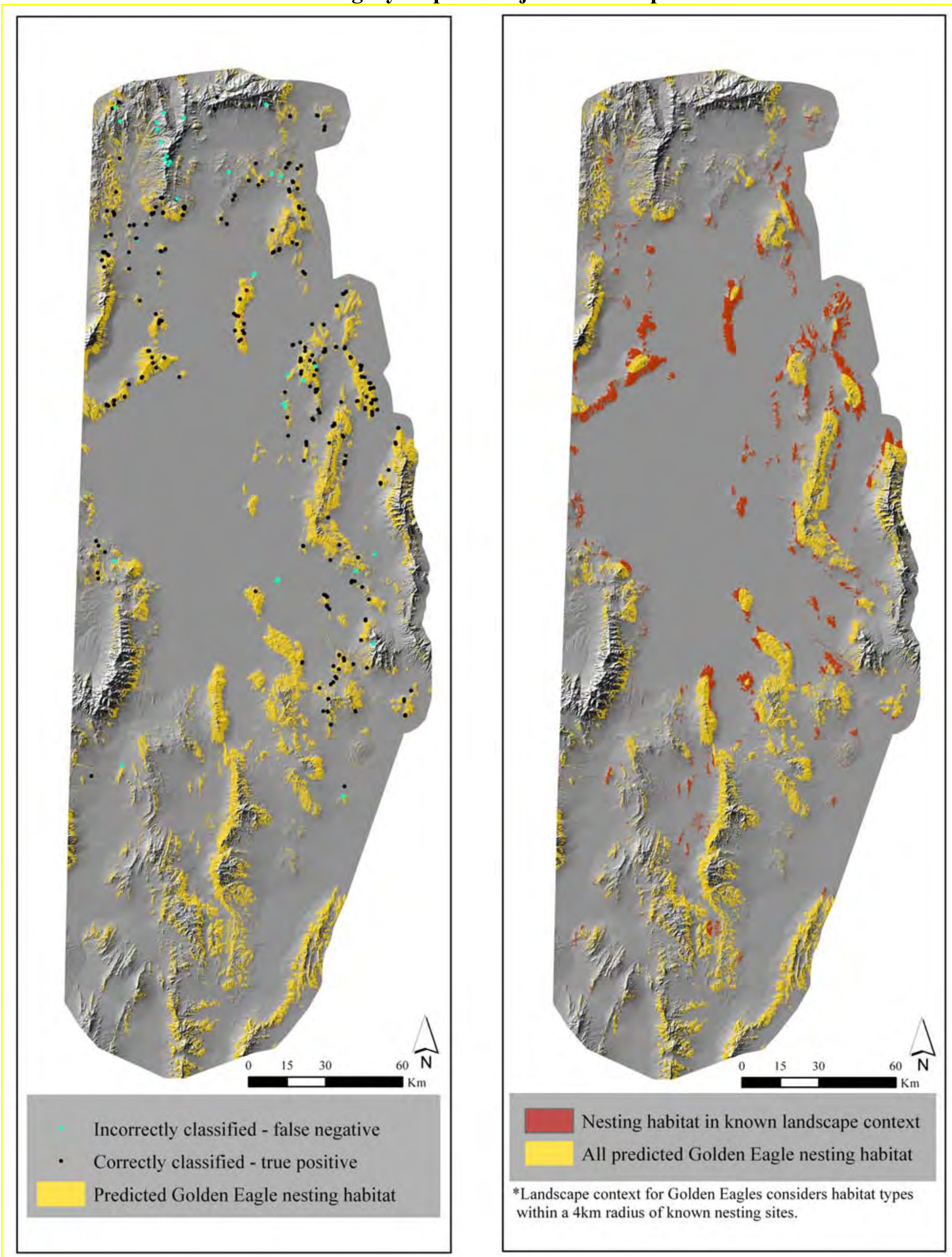
Appendix 2. Landcover in ULRP study area. Major cover types were simplifications of SWReGAP cover types based on basic habitat structure.



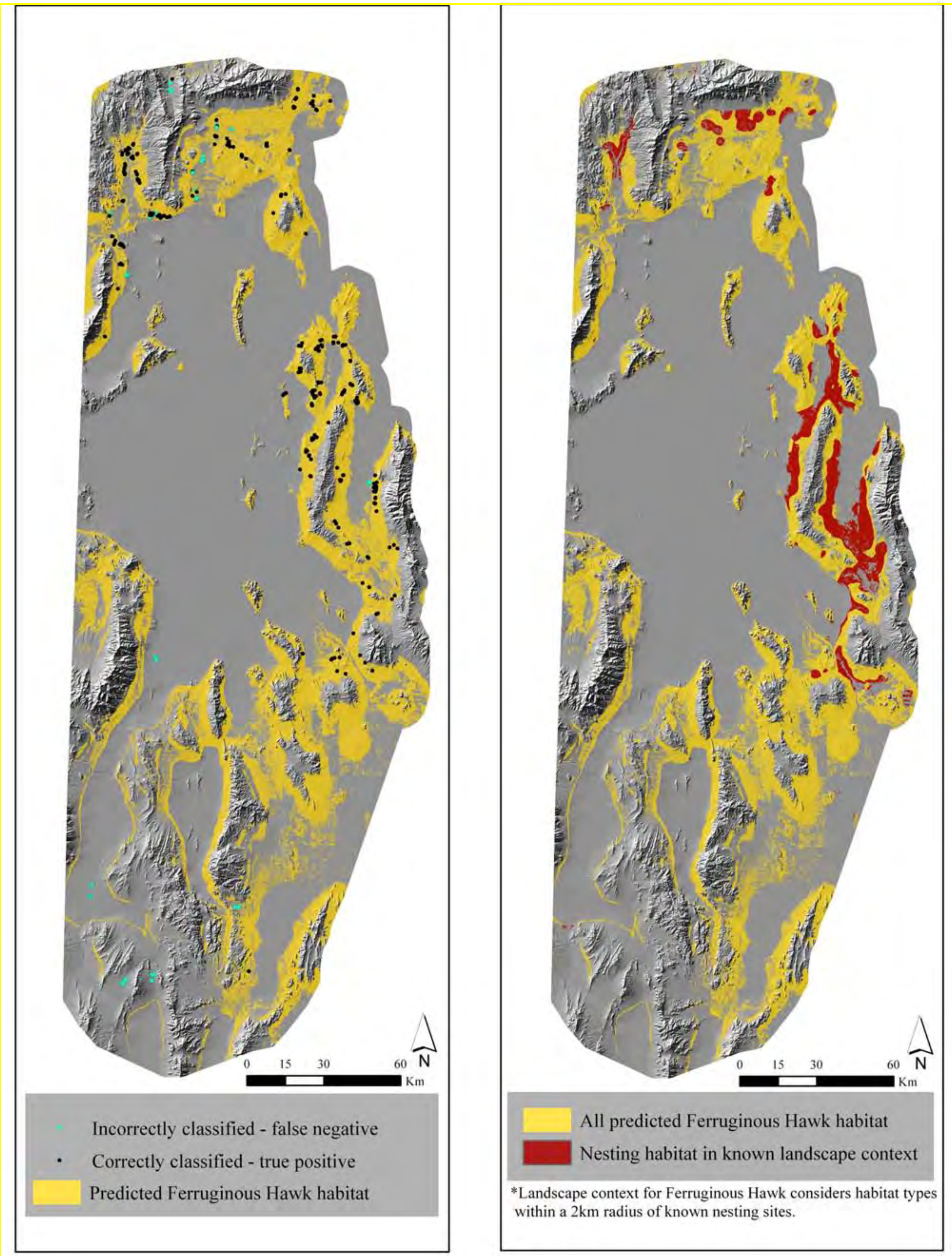
Appendix 3. Fire occurrence on BLM land within and near the ULRP study area throughout the study period. Includes any fire that intersected the study area.



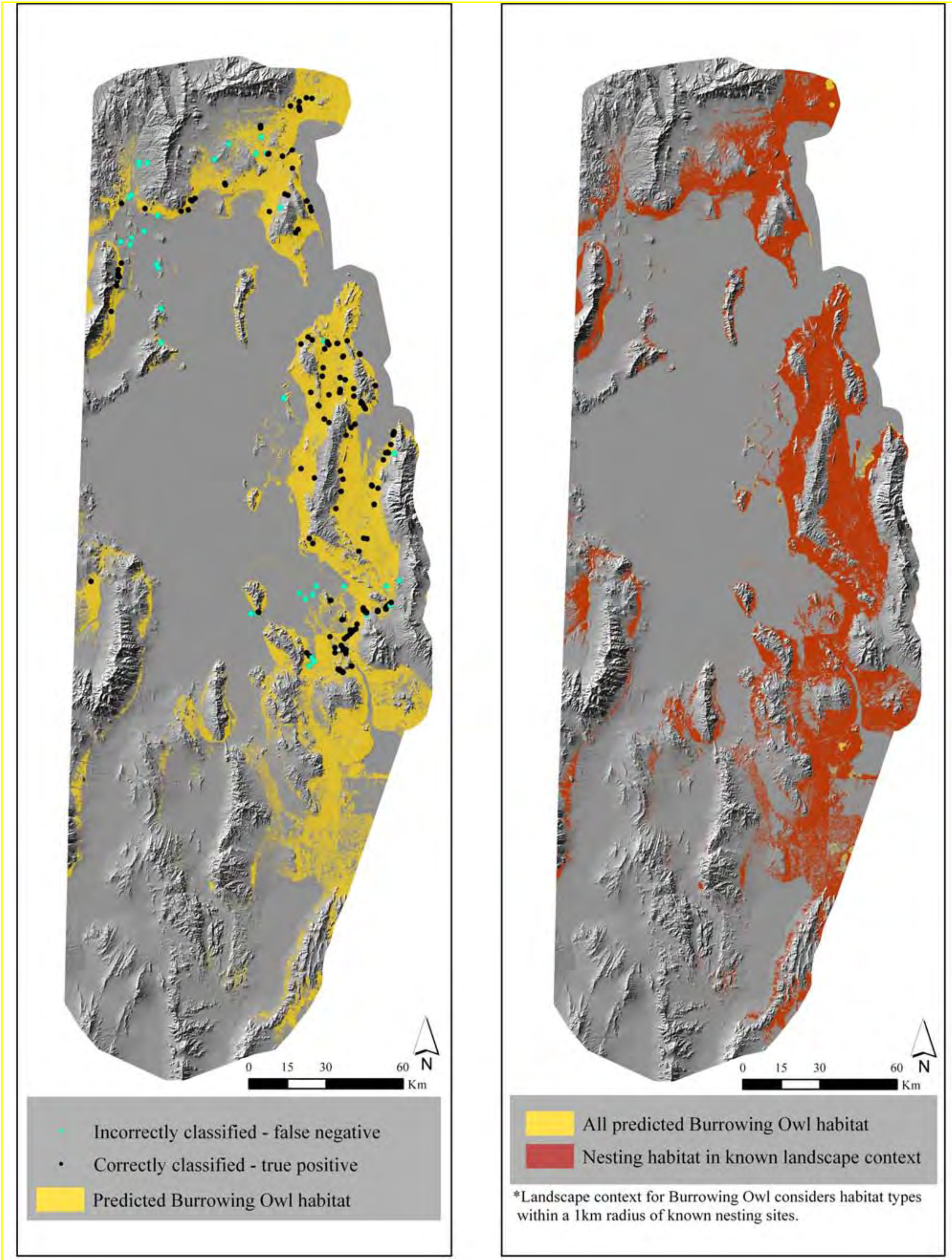
Appendix 4. Territories created in GIS for analysis of Golden Eagles (167), Ferruginous Hawk (124), and Burrowing Owls (282) in the ULRP study area.



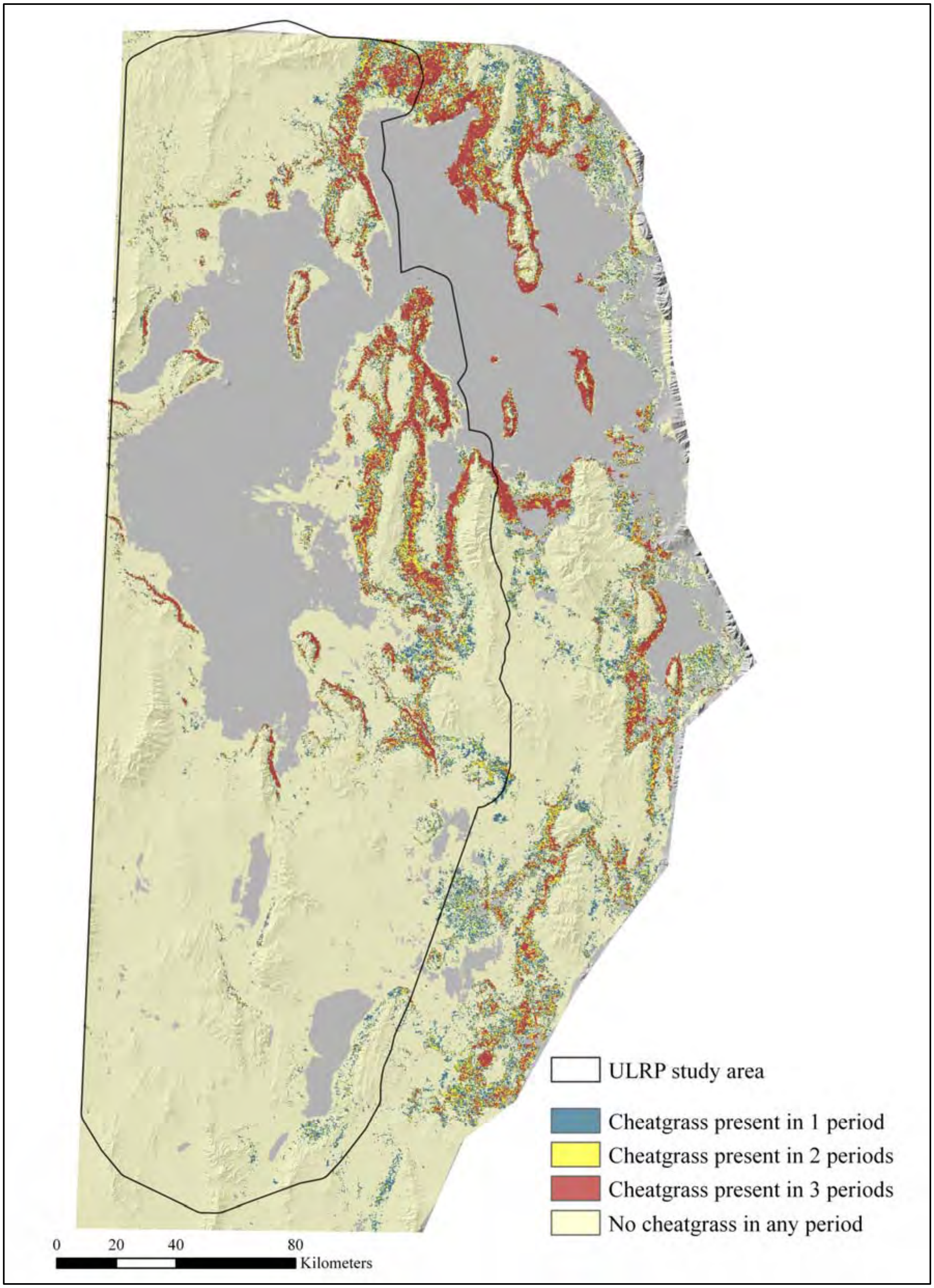
Appendix 5. Potential nesting habitat for Golden Eagles in the ULRP study area. Nesting habitat in known landscape context (red) is nesting habitat within landscapes similar to that of known territories based on discriminant function analysis of vegetation variables.



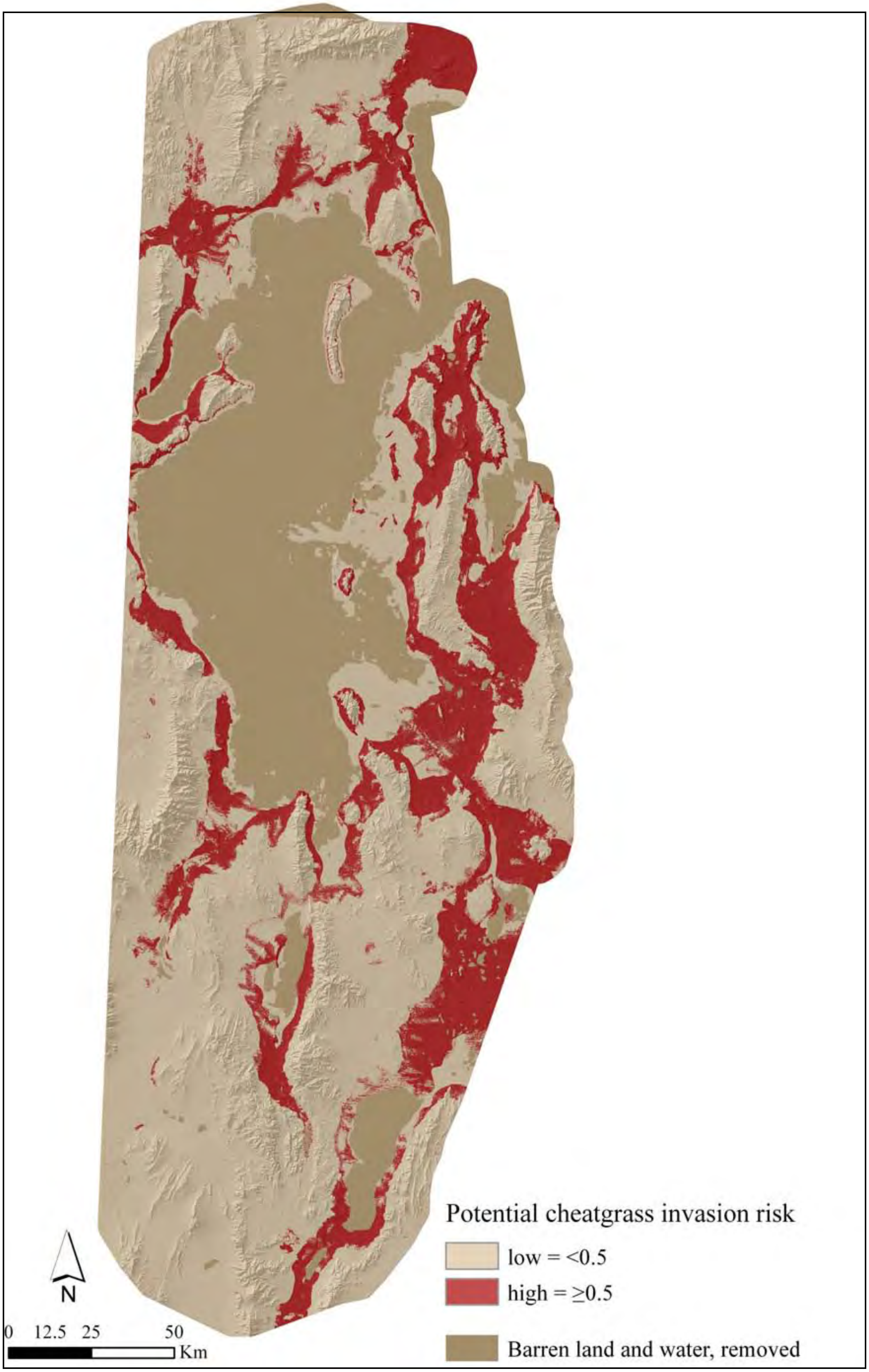
Appendix 6. Potential nesting habitat for Ferruginous Hawks in the ULRP study area. Nesting habitat in known landscape context (red) is nesting habitat within landscapes similar to that of known territories based on discriminant function analysis of vegetation variables.



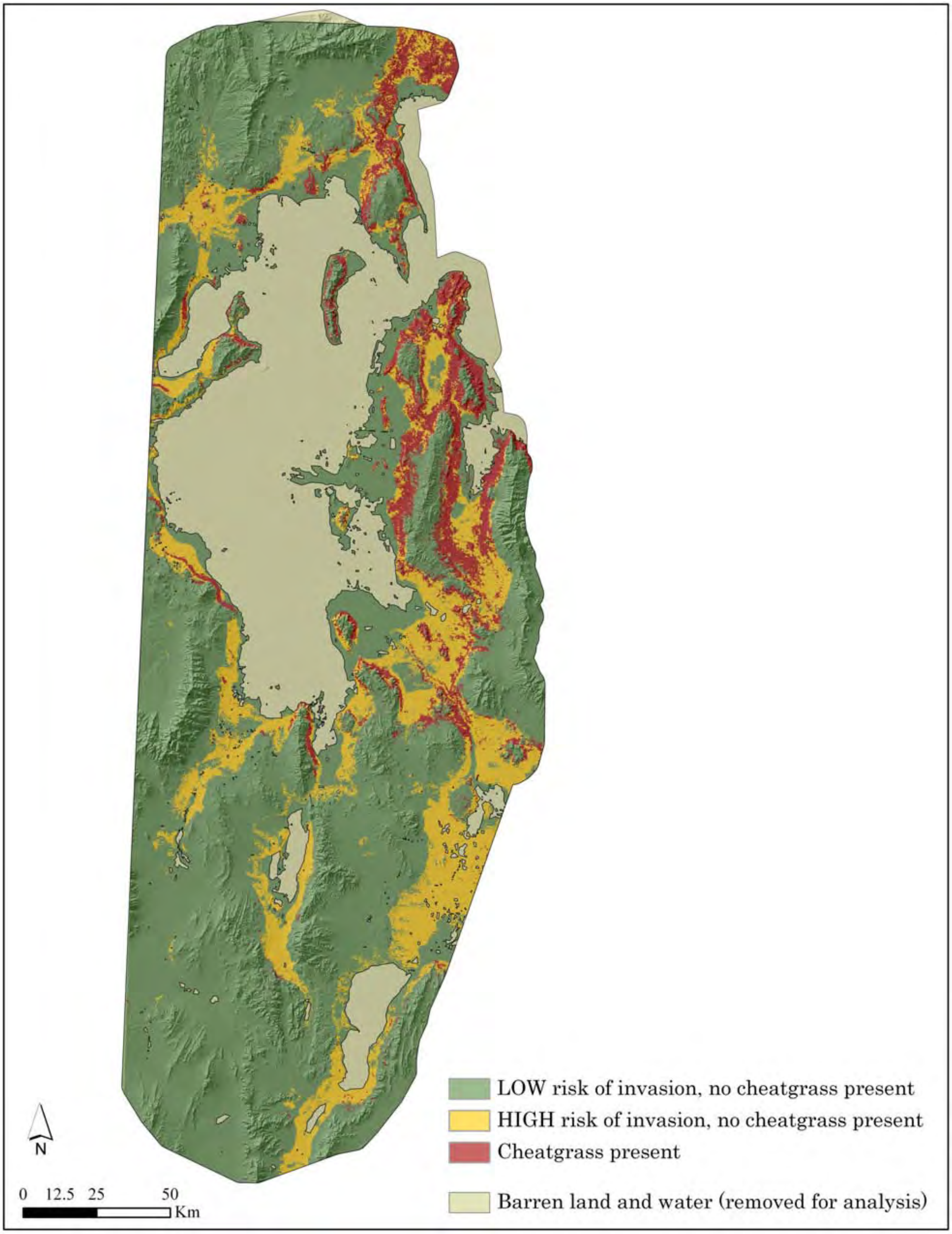
Appendix 7. Potential nesting habitat for Burrowing Owls in the ULRP study area. Nesting habitat in known landscape context (red) is nesting habitat within landscapes similar to that of known territories based on discriminant function analysis of vegetation variables.



Appendix 8: Cheatgrass coverage for the ULRP study area and surrounding region.



Appendix 9. Cheatgrass invasion risk in the ULRP study area.



Appendix 10. Cheatgrass coverage extent and invasion risk in the ULRP study area.