GOLDEN EAGLE NEST SITE SELECTION AND HABITAT SUITABILITY MODELING ACROSS TWO ECOREGIONS IN SOUTHERN NEVADA

by

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ABSTRACT

Because of perceived declines in populations of the golden eagle (*Aquila chrysaetos*) in the western United States, the United States Fish and Wildlife Service (USFWS) closely monitors population trends throughout their range. An inventory of golden eagles in two ecosystems in Nevada (the northern Mojave Desert and southern Great Basin) was conducted from 2011-2014 with the objectives to: 1) locate and determine the abundance of golden eagle nest sites (active and inactive) in two eco-regions (Mojave Desert and Great Basin); 2) quantify golden eagle nest density and abundance within the designated study sites; 3) determine the size of territories of nesting golden eagles; 4) determine the influence of nest site variables on acquired data; 5) develop a habitat suitability model using nest site variables to delineate areas with high probability for nest site selection.

Cliff and canyon habitats of the southern Great Basin and northern Mojave Desert ecoregions were surveyed for active and inactive nests of golden eagles and to measure nest site parameters by helicopter in 2011-2014. Nest site parameters used for analysis were: general location, mountain range, cliff height, viewshed, soils, geology, elevation, aspect, slope, habitat, use, productivity and distances to the nearest road and water. A suitability index was created using these parameters and the program MaxEnt to map potential nesting habitats within the boundaries of my study sites. A total of 96 nest sites (old/abandoned and newly decorated) were located and analyzed. During the four years, 27 active nests produced 36 fledglings. Two nests were occupied for three years and three nests had double occupancy in a year. Nesting habitat variables that were chosen for the final predictive model include: elevation, slope, distance to nearest road and distance to water. The results of my project will aid in establishing a monitoring program to provide guidance in avoiding and minimizing disturbances and other kinds of future “take” by federal agencies requiring consultation with USFWS.

CHAPTER 1

INTRODUCTION

The golden eagle (*Aquila chrysaetos)* is one of the largest and most renowned birds of prey in North America. They range throughout the northern hemisphere in North America, Eurasia and parts of Africa. Golden eagles in North American represent 47% (79,000 birds) of the global population (Hawk Mountain 2007). Golden eagles breed in an array of available habitats in the eastern and western United States and are most abundant west of 100° W longitude from the Arctic slope to central Mexico (Kochert et al. 2002). However, data from the Audubon Society's Christmas Bird Counts and Raptor Migration Counts indicate that populations have declined since the early 1980s with the most severe waning since 1998 in the western North America (Hawk Mountain 2007). Hoffman and Smith (2003) reported declines in immature eagles from 1987-2001 at Wellsville Mountains in northern Utah and from Lipan Point (South Rim of the Grand Canyon, Arizona) from 1992-2001.

Other statistically significant long-term declines of golden eagles by raptor migration counts were recorded from 1983 to 2005 at the Goshute Mountains, Nevada and from 1985 to 2005 and at the Manzano Mountains, New Mexico (Hawk Mountain 2007). The rates of decline at these sites greatly increased in magnitude from 1995-2005. Other studies suggest declines in golden eagle populations representing potential downward trends throughout the west (Leslie 1992, Steenhof et al. 1997, Bittner and Oakley 1999, Kochert et al. 2002). More recently, a study conducted by WEST, Inc. (Nielson et al. 2014) estimated declines in the total number of juvenile golden eagles from 2006-2012; however, overall abundance in the western United States appeared relatively stable. Wildlife biologists at the United States Fish and Wildlife Service (USFWS) estimate that approximatly 30,000 golden eagles inhabit the U.S., although populations may undergo 10-year cycles and more years of surveys are needed to accurately predict population trends (Gulf South Resource Corporation 2012).

Golden eagles are annual residents in southern Nevada. Nesting habitat in southern Nevada generally includes mountain cliffs, canyons and rim rock formations adjacent to shrub steppe, native grassland, open deserts, and playas. Golden eagles avoid urban or densely forested regions for nesting and select high cliffs adjacent to open terrain for foraging. Golden eagles in southern Nevada nest on cliff faces that offer safety from predation, plus an unobstructed view of the surrounding landscape. Protection against predators, mainly carnivorous mammals and humans, is probably the greatest single factor influencing nest site selection (Watson 2010). Golden eagles use other available nest sites (trees or artificial structures) if cliff sites are unavailable (Good et al. 2004).

Illustration 1. Adult golden eagle incubating eggs (NNRP 2011).

Golden eagle nests are identified by their large size and the big sticks used to form the nest (Driscoll 2010). Nests are built of branches and twigs and lined with grass and green foliage (Cramp & Simmons 1980). Typically, a pair of golden eagles possess several alternative eyries or supernumerary nests (McGahan 1968), usually two or three but sometimes a dozen or more (Watson 2010). Nesting material is added to one or more of these sites yearly (Watson 2010).

Reports of nesting success and characteristics of breeding golden eagles can be found not only within the scientific literature (i.e., Thompson et al. 1982, Lee and Spofford 1990, Watson et al. 1992, D. Young et al. 1995), but also within industry due to regulations and management of commercial development and windfarms (Page & Siebert 1972, Ecosphere Environmental Services 2008, Isaacs 2011).

Bergo (1948), Donazar et al. (1989), and Mosher and White (1976) characterized nest site selection by golden eagles; and development of habitat suitability indices have become common for bird species, such as Newells shearwater (Troy et al. 2014) and the white-headed woodpecker (Holldenbeck et al. 2011). Despite the extensive literature on golden eagles in the western U. S., few quantitative data have been published describing the features of nest sites, extrapolating them over a desired management area using a Geographic Information Systems (GIS) model based approach.

Because of potential downward trends, the USFWS has increased conservation protocols for the western populations of the golden eagle. Although uncertainty exists over the current population size and status of golden eagles in the U.S., factors that may cause population declines, such as habitat loss, are increasing (Good et al. 2004). Golden eagles are protected by the Migratory Bird Treaty Act (16 U.S.C. 703–712) and the Bald and Golden Eagle Protection Act (16 U.S.C. 668-668c); therefore, management of this species is especially important for regulatory agencies, especially the USFWS. Conservation and proper management of this species requires baseline information on population size, distribution and productivity. The effects of environmental influences impressed upon any population can only be determined accurately by a thorough study (McGahan 1968). Additionally, assessments of breeding and nesting habitats are vitally important to the preservation of potential nesting habitats in areas where disturbances may be imminent. Without reliable estimates of the population size and trends, it is difficult for the USFWS to determine the appropriate number of permits to issue for various take requests to ensure a sustainable golden eagle population (Good et al. 2004).

The objectives of mystudy are to 1) locate and determine the abundance of golden eagle nest sites (active and inactive) in two eco-regions (Mojave Desert and Great Basin); 2) quantify golden eagle nest density and abundance within the designated study sites; 3) determine the territory size of nesting golden eagles; 4) determine the influence of nest site variables on acquired data and 5) develop a habitat suitability model using nest site variables to delineate areas with high probability for nest site selection.

CHAPTER 2

STUDY SITE

My study site was located within a closed access military range operated by the Department of Defense and managed by the 98th Range Wing of Nellis Air Force Base (NAFB) in southern Nevada. The southern boundaries of the designated study site are located in Clark, Lincoln and Nye counties approximately 64 km north of Las Vegas within the Mojave Desert and the Great Basin Desert ecoregions (Fig. 1). These ecoregions are typified by broad desert valleys bounded by relatively high mountain ranges. The Mojave Desert ecoregion is among the driest of North America's arid lands where precipitation averages < 12.7 cm per year in basins (United States Geological Survey 2010). The Great Basin ecoregion is known for series of mountain ranges and intervening valleys with greater rainfall and snowfall occuring at higher elevations and less precipitation in basins. The general plant associations at the study sites are four-wing saltbush (*Atriplex canescens*), shadscale saltbush (*Atriplex confertifolia*), creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) in the lower elevations (610-914 m mean sea level (MSL)); Joshua tree (*Yucca brevifolia*) and creosotebush in the mid-elevations (914-1371 m MSL) and sagebrush (*Artemisia tridentata, A. nova),* pinyon pine (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) from 1372 m MSL and above. The Nevada Department of Wildlife (NDOW) has developed a Wildlife Action Plan to assist with the management and conservation of wildlife and habitats across Nevada. As an integral part of this comprehensive plan, NDOW (2004) prepared a GIS map with layers of key wildlife habitat throughout the state. The designated study sites showcase a variety of key habitats; however, nests of golden eagles are primarily located within the cliffs and canyons key habitat. Other habitats surrounding these cliffs and canyons mainly include: lower montane woodlands, sagebrush, intermountain cold desert scrub, mojave-mid elevation desert scrub and mojave/sonoran warm desert scrub (Fig. 2 & Fig. 3). Mountain ranges surveyed in my study included: the Kawich Range, Belted Range, Stonewall Mountain, Cactus Range, Black Mountain, Quartz Mountain, Tolicha Peak, Sheep Mountain, Pintwater Range, Desert Range, Pahranagat Range, Spotted Range, Buried Hills and the Half Pint Range (Fig. 4.)

Illustration 2. Typical intermountain nesting habitat of the golden eagle in southern Nevada (NNRP 2011)

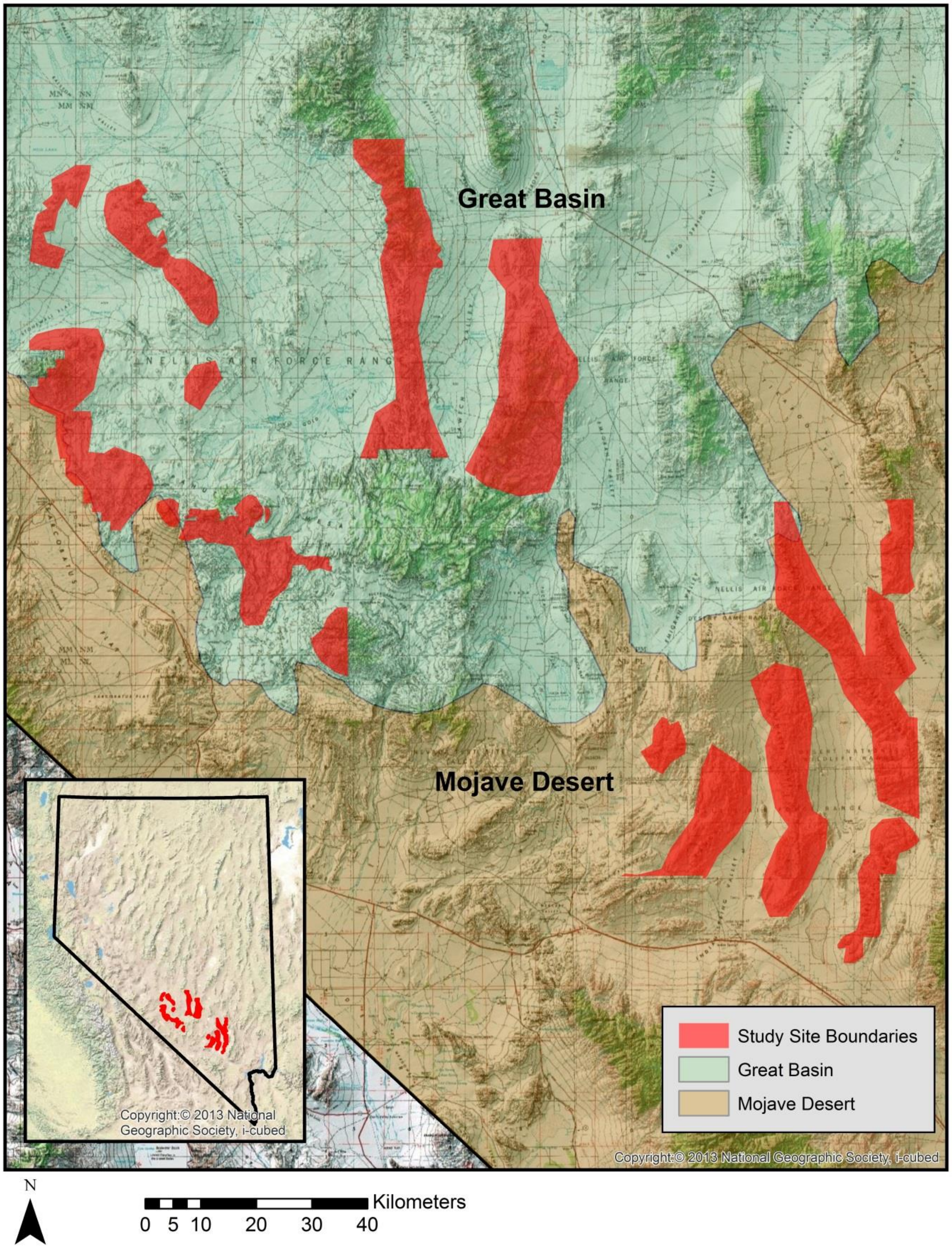

Figure 1. Study site boundaries in relation to ecoregions, Southern Nevada

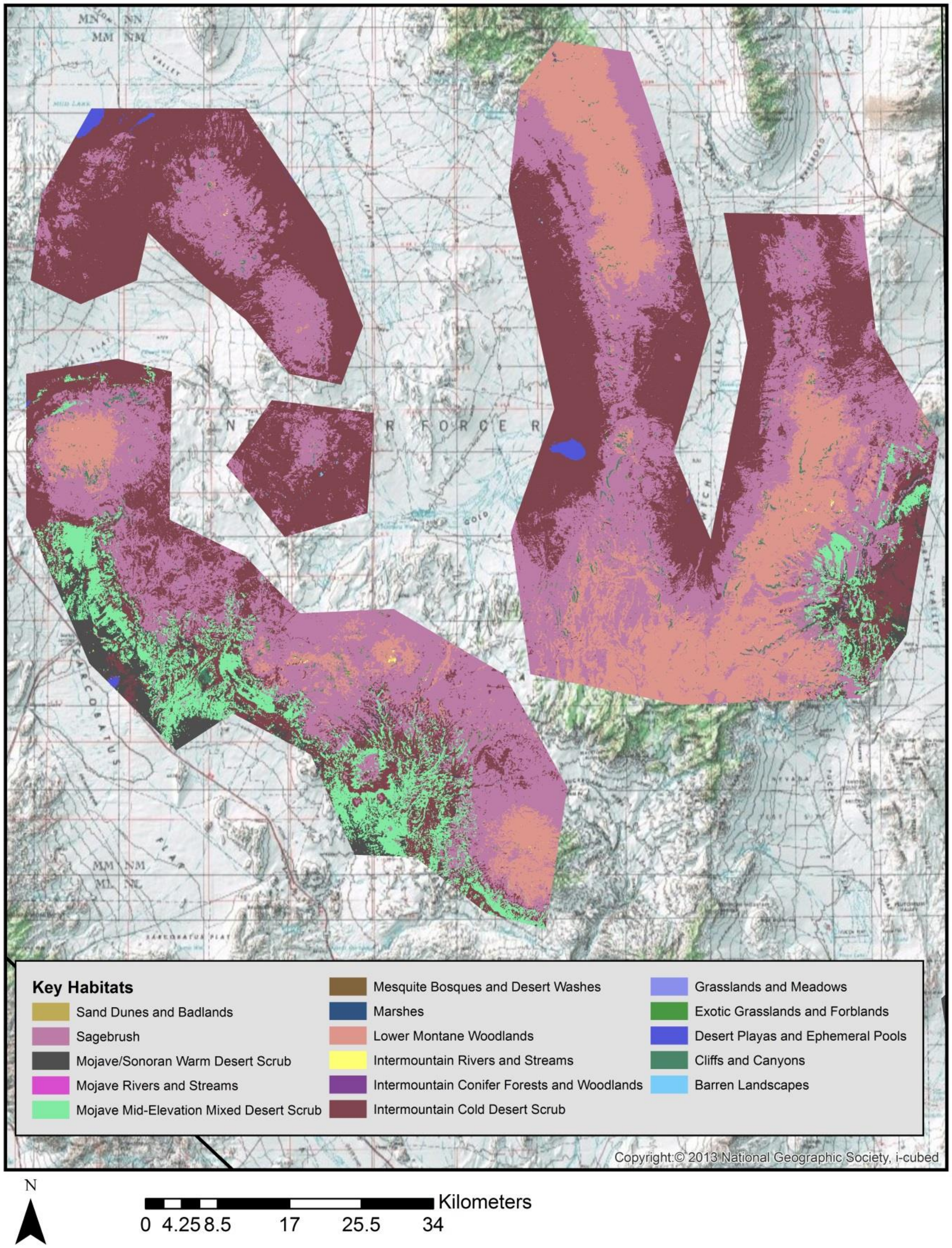

Figure 2. Key habitats surrounding study site boundaries, Great Basin, Southern Nevada

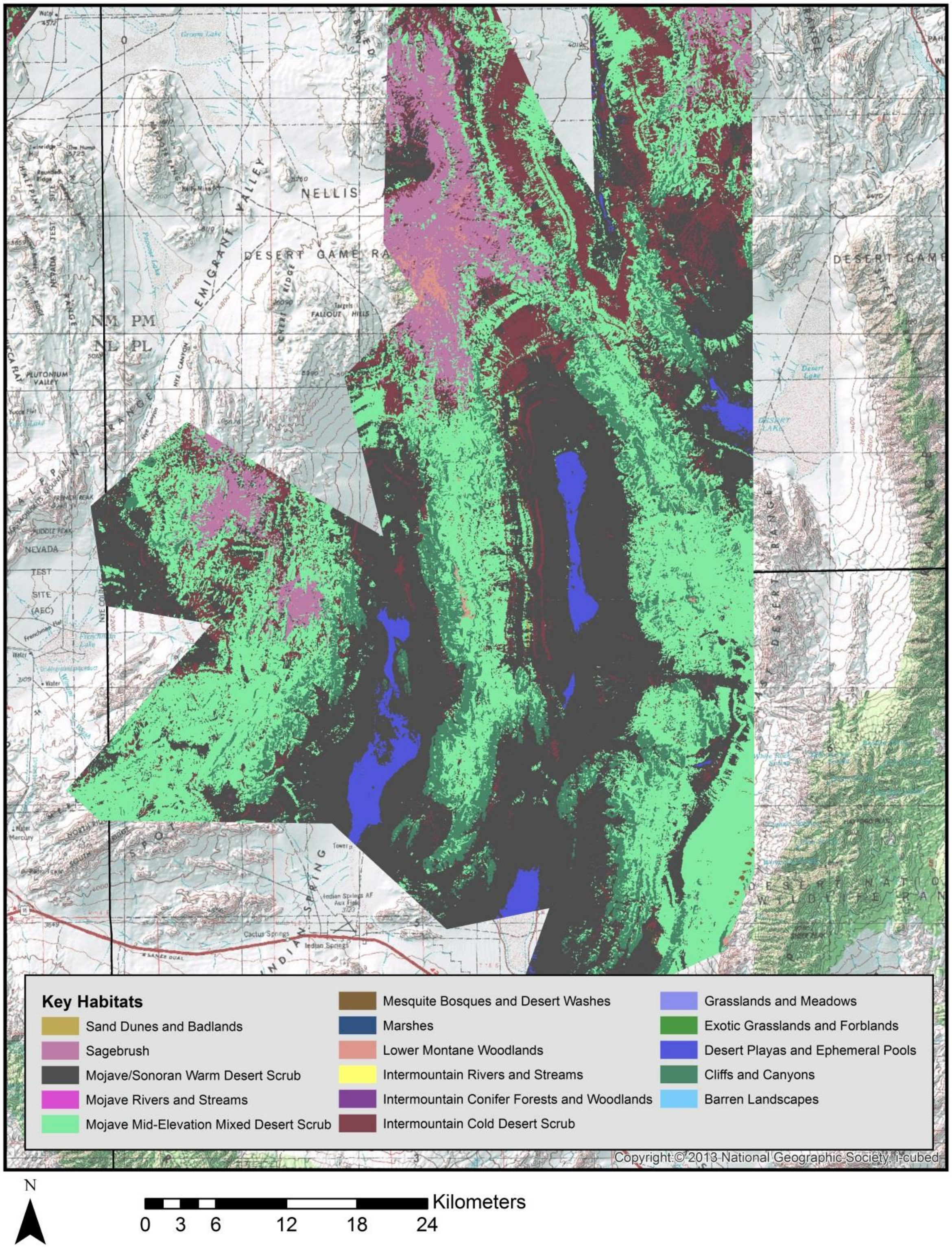
Key Habitats
Sand Dunes and Badlands
Sagebrush
Mojave/Sonoran Warm Desert Scrub
Mojave Rivers and Streams
Mojave Mid-Elevation Mixed Desert Scrub
Mesquite Bosques and Desert Washes
Marshes
Lower Montane Woodlands
Intermountain Rivers and Streams
Intermountain Conifer Forests and Woodlands
Intermountain Cold Desert Scrub
Grasslands and Meadows
Exotic Grasslands and Forblands
Desert Playas and Ephemeral Pools
Cliffs and Canyons
Barren Landscapes
NELLIS
DESERT GAME RANGE
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Figure 3. . Key habitats surrounding study site boundaries, Mojave Desert, Southern Nevada

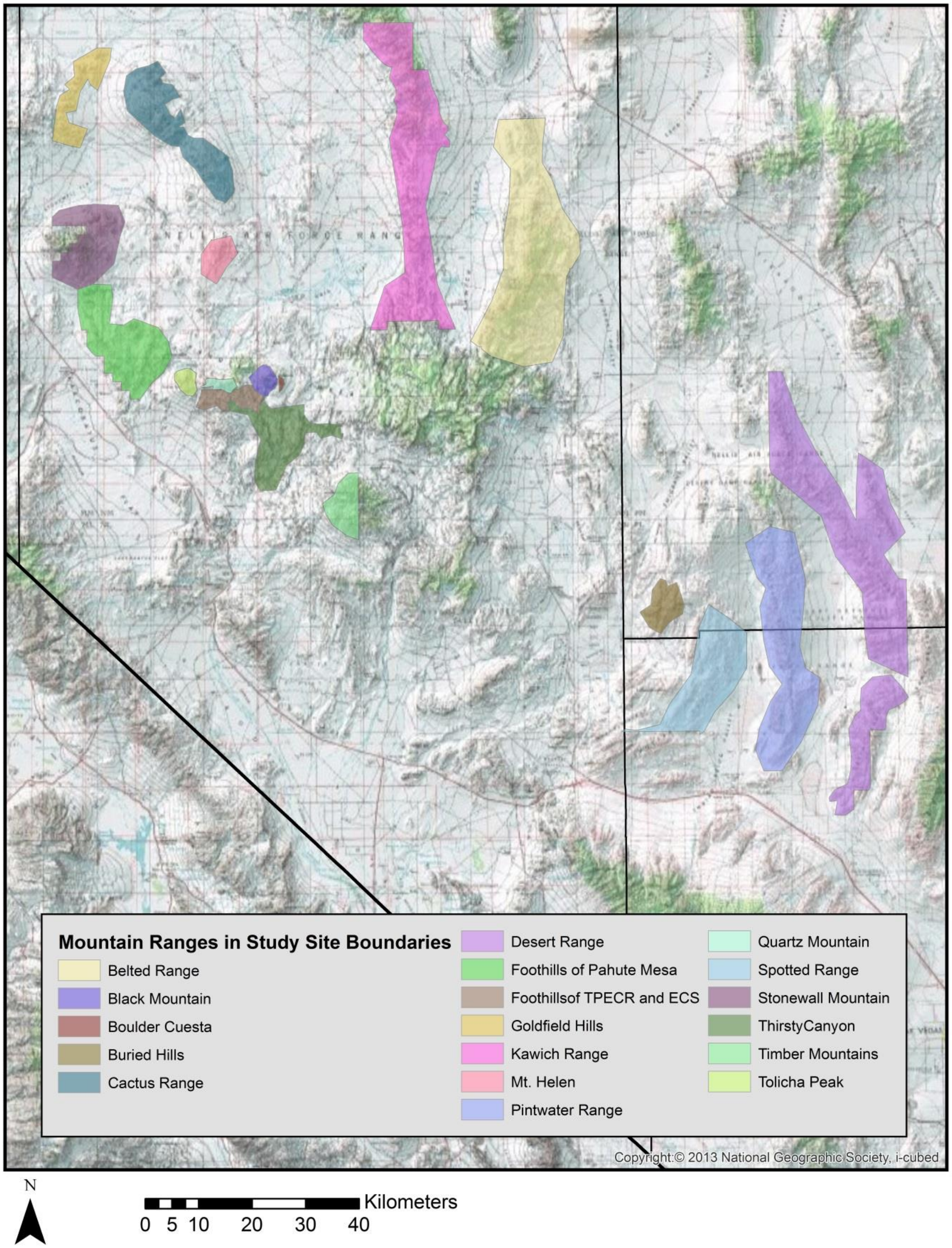

Figure 4. Mountain ranges surveyed, Southern Nevada

Methods

Aerial Surveys

Together with a team of biologists, I conducted comprehensive helicopter surveys of all cliff habitats with an EC-130 helicopter in accordance with USFWS protocol beginning in 2011. Aerial surveys were initiated early in the morning and usually completed by noon. These surveys were conducted by contractors of the Nellis Natural Resource Program (NNRP) within the designated study site boundaries. The objectives of the surveys were to locate and identify nests of golden eagles. Observations and data for each nest site were collected within 200 m of the nest or closer, if possible. The helicopter approached no closer than 10-20 m of any occupied nest and remained in place no longer than 30 sec. A close approach and extended hovering were allowed only at unoccupied nests. During surveys, observers collected nest and nest site data, counted eggs, counted eaglets, determined the fate of eaglets (dead or alive), or confirmed nest success or failure. If a golden eagle appeared disturbed, the helicopter banked away to terminate the nest search. Scheduling of all surveys was based on the timing of courtship, breeding and nesting seasons observed by the NNRP prior to my study. Inventories of golden eagles were initiated during courtship when adults were mobile and conspicuous. Surveys were conducted approximately 30 to 60 days apart from January (initial territory surveys) to July. Egg laying usually occurs in late February for the Mojave population and mid-February to March in the Great Basin population. Golden eagles normally lay two eggs, but are known to produce clutches with as many as four eggs (Pagel et al. 2010). Incubation lasts approximately 35-45 days and fledglings take flight 75-80 days post-hatching (Dunstan 1989).

Survey timelines- During November-December 2010, helicopter survey routes were determined based on data available from previous raptor surveys. Surveys began in January the first year and consisted of territory surveys, nesting surveys and subsequent productivity/occupancy surveys.

Territory surveys began in late January 2011. All stick nests identified as golden eagle were documented, marked by GPS and mapped. The presence of a golden eagle or other raptor species near the nests was recorded and territorial displays noted. Nests later determined as other than golden eagle were removed from the dataset. Data collected for golden eagle nests included: GPS location (UTM), GPS elevation, visual estimation of nest size, location of nest relative to cliff height (height of nest : height of cliff), elevation and aspect.

Each nest and subsequent territory were identified as positively occupied, positively unoccupied, possibly occupied or unknown. Nest sites with a preponderance of whitewash or fresh defecation from a perch site were recorded as possibly occupied.

Nesting surveys extended from late April to early May within the Mojave study site and May to early June within the Great Basin site. All nests in previously identified territories were surveyed and recorded as active/occupied or inactive/unoccupied. Active nests had eggs and/or hatchlings present. The breeding status for active nests was designated as successful or unsuccessful. I used the sightings of eggs, hatchlings, incubation by female or nest decorating to confirm active nests. A nesting chronology (estimated hatch date, current age, estimated fledge date) was developed by data collected (number of eggs, hatchlings present or age class of nestlings) during the nesting surveys. The age classification of eaglets was critical in deciding the time frame for conducting the productivity/occupancy surveys.

I initiated productivity/occupancy surveys no earlier than 51 days after the nesting surveys to finalize occupancy and nesting success. At this time, the nesting phenology (estimated dates of laying, hatching and fledging) was constructed by back-dating from the survey date assuming: 1) incubation started after the first egg was laid (Collopy and Edwards 1989) and lasted 45 days; and 2) a nesting period, from hatching to fledging, was 70 days (Palmer 1988). Nests were then categorized as successful, unsuccessful or unknown, and nesting success was quanitified based on the number of successful fledglings per number of eggs laid. Fledgling success was established via the observation of young at least 51-days-old or known to have fledged from the observed, previously occupied nest. Nesting was deemed successful if fledglings were observed > 51 days from hatching. Nesting failure was determined when eggs were laid or incubation behavior was observed, but failed to have any young after 51 days. When nest failure was determined, a spotting scope was used to search for the dead young.

During all years, date of observation, date of each survey, helicopter routes, nesting status and age class of all golden eagles observed were documented. A nesting chronology was calculated for each occupied nest based on: the date the clutch was completed (estimated), description of observed incubation behavior (used to estimate date of completed clutch), hatch date (estimated from age of nestlings), fledge date (known or estimated), date nesting failure was first observed and confirmed, number of young at each visit and >51 days of age, digital photographs, landscape view of area and nests. Weather and time of day were also recorded. Nest searches were not conducted in inclement weather (high winds or rainfall) due to the safety of the crew and the potential for nest site abandonment. High temperatures were also considered inclement because of the potential of overheating and mortality of the egg or young if the adult flushes. At the end of each year, all data were entered into a GIS database for analysis.

Geographic Information Systems (GIS)

I used ArcMap 10.1.1 (ESRI 2011) to view and process spatial data for the purposes of this project. All locations of nest sites, whether active or inactive, were represented by point locations projected into a WGS 1984 UTM Zone 11 N Coordinate System. I used ArcMap random point generator to represent pseudo-absent points (constrained to cliffs and canyons) for comparison to true nest sites for golden eagles. Pseudo-absent points represent randomized locations where nest sites do not occur.

I obtained categorical habitat data from the NDOW key habitat GIS layer as described in the NDOW Wildlife Action Plan (NDOW 2010), along with soil associations and geological formations (NNRP 2011). Continuous data obtained online through open source geospatial data included Digital Elevation Models (DEM) and aspect and slope (USGS 2015). I entered the NDOW key habitat layers, geological formations and soil associations as vector data in shape files represented by polygons. The DEM, aspect and slope layers all represent raster grid data files converted to ASCII format for input into the program MaxEnt.

I intersected all nest site points with these layers to obtain values for DEMs aspect, slope, geology and soils. I transformed aspect data from a circular variable (0-360) to a continuous variable (-1 to 1) for use in the analysis by applying cosine to the aspect multiplied by pi divided by 180° [Northness = COS ((aspect x 3.14159)/180)].

Seeps and springs, represented as point data, were obtained from the land managers (NNRP 2011) for use in calculating the distance from each nest to the nearest water source. A road layer represented as a polyline was also obtained from the land managers. I calculated distance to water and distance to the nearest road using the spatial join tool set to match closest points from one another (eagle nest points to seeps and springs points and eagle nest points to road polylines). The Euclidian distance tool was then used to convert the nest site point files and the distance to road polyline files into a categorical raster grid representing continuous data. Data for each of these variables was then obtained in the same manner for randomly generated points.

Viewshed is the geographical area that is visible from a point location. In GIS it is a computational algorithm derived from a DEM that estimates the difference of elevation from one grid (viewpoint cell) to the next (target cell). My goal was to quantify the area observed by a golden eagle from its nest (within 1.61 km); assuming cliffs or canyons hinder the potential 360° view. I considered the value obtained from a 1.61 km buffer) with a 0-360° view as the attribute for viewshed (km^2). Viewshed was visually represented using ArcScene 10.1 (ESRI 2011). A visual example of this attribute is shown in Fig. 5. I used a geoprocessing model builder for this analysis (Fig. 6).

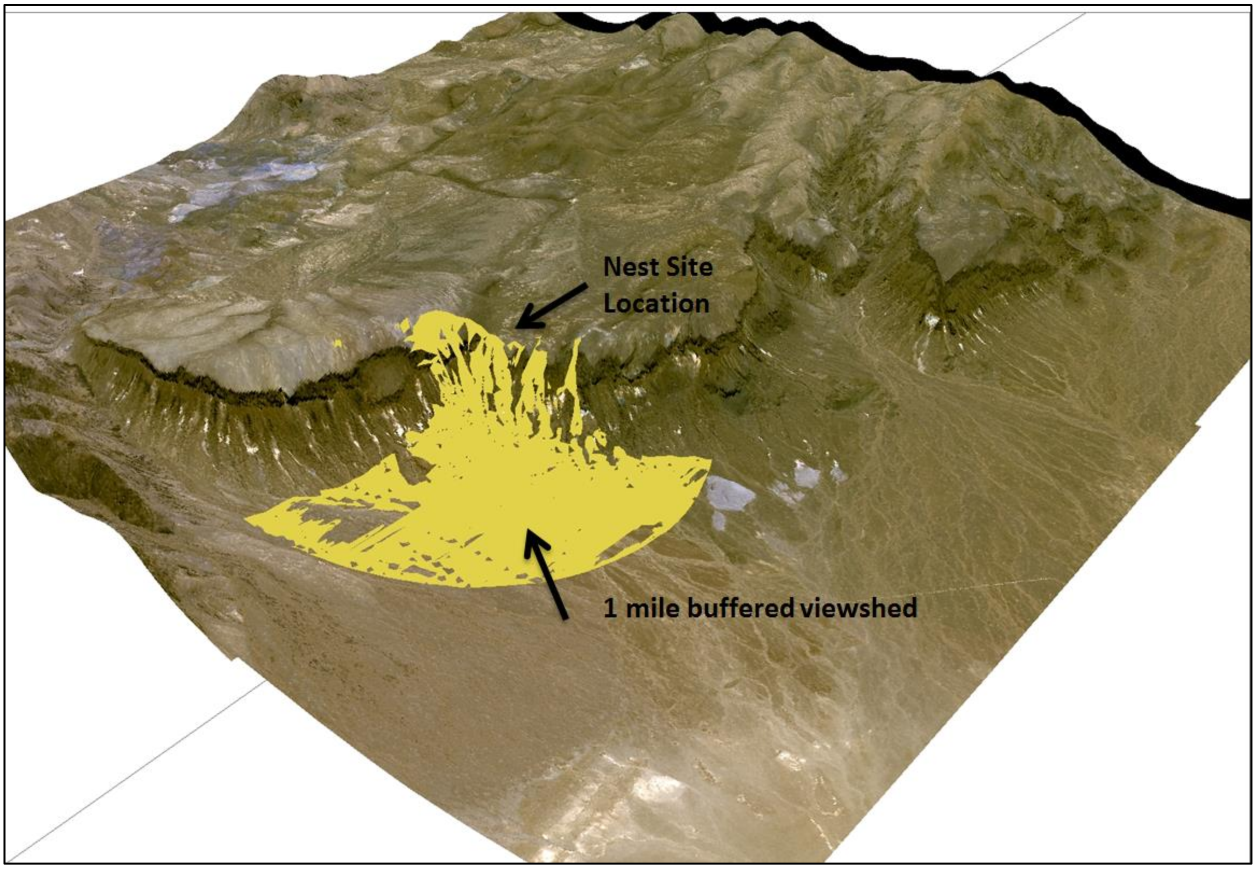

Figure 5. ArcScene 3D aerial view of a nest site location with viewshed attribute

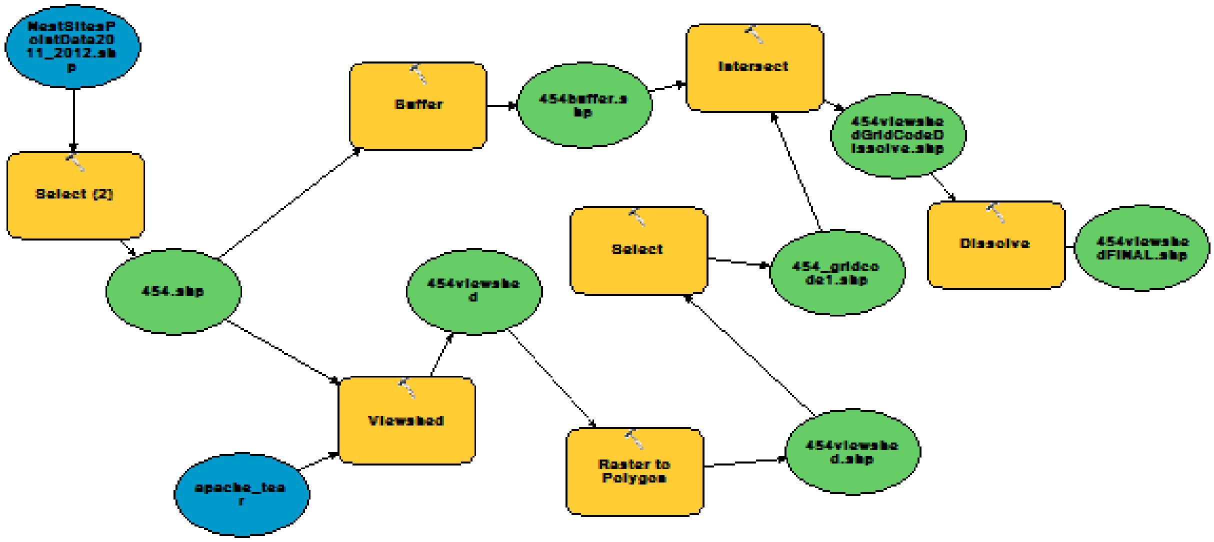

Figure 6. Geoprocessing model builder used for viewshed analysis of each nest site

Spatial and Statistical Analysis

To model the probability of suitable nesting habitat within the designated study site, I selected, *a priori*, several environmental parameters (elevation, slope, aspect [northness], distance to water and distance to road) that would likely influence nest site selection in a desert ecosystem based on the availability of geographic layers. These parameters were used for the final habitat suitability model. I also investigated other ancillary parameters (key habitat, relative nest height, soil, geology and viewshed) and included them in the results and discussion section. Many external factors may be regionally important in nest site selection by golden eagles, and it is difficult, if not imposible, to include all variables in a spatial model. Many other parameters may be important for nest site selection by eagles (*e.g*. proximity to hunting grounds and relation to other nests); however, I was constrained by the GIS layers available for the study site.

I applied general descriptive statistics to the dataset and investigated general trends in the data such as overall nest occupancy by year and productivity by year and mountain range. All instances of occupied nests were lumped together and counted once for productivity. If a nest site was occupied in multiple years, it was counted only once in the following analyses.

I tested for significant differences in productivity between ecoregions. I examined nesting chronology and reported general trends using dates and timing of nesting behaviors (egg laying, hatching and fledging). I described nest abundance (total number of nest sites observed) and density (number of nest sites/km^2) for each ecoregion and summarized the ancillary environmental parameters for each nest site. The height of each nest in relation to its overall cliff height was also investigated.

Environmental parameters involved in nest site selection were investigated. General trends in nest site selection were described including surrounding key habitat, mountain range, cliff height in relation to total height, soils, geological formation and viewshed. The characteristics of those parameters were not used in the final habitat suitability model; however, these are important in terms of characterization of the environment. For the model, occupied nests versus unoccupied nests and all combined nest sites versus randomized pseudo-absence nest sites were compared. For this analysis, elevation, slope, aspect (converted to northness), distance to water and distance to road were used. Environmental attributes and their potential influence are shown in Table 1.

Table 1. Environmental attributes and their potential influence on nest site selection.

Attribute	Potential Influence
Elevation	Cliff faces are found in high elevations within the desert habitat. Position of nest sites must balance the cost of nesting high enough to avoid nest predation and gain a vantage view, but low enough to limit energy expenditure of bringing prey to the nest (Watson J. , 2010)
Slope	Nest sites are typically found on sheer cliff faces to obtain protection from predators, provide for a clear take off and avoid saturation from accumulated rain water.
Northness	Nest site preference in the desert is influenced by the sun's rays due to temperature influence on nesting eagles. Northness value was obtained from aspect (-1 to 1)
Distance to Water	Water is a limiting factor within the desert environment on which avian species rely
Distance to Road	Nesting eagles are sensitive to disturbances. Nest sites further away from human presence are preferred

Habitat selection parameters were evaluated by comparing nest sites (active and inactive) to randomly selected pseudo-absence points in cliff and canyon habitats within the study site. For each parameter, I tested the hypothesis of no significant differences between the means of active and inactive nest sites ($p \leq 0.05$), and then tested the hypothesis of no significant differences between the combined nest sites (active and inactive) and pseudo-absent nest sites ($p \leq 0.05$).

I evaluated habitat selection by using a series of logistic regressions (generalized linear models with a binomial error distribution and a logit link function). I tested whether golden eagle nest sites (coded as = 1) could be distinguished from pseudo-absent nest sites (coded as = 0) based on the previously discussed environmental parameters. Each predictor value was then weighted and ranked according to its strength in representing the data. The final model was used to predict the potential distribution of golden eagle nest sites using the program MaxEnt.

Breeding territories generally vary in size and configuration with topography and prey availability (Gulf South Resource Corporation 2012). A nesting territory for the purposes of this study was an area that contained, or historically contained, one or more nests within the home range of a mated pair. Golden eagles live in more or less discrete home ranges and tend to use nesting sites that are evenly spaced over the landscape (Newton 1979). This pattern of nesting, known as over-dispersion, means that when sites are plotted on a map they appear regularly distributed; much more regularly than if birds were selecting nest sites at random (Watson 2010). Regular spacing of nest sites is the norm with golden eagles because territorial pairs appear to select nest sites as far from their neighbors as conditions will allow (Watson 2010). In order to test whether nest sites were selected at random or whether over-dispersion was found, I applied a nearest neighbor analysis to the active nests observed in the Great Basin and Mojave Desert ecoregions (over four years). Territory delineations were then mapped using the mean inter-nest distance extrapolated over all active nest sites.

I used the MaxEnt software package (Phillips et al. 2006) to develop a suitability model for nest sites. MaxEnt is one of the most popular tools for species distribtuion and environmental niche modeling (Merow et al. 2013). A niche-based model represents an approximation of the species realized niche within the study area and environmental dimensions being considered (Phillips et al. 2006). It is used to predict the habitat suitability for the species as a function of the given environmental variables in a probability based on a grid of pixels represented in a map. The environmental variables for study were taken from the same GIS raster grids as previously discussed. For the purposes of MaxEnt software, the following variables were used as inputs into the software: elevation, slope, distance to water and distance from road. Soils, geology and viewshed were not applied due to their categorical nature. Viewshed was not applied due to its inability to be extrapolated over the study site boundaries.

CHAPTER 3

RESULTS

Nesting Productivity

Ninety-six nest sites were identified as golden eagles within my study sites from 2011-2014. Of these nest sites, 65 occurred in the Mojave Desert ecoregion (Fig. 7) and 31 in the Great Basin ecoregion (Fig. 8). During four years of observations, 22 nests (71%) were occupied in the Great Basin ecoregion, and only 5 (8%) were inhabited in the Mojave Desert ecoregion. A total of 36 eaglets (96%) successfully fledged during the four-year study, three in the Mojave Desert ecoregion and 33 in the Great Basin ecoregion. During the study, one eaglet failed to fledge and the status of one other was unknown.

Nest productivity significantly varied by ecoregion (Table 1). In 2011, eight nests occupied in the Great Basin ecoregion produced 13 young (successful fledges). No nests were observed with chicks or eggs in the Mojave Desert ecoregion. In 2012, only one nest in the Great Basin ecoregion was active throughout the year. This nest produced a single eaglet that successfully fledged. In 2013, nine nests in the Great Basin ecoregion produced 14 young and one nest in the Mojave Desert ecoregion produced one young. In 2014, the Great Basin ecoregion had four occupied nests that produced five young. The Mojave Desert ecoregion had four occupied nests, however, only two nests fledged young. One nest failed (chick observed dead) and the status of another nest was unknown. The unknown fledgling was not observed on the final survey after 51 days post-hatching.

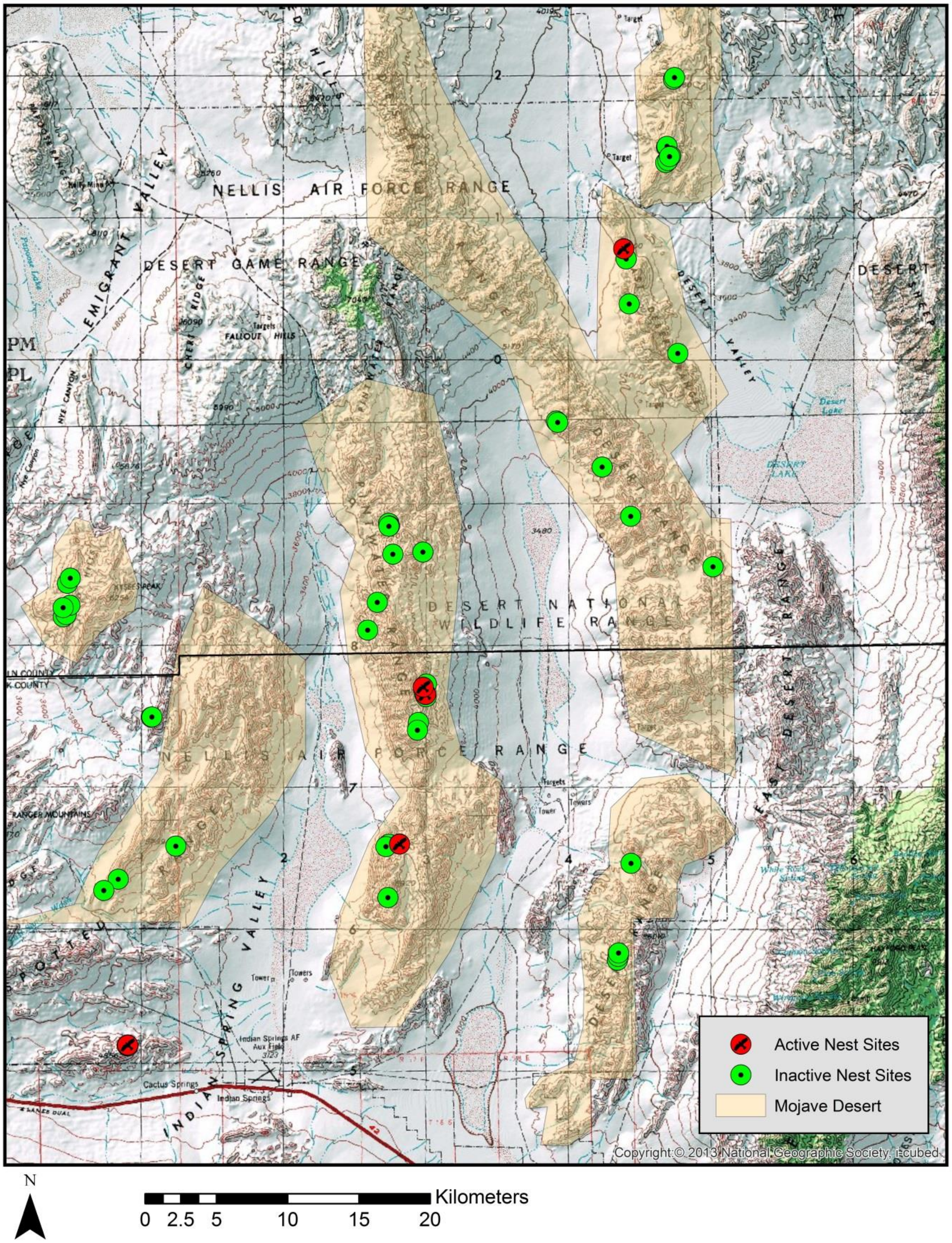

Figure 7. Golden eagle nest sites observed 2011-2014 in the Mojave Desert

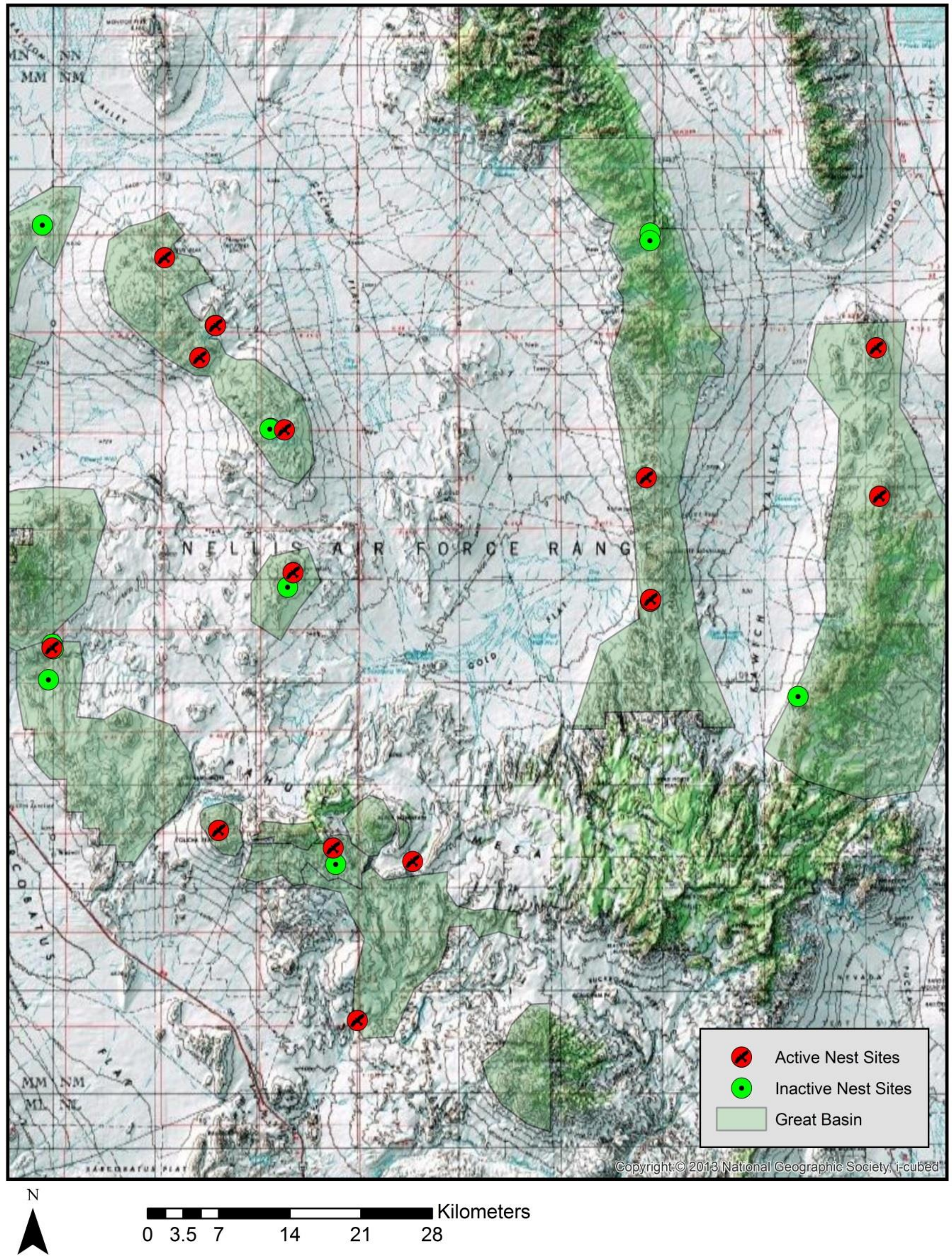

Figure 8. Golden eagle nest sites observed from 2011-2014 in the Great Basin.

Productivity varied by mountain range (Table 2). All nests with multiple year productivity were located within the Great Basin ecoregion. Two nest sites had three-year occupancies (one observed on the Kawich Mountain Range and one on Mount Helen Range), and three nest sites had double year occupancy (both on the Cactus Range). From 2011-2014, three nest sites had double year occupancy (both on the Cactus Range). The Desert Range and the Pintwater Range had the greatest number of nest sites; the Cactus and the Kawich ranges had the greatest number of occupied nests and the Cactus Range and Buried Hills had the greatest nest productivity over four years (Table 3). There were significant differences in productivity rates by ecoregion ($t_{95} = 5.70$, $P = <.001$).

Mountain Range

The Pintwater and Desert Mountain ranges (Fig. 4), located in the Mojave Desert ecoregion, contained the largest number of nest sites; however, both had low productivity during the four years of data collection (Table 3). In contrast, the Cactus and Kawich Mountain ranges (Fig. 4), located in the Great Basin ecoregion had the lowest number of nest sites and higher productivity during the study (Table 3).

Nesting Chronology

The annual cycle of the golden eagles began with undulating display flights (the chief form of territorial behavior) becoming increasingly frequent in early spring just prior to breeding (Fig. 9). Nest-building activity tended to increase by February, with egg laying beginning in early March, six weeks prior to hatching. The majority of golden eagles on my study site hatched in mid to late April and fledging occurred in late June.

There was little variability (1-2 weeks) in the different stages of the cycle in the Mohave Desert and Great Basin ecosystems.

Nest Site Abundance and Density

Although a greater percentage of occupied nests occurred in the Great Basin ecosystem, the amount of nesting habitat and number of historic or old/abandoned nest sites in the Mojave Desert far outnumber those of the Great Basin ecosystem. The quantity of cliff and canyon nesting habitats (263.7 km^2) in the Mojave Desert ecoregion was 10.4-fold greater than the quantity (25.3 km^2) of cliff and canyon nesting habitats in the Great Basin ecoregion. By normalizing the number of nests to the amount of available nesting habitat (cliffs and canyons)

total nest density of 1.23 nests/km^2 was obtained for the Great Basin ecosystem and 0.25 nests/km^2 for the Mojave Desert ecoregion (Table 4).

Table 2. Nest occupancy and productivity based on numbers of active nests (Active), numbers of chicks initially observed (Observed), numbers of chicks successfully fledged (Success), numbers of chicks failed to fledge (Fail), numbers of chicks unknown to fledge (Unknown) by year and ecoregion.

Year	Ecoregion	Active	Observed	Success	Fail	Unknown
2011	Great Basin	8	13	**13**	0	N/A
2011	Mojave Desert	0	0	**0**	0	N/A
2012	Great Basin	1	1	**1**	0	N/A
2012	Mojave Desert	0	0	**0**	0	N/A

Table 2. Continued

2013	Great Basin	9	14	**14**	0	N/A
2013	Mojave Desert	1	1	**1**	0	N/A
2014	Great Basin	4	5	**5**	0	N/A
2014	Mojave Desert	4	4	**2**	1	1
TOTALS		**27**	**38**	**36**	**1**	**1**

Table 3. Number of nests (active and inactive) and their four-year productivity by ecoregions and mountain ranges in 2011-2014. Nests with multiple years of productivity were only counted once.

	Total Number of Active Nest Sites	**Total Number of Nest Sites**	**Productivity**
Pintwater Range	3	24	1
Desert Range	1	22	0
Spotted Range	1	11	1
Buried Hills	0	8	0
Mojave Desert Total	**7**	**65**	**2**
Cactus Range	5	8	13
Kawich Range	5	7	9
Mount Helen	1	2	4
Belted Range	3	3	3
Thirsty Canyon	2	3	3
Grand Canyon	1	7	1
Tolicha Peak	0	1	0
Great Basin Total	**16**	**31**	**35**

Table 4. Total number of nest sites and their four year productivity (2011-2014) by ecoregion and mountain range.

	Total Number of Nest Sites	Productivity
Pintwater Range	24	1
Desert Range	22	0
Spotted Range	11	1
Buried Hills	8	0
Mojave Desert Total	**65**	**2**
Cactus Range	8	13
Kawich Range	7	9
Mount Helen	2	4
Belted Range	3	3
Thirsty Canyon	3	3
Grand Canyon	7	1
Tolicha Peak	1	0
Great Basin Total	**31**	**35**

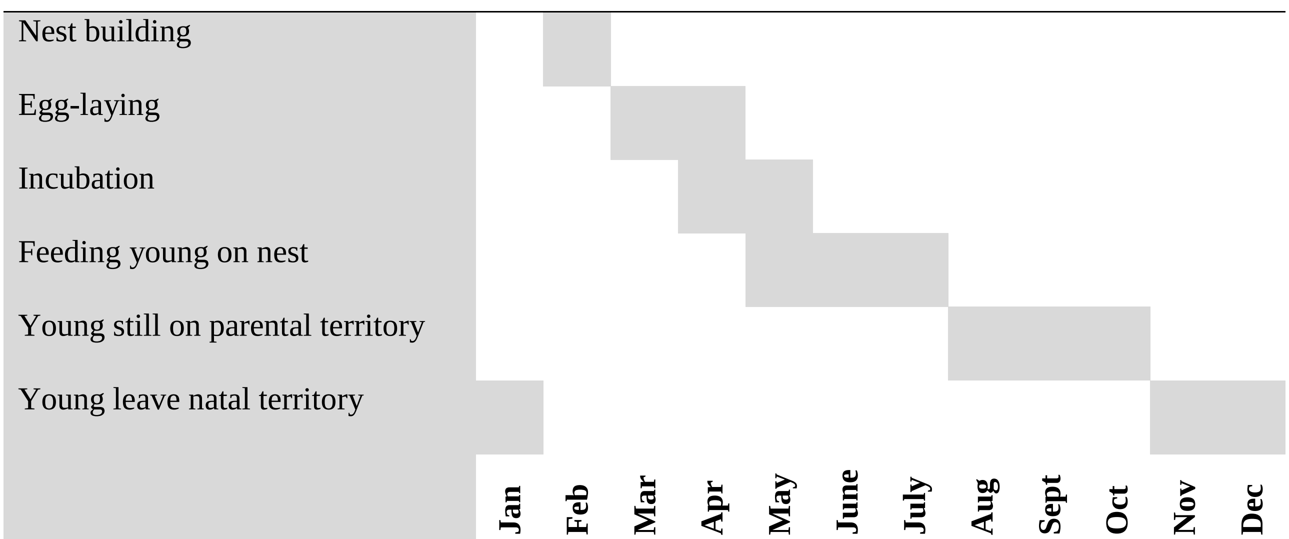

Figure 9. Mean annual chronology cycle observed in the Mojave and Great Basin

Table 5. Relative differences in productivity and nest abundance based on total number of occupied nests (Occupied), total number of nests (Total), ratio of occupied nests to total nests (Ratio), area of cliff canyon habitat (km^2) (Area), occupied nest density (occupied nests/km^2) (Density 1) and overall nest density (total nests/km^2) (Density 2) by ecoregion.

Ecoregion	Occupied	Total	Ratio	Area	Density 1	Density 2
Great Basin	16	31	51.6%	25.30	0.63	1.23
Mojave Desert	7	65	10.7%	263.66	0.03	0.25

Illustration 3. Nesting golden eagles observed during this study, approximately three weeks old (NNRP 2011).

Illustration 4. Nesting golden eagles observed during this study, approximately eight weeks old (NNRP 2011).

Key Habitat

All nest sites were found within the boundary of the cliff and canyon key habitat. The surrounding habitat (i.e. likely hunting grounds) was evaluated and compared. Of the 96 total nest sites, 66 (69%) were surrounded by the Mojave Sonoran Warm Desert Scrub key habitat, 19 (20%) were found surrounding Intermountain Cold Desert Scrub key habitat, and 11 (11%) were found surrounding Sagebrush key habitat (Fig. 10).

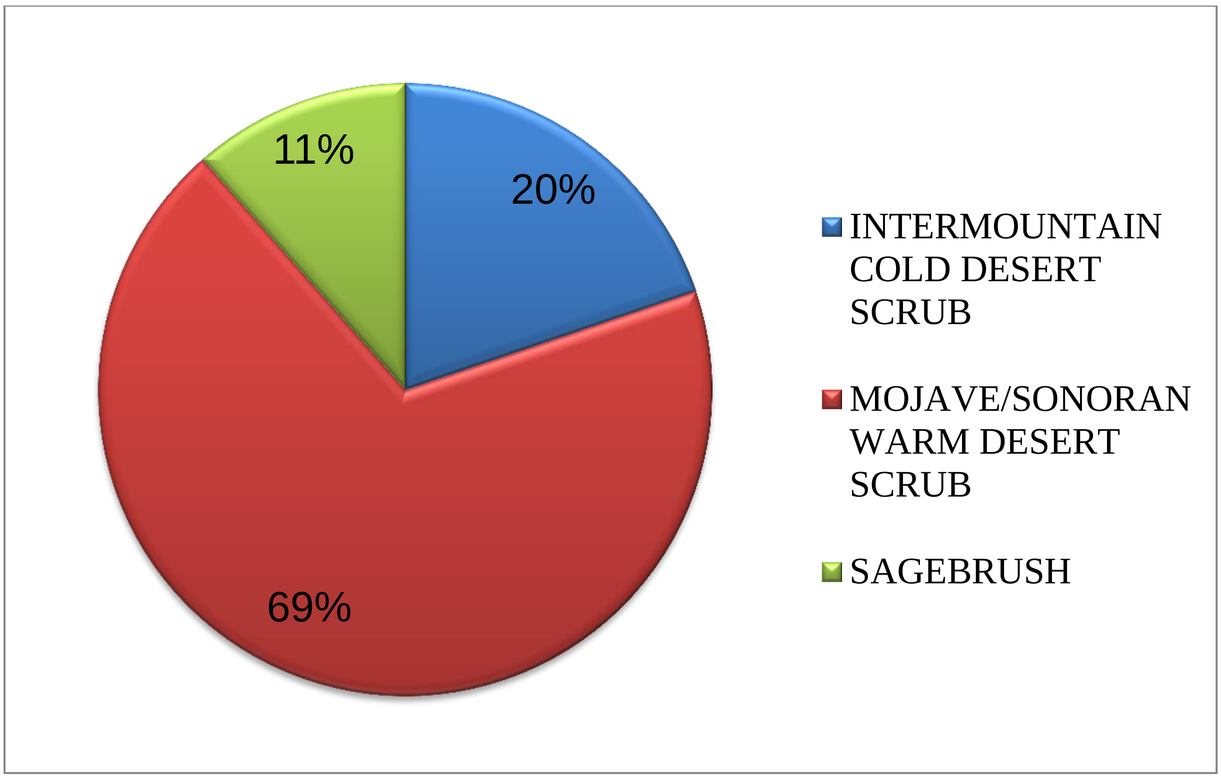

Figure 10. Key habitats associated with all nest sites in the Mohave Desert and Great Basin.

Relative Nesting Height

The mean ratio of nesting height to total cliff height was 0.69 ±0.21, with a range of 0.33 to 1.00. This one occasion (1.00) was a nest site observed sitting on top of the cliff, however the nest site was unoccupied across all the years of the survey.

Soils

The majority of nest sites (59, 61%) were observed on St. Thomas-Rock Outcrop (NV204) soil association (Fig.11). The second most abundant (27, 28%) soil type was Stewval-Rock Outcrop Gabbvally (NV308). Four other soils accounted for < 3%.

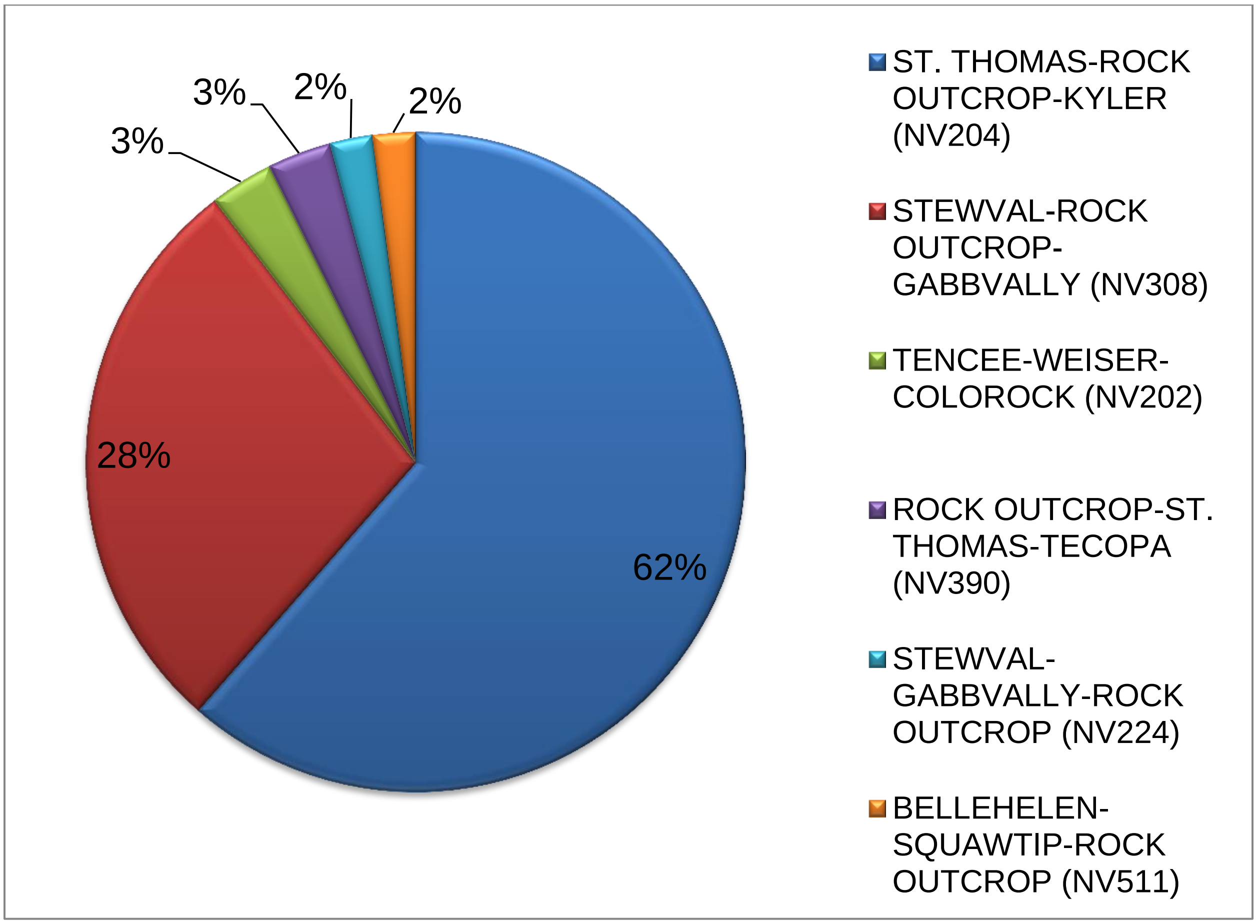

Figure 11**.** Soil associations found all nest sites observed.

Geological Formations

Forty-six percent of all nest sites were observed on Limestone, Dolomite, Shale and Quartzite (Fig.12). Eighteen percent were observed on Welded and Non-welded Silicic Ash-flow Tuffs and 14% were observed on Limestone, Dolomite, Locally Thick Sequences of Shale and Siltstone. All other nest sites were observed less than six percent.

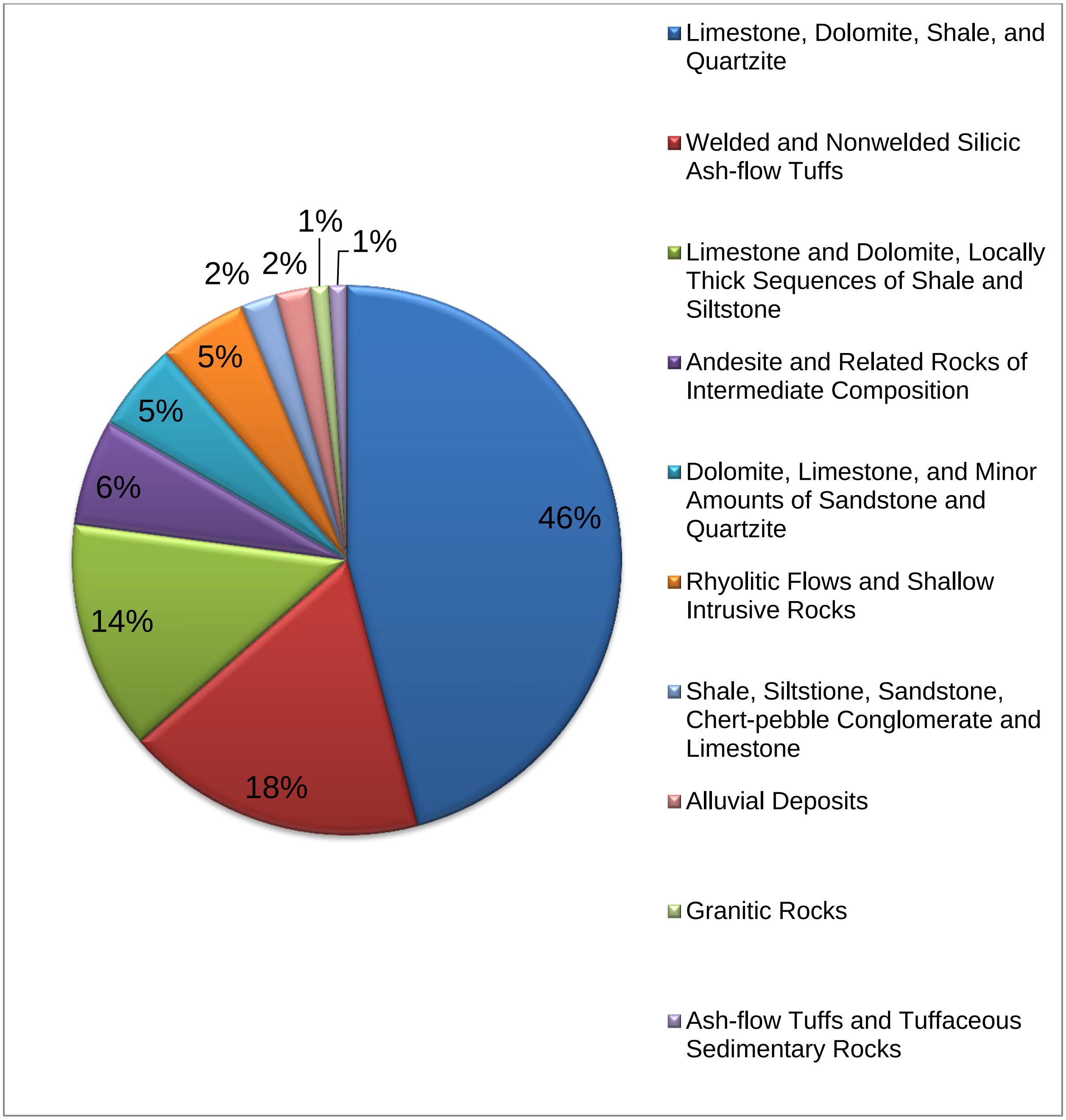

Figure 12**.** Geological formations found at all nest sites observed.

Viewshed

I buffered each nest site (360°) by 1.61 km for a total area of 8.14 km^2. A viewshed parameter was obtained for 89 nest sites. A total of 89 nest sites were used for the analysis, all others were thrown out due to difficulty with the spatial analysis. Between both ecosystems, the mean of the viewshed area was 0.78 km^2 (±57), with a range of 0.06-2.73 km^2. Therefore < 10 % of the surrounding landscape could be viewed from each nest site. When comparing ecoregions, I found no significant difference (t_{86} = 0.52, $P = 0.60$) between viewshed values of the Mojave Desert ecoregion (mean = 0.83 ±0.58) and the Great Basin ecoregion (mean = 0.76 ±0.57).

Attributes Used for Modeling

I found significant differences in active and inactive nests sites for all environmental parameters mentioned above. I found significant differences between nest sites and randomized pseudo-absent nests sites for elevation, slope and distance to nearest road. I found no difference between combined nest sites and pseudo-absent nest sites for distance to nearest water and northness. For all two tailed *t* - tests applied: *n* (active) = 21, *n* (inactive) = 95 and *n* (combined) = 97, *n* (random) = 96.

Elevation (m). The mean of active nest sites was 1867 m MSL and the mean of inactive nest sites was 1581 m MSL (combined mean of 1643 m, ±306.23, range = 1155-2640 m). The results of two sample t-test of active versus inactive: $t_{95} = 4.08$, $p < 0.01$. Results of two sample *t*-test of combined versus active: $t_{191} = 7.12$, $P < 0.01$.

Slope (%). The mean of active nest sites was 30.5% and the mean of inactive nest sites was 38.7% (combined mean of 37.1%, ±13.1, range = 6.1-62 m). Results of two sample *t*-

test of active versus inactive: $t_{94} = -2.62$, $p = 0.005$. Results of two sample t-test of combined versus active: $t_{190} = 6.39$, $p < 0.01$.

Distance to Nearest Road (km). The mean of active nest sites was 3.62 km and the mean of inactive nest sites was 5.01 km to the nearest road (combined mean of 4.73, ±1.47, range. = 0.1-9.83 km). Results of two sample t-test of active versus inactive: $t_{28} = -2.26$, $p = 0.03$. The results of two sample t-test of combined versus active: $t_{191} = 3.07$, $p = 0.002$.

Distance to Water (km). The mean of active nest sites was 3.57 km and the mean of inactive nest sites was 6.55 km to water (combined mean of 5.91, SD = 3.48, min. = 0.18, max. = 19.2 km). Results of two sample t-test of active versus inactive: t_{95} -2.20, p = 0.03. Results of two sample t-test of combined versus active: $t_{191} = 1.65$, $p = 0.10$.

Northness (-1 to 1). The mean of active nest sites was 0.05 and the mean of inactive nest sites was 0.06 (combined mean of 0.06, ±0.68, range = -099-1.00). Results of two sample t-test of active versus inactive: $t_{94} = 0.03$, $p = 0.97$. Results of two sample t-test of combined versus active: $t_{190} = 0.71$, $p = 0.48$.

Logistic Regression Analysis

A series of logistic regressions were used to model nest site selection from nesting parameters, and information-theoretic model selection was used to rank candidate models using Akaike's Information Criterion (AICc) corrected for small-sample size and associated Akaike weights (Table 6). The model with the lowest AICc value was determined the best model representing the data. This model consisted of Elevation + Slope + Distance to Water. Northness was thrown out due to its lack of influence as a variable.

Table 6. Results from logistic regression analysis

Candidate Models	Log (L)	AICc	Delta	Akaike Weights	Rank
Elevation + Slope + Distance To Road + Distance To Water	-89.769	189.9	0	0.533	1
Elevation + Slope + Distance To Road + Distance To Water + Northness	-89.428	191.3	1.45	0.258	2
Elevation + Slope + Distance To Road	-91.925	192.1	2.2	0.177	3
Elevation + Slope	-94.692	195.5	5.65	0.032	4
Elevation	-109.869	223.8	33.94	0	5
Slope	-114.622	233.3	43.45	0	6
Distance To Road	-129.124	262.3	72.45	0	7
Distance To Water	-132.402	268.9	79.01	0	8
Northness	-133.5	271.1	81.2	0	9

Territory Delineations

Active nests in the Great Basin ecoregion in 2011-2014 did not have a pattern that was different from random spacing. The observed mean distance between active nest sites in the Great Basin study site was 7.9 km. The expected mean distance was 9.47 km. The nearest neighbor ratio was 0.834, z = -1.186, p = 0.2354 (Fig. 13).

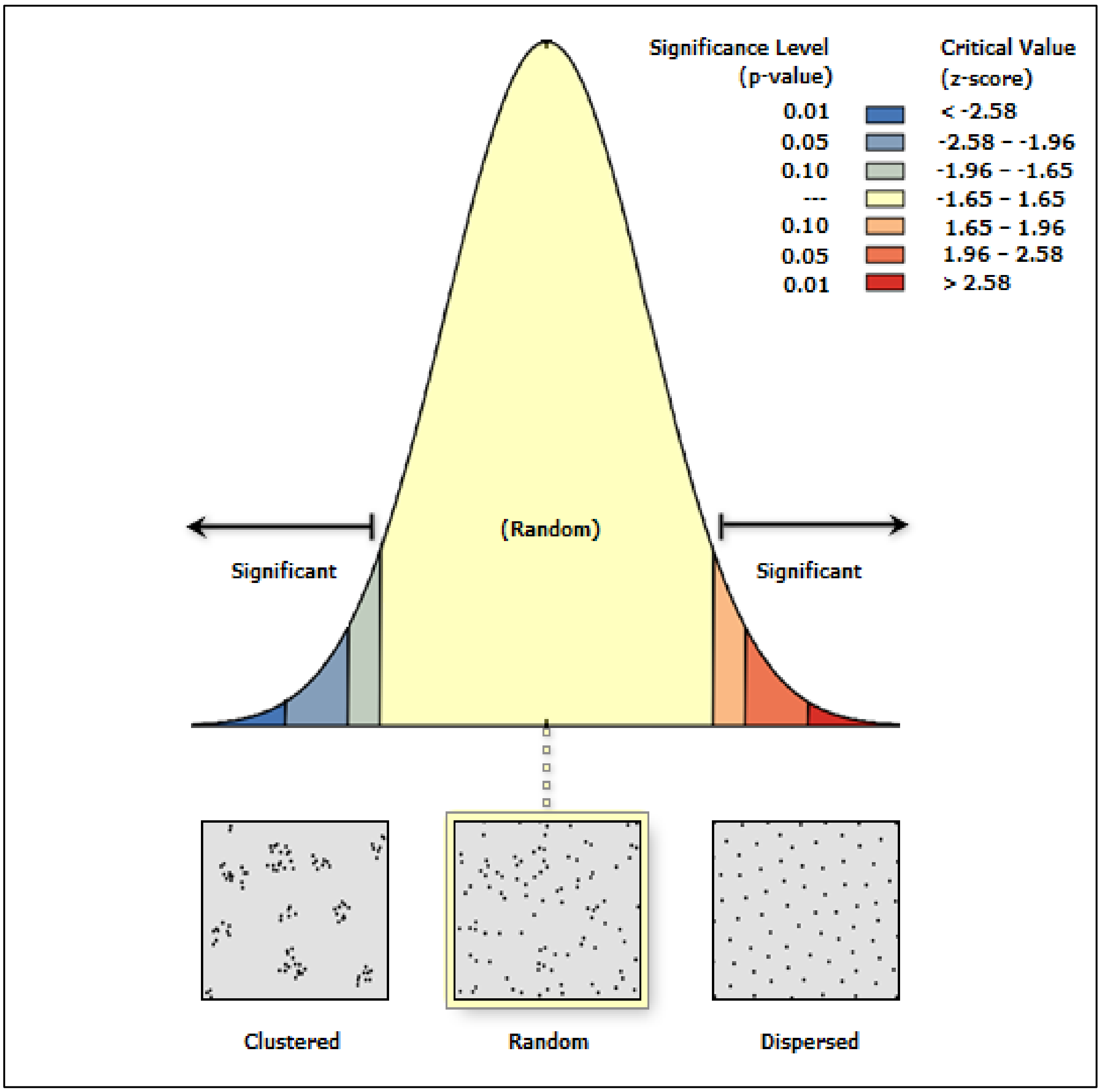

Figure 13. Nearest neighbor results of the Great Basin population of active nest sites.

Active nests (2011-2014) in the Mojave Desert ecoregion had a pattern of over-dispersion. There was < 1% likelihood that this pattern was by random chance. The observed mean distance was 11.4 km and the expected mean distance was 2.55 km. The nearest neighbor ratio was 4.48, z = 13.3, p = 0.00 (Fig. 14).

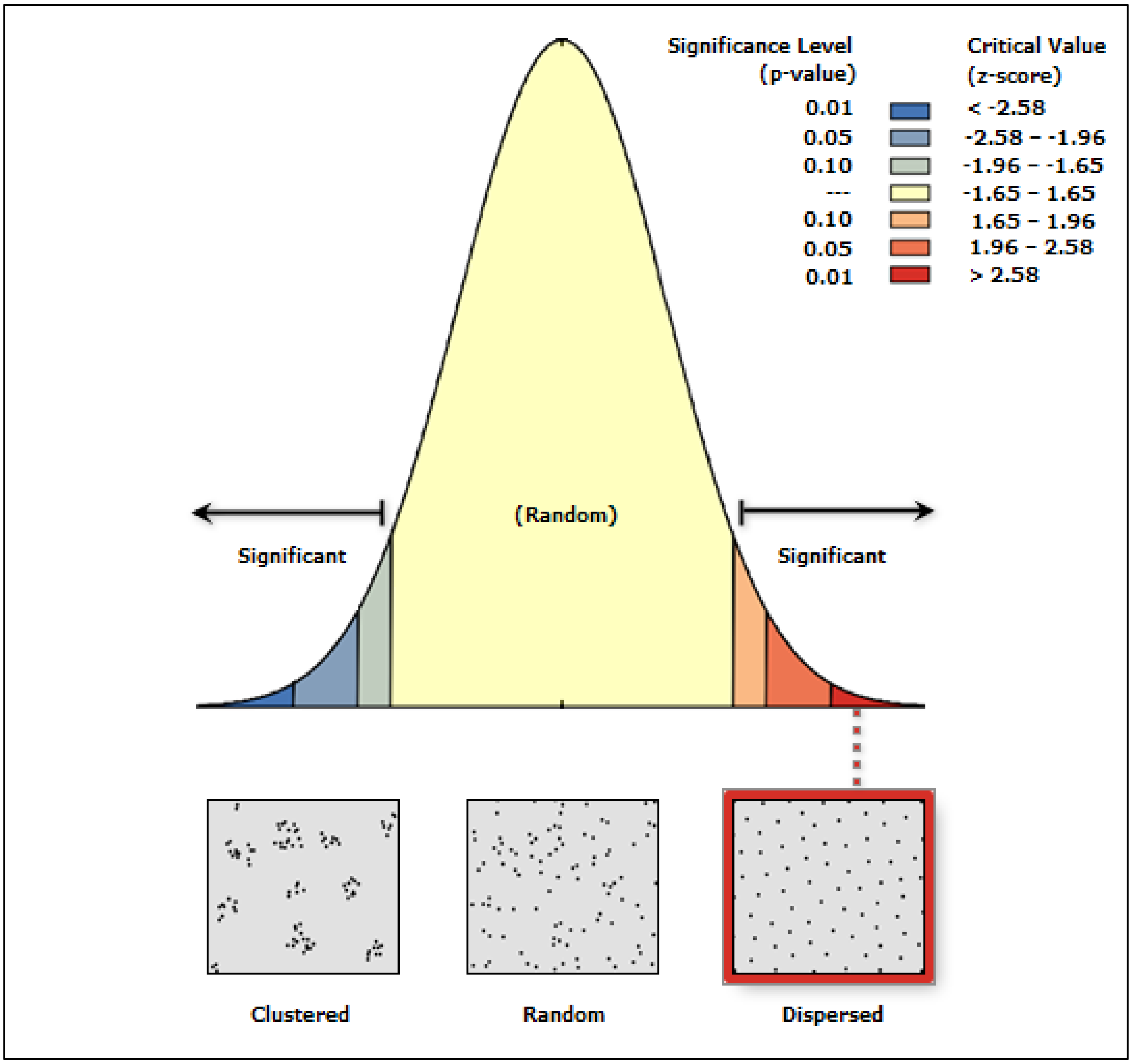

Figure 14. Nearest neighbor results of the Mojave Desert ecoregion of active nest sites.

At the present time, the breeding territory or home range of golden eagles within the study site boundaries was assumed all land within 9.65 km of an active nest. This figure (Fig. 15) is the mean inter-nest distance of both the Great Basin and Mojave Desert ecoregions combined. This coincides with the 9.98 km guideline adopted from a draft Golden Eagle Guidance Document (Gulf South Resource Corporation 2012). Active nest sites with delineated territories are found in Fig. 15 and Fig. 16.

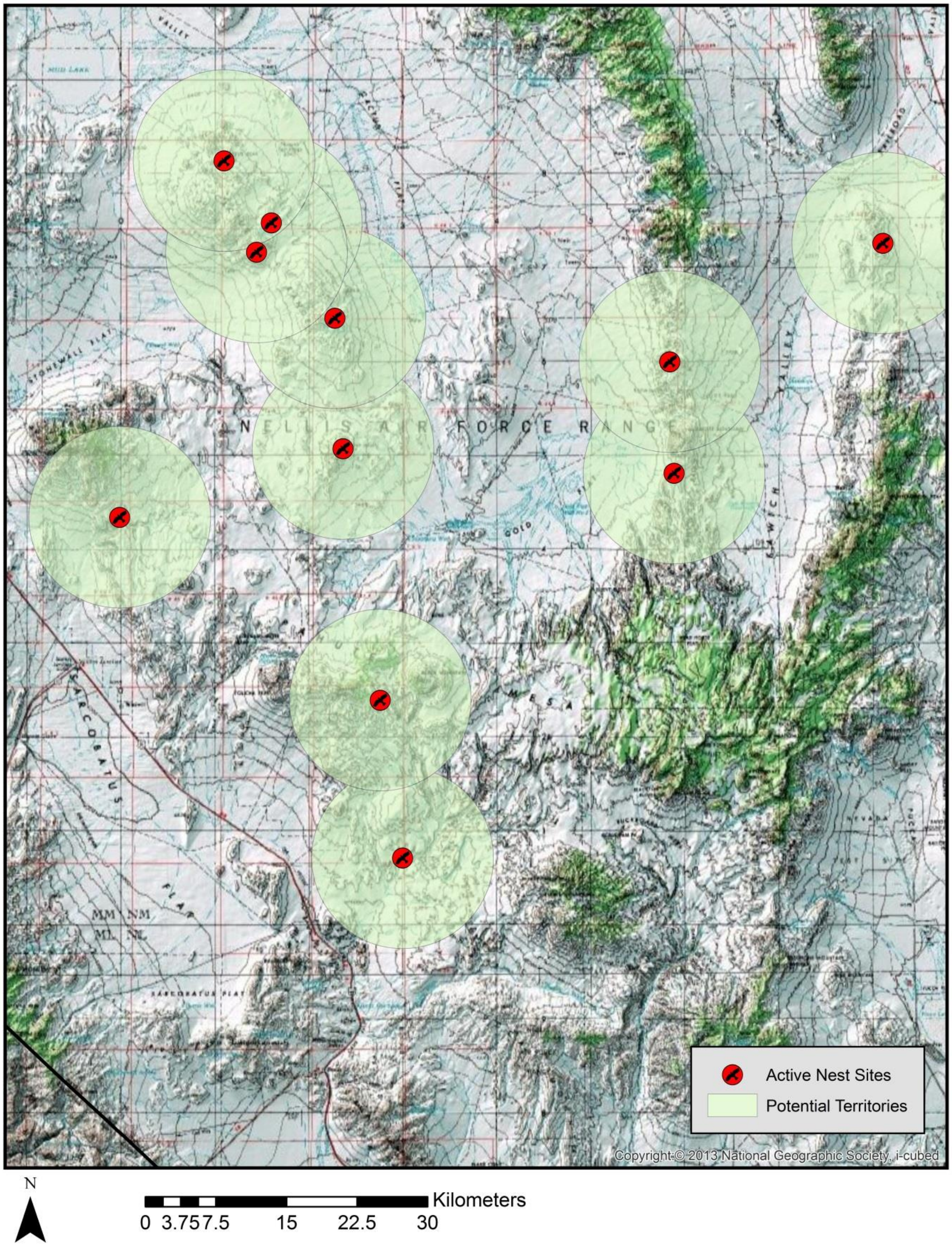

Figure 15**.** Potential territories of golden eagles observed within the Great Basin.

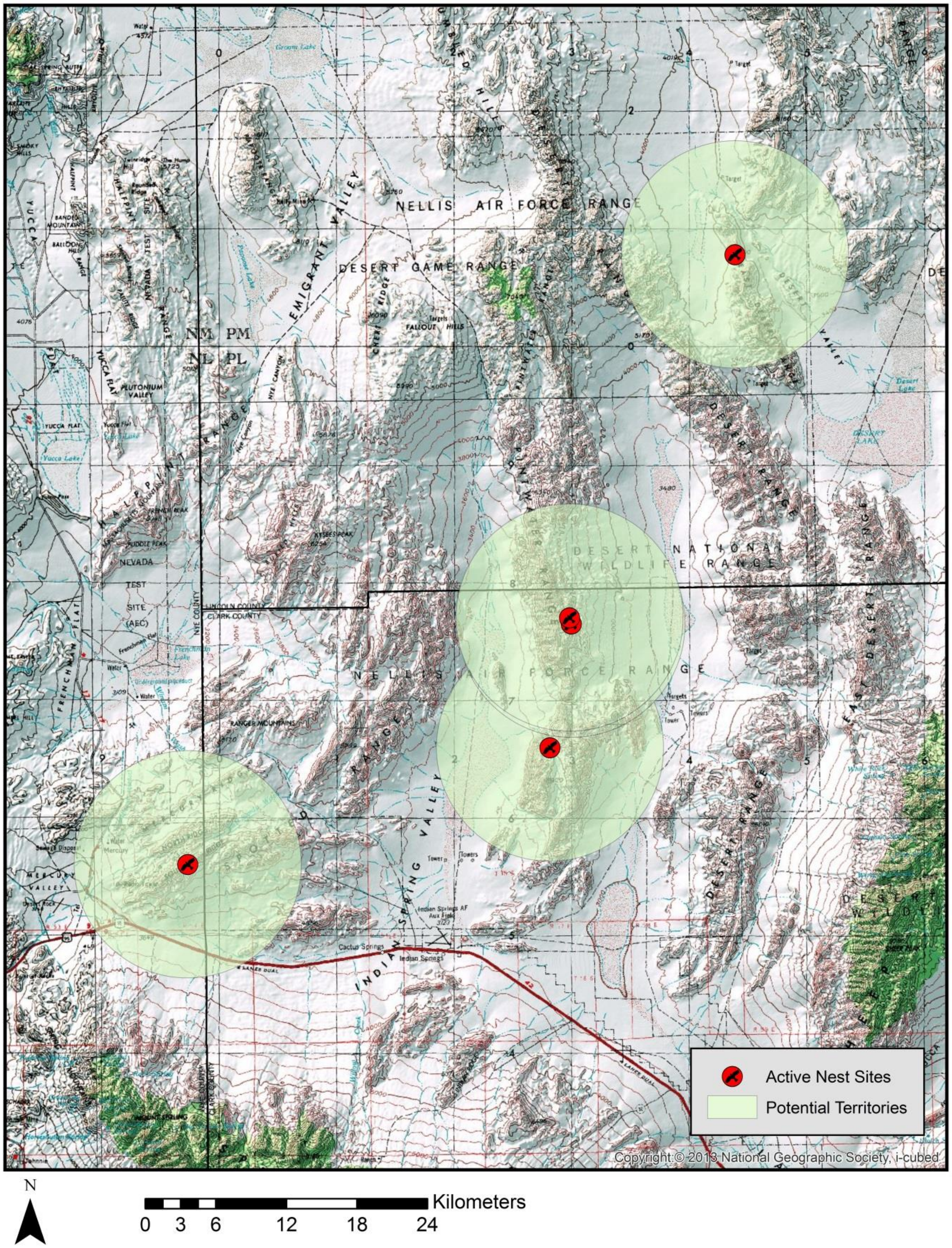

Figure 16. Potential territories of golden eagles observed in the Mojave Desert.

Habitat Suitability Model

A total of three models were run to test against the validity of the first. The model is constrained by the estimation of the potential influence of each environmental attribute and the accuracy of the raster grids used in the output. There were no differences between the model run with active nests versus the model run with combined nests. However, when the third model was fun with the added northness attribute, a lower AUC value was obtained. This validated my assumption (based on the logistic regression analysis) that adding northness to the dataset decreases the predictability of the model. The AUC value allows you to compare performance of one model with another. The AUC for the active and combined nest sites were both 0.96 (Fig, 17). The AUC for the model with northness was 0.88. For the model selected (combined nest sites), slope was the variable with the greatest percent contribution (97.1%), whereas distace to water (2.3%) elevation (0.5%) and distance to road (0.1%) were significantly less (Table 6). The final habitat suitability model indicates very small areas of high probability nest sites, shown in red (Figures 18 and 19). These areas are where golden eagles nests have been found.

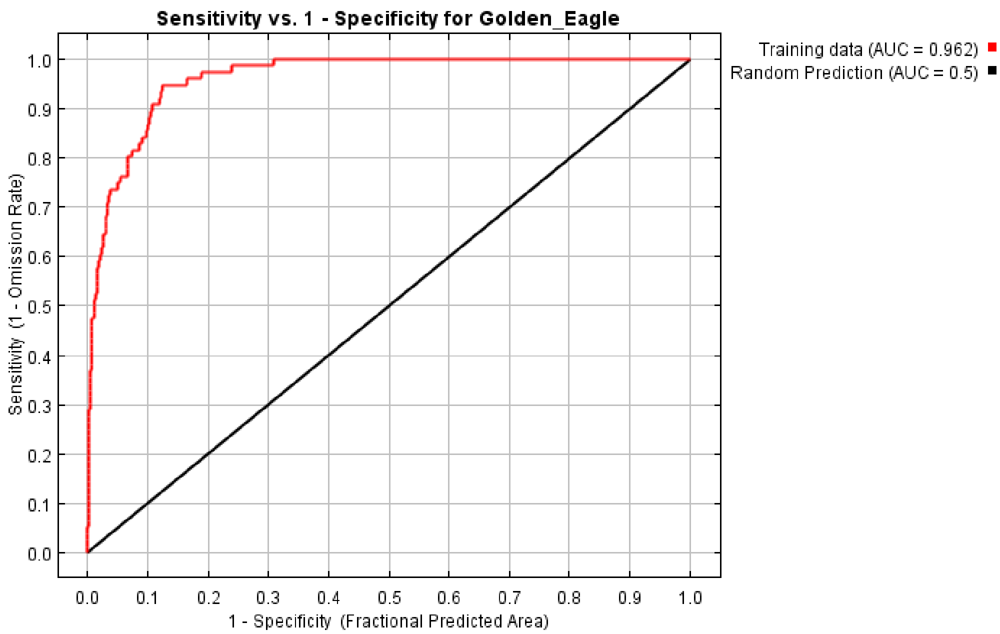

Figure 17. Area Under the Receiver Operating Characteristic (ROC) Curve or AUC Value. An AUC value of 0.5 indicates that the model is no better than random, while values closer to 1.0 indicate better model performance.

Table 7. Analysis of Variable Contributions shows the environmental variables used in the model and their percent predictive contribution. The higher the contribution, the more impact that particular variable has on predicting the occurrence of that species.

Variable	Percent Contribution	Permutation Importance
Slope	97.1	98.3
Distance to Water	2.3	1.3
Elevation	0.5	0.3
Distance to Road	0.1	0.2

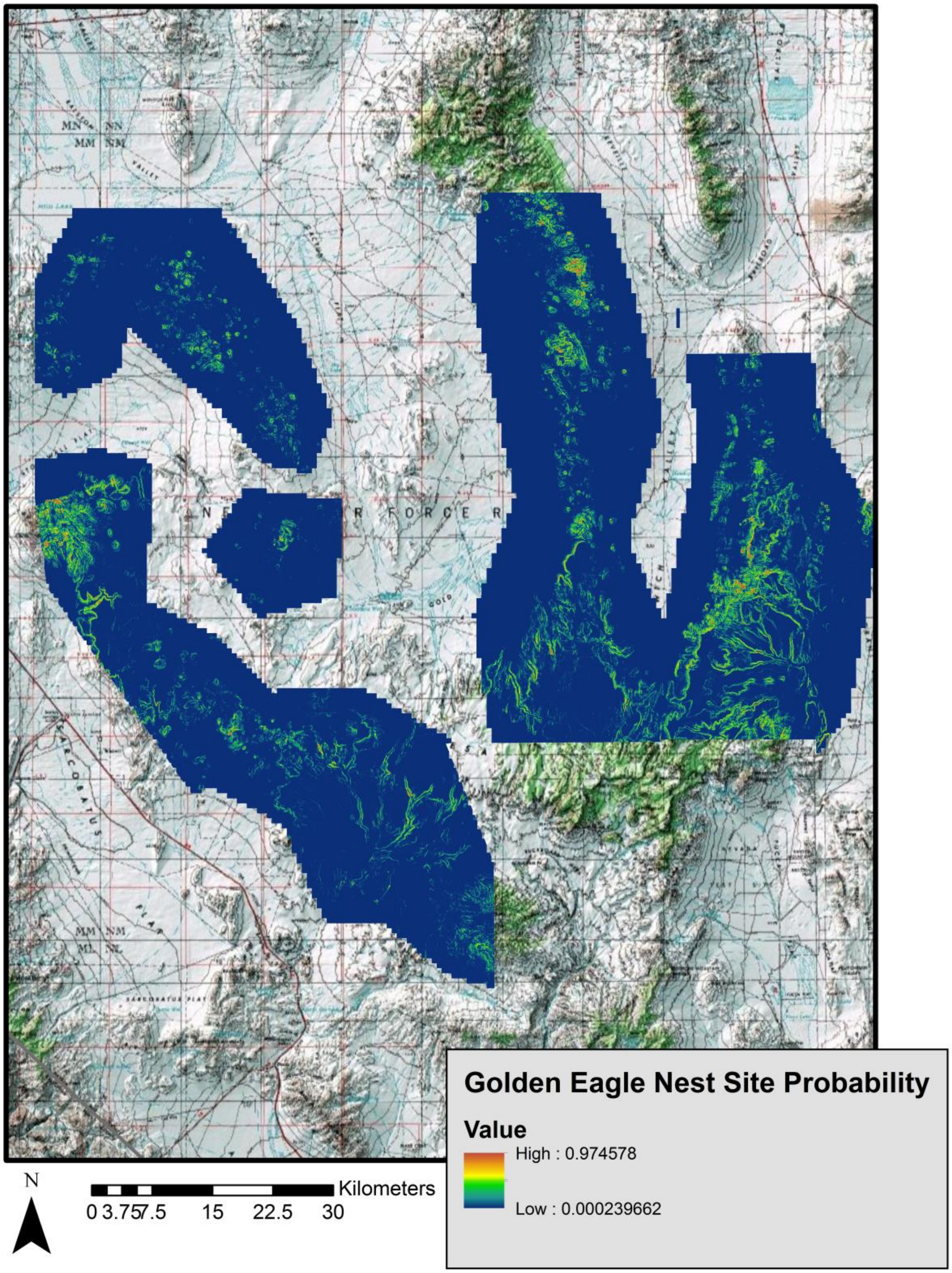

Figure 18. Habitat suitability model for nesting golden eagles in the Great Basin

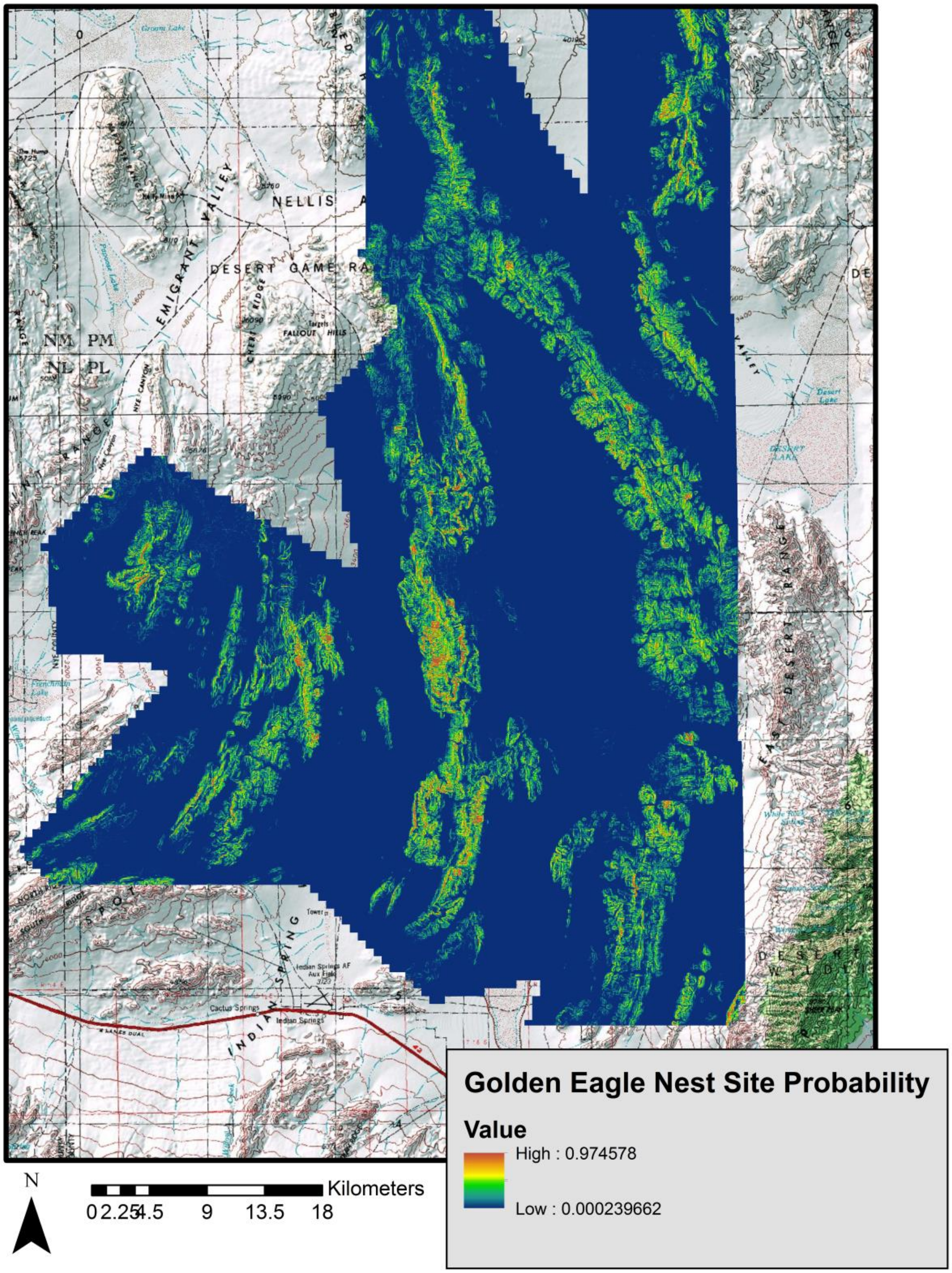

Figure 19. Habitat suitability model for nesting golden eagles in the Mojave Desert

CHAPTER 4

DISCUSSION

Measurement errors occur when investigators incorrectly interpret the status of a particular pair of eagles or nesting territory, or incorrectly count the number of eggs or young (Steenhof & Newton 2007). It is difficult to know how well this sample of the population truly represents the actual demography of golden eagles within my study site. I intended to follow the USFWS protocol for monitoring eagles, as closely as possible. However, constraints such as field situations, observer bias, and weather were not assessed. For future management guidelines, measuring standard observer error can be analyzed in aerial surveys where all territorial pairs have been found (Fraser et al. 1984).

Aerial inventories of eagles have considerable advantage over ground surveys in obtaining information such as nest site locations, habitat types and nesting attributes. Helicopter surveys are the preferred method to survey vast swaths of habitat when budgets allow. These aerial surveys allow for greater access to population data than could be obtained via ground surveys. Regulatory agencies assigned responsibilities for management of golden eagle are accountable, both monetarily and ethically, in a large measure for the protection of this species. Decisions made to protect nesting golden eagles will be dictated by the governing regulatory body and the nature of the threat or combination of threats to the species. Management options for golden eagles on military lands include: direct protection of golden eagles, nest sites and habitat, as well as a blanket policy for protection and education. Any management option needs to be underpinned by good-quality applied research (Watson 2010). It is the hope of the researchers and biologists involved in this study that the documentation and data analyses shall add to the available literature for western populations of golden eagles and aid in quality management for this species.

Nesting Productivity

The estimated population of wintering golden eagles in Nevada was reported as 4685 across the state (Olendorff et al. 1981). This estimate did not likey include eagles on military land. It is important from a management perspective to compare populations in different areas and different years, and to use all available data to evaluate populations of eagles statewide.

The results of this study indicate a maximum of 18 breeding golden eagles (9 nest sites active in 2013) in the Great Basin ecoregion and 8 golden eagles (4 nest sites active in 2014) in the Mojave Desert ecoregion. Because of variability across the years of this study, these numbers are likely tentative. Populations of golden eagles are closely linked with their prey base (black-tailed jackrabbits, *Lepus californicus*), whose populations experience variability in 10 year cycles. Because of cyclic prey populations, more years (≥10 years) of data collection on eagle populations may be necessary before a definite population size can be predictable. This study indicated a remarkable 95% fledging success rate, when compared to similar studies (Watson A. 1957, McGahan 1968, Murphy 1975, Predatory Bird Research Group, 1995, Young et al. 1995). There is the possibility that some pairs which appeared to have lost eggs early may have laid eggs before they were detected. Non-laying or early failing pairs are less likely to be detected than successful pairs (Newton, 1979).

Eighteen breeding pairs of golden eagles produced 35 fledglings over the four years resulting in a ratio of 0.51 fledged young per territorial pair. This number is comparable to a study in central Utah where 0.31-1.06 young fledged per territorial pair over seven years (Murphy 1975).

Nesting success is defined as the proportion of nesting or laying pairs that raise young to the age of fledging. For this study nest, I used success per territorial pair due to the lack of data on non-layers. I considered a pair successful when a well-grown young was observed in the nest just prior to fledging. Because productivity surveys were completed just prior to fledging (based on back calculations from dates of previous surveys), I assumed an overestimation of the number of fledglings was not an issue. Calculating nest survival using the Mayfield method (Mayfield, 1961) would estimate nest success by calculating a daily nest survival rate and might minimize bias from a more limited survey methodology.

There was a large amount of variability in nest productivity in the four years of my study. The lack of productivity in the Mojave Desert ecoregion was unexpected. In a region with a large amount of potential nest sites, there was little productivity. Regional variation was expected, and the nest sites observed in the Mojave Desert are likely historic. Year to year fluctuations in nest site use are also common in raptors and a short-term decline in productivity need not affect the long-term stability of a populations (Steenhof & Newton, 2007).

Overall, the nest productivty appeared relatively stable, with annual fluctuations. Golden eagle reproduction is closely linked with the jackrabbit prey base (Smith & Murphy 1979) and collecting additional data on the prey base might put these population demographic numbers for golden eagles into perspective. Only long-term collection of population data can verify the vitality of the population of golden eagles in these ecoregion management boundaries.

Nesting Chronology

Nesting chronology varies by ecoregion in the western United States. Generally, eagles at higher latitudes nest later in the spring than those at lower latitudes. The dates for breeding activities by golden eagles on this Nevada site are likely biased in favor of pairs that produce nestlings. Although the actual dates were not reported in the results, the patterns are clear (Table 3). The specific dates when eagles fledge were hard to determine, due to the structure of my study. Repeated checks during the laying period would help to more accurately estimate the dates. Nest success has been correlated with dates of laying, where birds laying earliest in the season usually are the most successful (Steenhof & Newton 2007). A more robust study would assess the variability in dates between egg laying, incubation, feeding and fledging and the effects of laying date on reproductive success, however these variables were outside the constraints of my study.

Nest Site Abundance and Density

The density of breeding eagles and other raptors in a landscape is primarily a factor of habitat quality, nest site availability and prey abundance or availability (Newton 1989, Hunt et al. 1997, Driscoll 2010). The number of occupied breeding areas within a region must initially be quantified to provide a baseline on which to compare future data (Driscoll 2010).

The results of my study indicated that a nest density in the Great Basin ecoregion (1.23 nests/km^2) was almost five-fold greater than the Mojave Desert ecoregion (0.25 nests/km^2). However, the amount of potential nesting habitat was 10-fold greater in the

Mojave Desert ecoregion than the Great Basin ecoregion. The ratio of occupied nests to total nests was 52% in the Great Basin ecoregion and only 11% in the Mojave Desert ecoregion. Some factors associated with high quality breeding habitat for golden eagles include: 1) nesting substrate that offers protection from the weather and predators; 2) sufficient prey abundance and biomass to sustain the eagle pairs throughout the year; 3) updrafts and thermals for soaring and hunting; and 4) isolation from human disturbance and development (Driscoll 2010). It is likely that the much lower nest density in the Mojave Desert ecosystem suggests that one or more of these key habitat components are likely absent or the cues that trigger selection.

Environmental Parameters/Attributes

Raptors are among the few groups of birds whose numbers and nest success are in regions clearly limited by the availability of quality nest sites (Newton 1979). Many factors influence nest placement by raptors. Protection from predators is probably the most important single factor influencing nest site selection (Watson 2010). Another assumed potential variable that might influence nest sites is high elevation, especially for cliff nesters. The conclusions of two studies in Spain (Donazar et al. 1989, Fernandez 1993) suggested that golden eagles select nest sites on high cliffs that were relatively inaccessible and farther away from human presence, specifically at greater distances from tracks, roads and villages.

The Mojave/Sonoran warm desert scrub is the most abundant key habitat associated with nest sites due to its open nature and prey base. Jackrabbits in the desert southwest inhabit dry desert scrubland. Nesting adjacent to these open arid lands provide golden eagles easy access to prey: whereas, other environs with denser vegetation make hunting more difficult.

Relative nesting height is important in nest site selection due to the opposing pressures of nesting high enough to avoid predation, and low enough to transport prey uphill without expending too much energy (Watson, 2010). Birds in the central Highlands of Scotland nest at 48% of the maximum surrounding elevation while those farther east are at 60% of the maximum (Watson & Dennis 1992). The mean height of nests of golden eagles in Nevada were located at 69% of the maximum cliff height, which is slightly higher than reported in other studies. Because golden eagles at my study sites primarily prey on black-tailed jackrabbits that weigh 4-6 kg, the burden of transport is likely not as high. Additionally, ground disturbances from humans may have a tendency to push the eagles higher.

Viewshed was not significantly different in the Great Basin ecoregion compared to the Mojave Desert ecoregion. The mean landscape that could be viewed from each nest site was $< 10\%$ of the surrounding environment. I interpreted these results as the viewshed was not important because golden eagles likely do not hunt strictly from their nest (due to sight constraints). Assessing differences between inactive and active nests, and between combined and random nest sites should be part of future investigations. It would be interesting to note whether there was a significant difference with this variable, and thus assess its importance in nest site selection.

Nest site attributes were compared both by those that were active (over four years) to those that were inactive. All nest site attributes were combined and then compared to randomly generated nest sites (within cliff and canyon key habitat layers).

There were significant differences between active and inactive nests. The locations of active nests were higher in elevation than inactive nests, as expected, and elevation was an important habitat factor when compared to randomly generated nest sites. I concluded that elevation was the most important nest site attribute I analyzed.

Slope appeared to be lower in active nests when compared to inactive nests. Although there was a difference, the difference was much smaller than the differences in elevation. The mean slope of combined nest sites (37% percent slope) was almost a 20° grade. This is a seemingly low value given that raptors nest on sheer cliff faces. I have determined that the microhabitat is not reflected in this value, rather is the slope of the generalized area. Slope is a significant habitat component based on the differences between combined nest sites and randomized points (based on the very small p-value).

Distance to nearest road also showed a significant difference when active and inactive nests were compared; however, the mean values were close (3.62-5.01 km). There were significant differences in distance to roads when combined nest sites were compared to randomized points. I speculated that due to the number of nearby roads and the topography of cliff and canyon habitats, most roads were rather close to all potential nest sites. An evaluation of roads based on use would be interesting, as some roads get little to no traffic (e.g. unimproved roads) and others get heavy traffic (e.g. paved roads).

Distance to water showed significant differences in active versus inactive nests. Because water is a limiting resource in the desert, and the water table for seeps and springs may change annually, golden eagles only used nest sites in close proximity to water. Nests within approximately 3.2 km of a water source were continuously used over the four years. There were no differences when combined nest sites were compared to randomly generated points; the mean of inactive nest sites was much higher than active and randomly generated points.

Northness, the index for aspect, showed no significant difference in either the active versus inactive analysis, as well as the combined versus randomized analysis. I conclude that along with slope, northness was a microhabitat value that was not reflected in the GIS layer used for analysis. A nest site can be situated within a small crevice and appear to be located in full sunlight (such as a near south facing), when in reality the nest site had substantial shading from the rock outcrop in which it was situated. If an analysis took into account microhabitat aspect I strongly believe this variable would be important to a raptor nesting in a desert.

Logistic Regression

A series of logistic regressions tested whether the locations of golden eagle nests could be distinguished from pseudo-absent nest sites based on five separate environmental variables. Predictor variables were based on those available for the study sites, and thus constrained the final model to these variables alone. Multicoliniarity was not assessed, but it was assumed to be the highest between slope and elevation. For model selection all combinations of variables were assessed, but settled on nine separate candidate logistic regression models that remained significant. Akaike's Information Criterion (Sugiura 1978) and Akaike weights (Burnham and Anderson 2002) were used as a basis for a model selection process (Troy et al. 2014). No single model had a Akaike weight > 0.9 (Burnham and Anderson 2002), so the final model with the highest rank was used and those attributes were inserted into the program MaxEnt.

Territory Delineations

Nest density was typically expressed as pairs per unit area, however, when pairs were distributed linearly, as along cliff escarpments, the distance between pairs was considered the more useful (Newton 1979). I did both, and the distance between pairs was identified by territory analysis. In continuously suitable habitat, nesting pairs are often separated from one another by approximately equal distances. This regular spacing was consistent and breeding density was limited by the territorial behavior of the eagles (Newton 1979). Regular or over-dispersion was observed in the Mojave Desert ecoregion, as expected. This pattern, however, was limited by the small number of active nest sites over the course of my study. Within the Great Basin ecoregion a more random pattern was detected. This type of pattern was indicative of a patchy or restricted nesting space, but did not take into account supernumerary nests, or the differences separating the years of breeding.

Nearest neighbor distances of 7.9 km (Great Basin ecoregion) and 11.4 km (Mojave Desert ecoregion) were both comparable to other studies where the nearest neighbor distances ranged from 8 km to 15.9 km, with an average of 11 km (from 9 studies) (Watson 2010).

These findings led me to believe that there was better quality, but more limited nesting habitat in the Great Basin ecoregion than compared with the Mojave Desert ecoregion. For a better analysis of spacing, I would use the GMASD statistic (which calculates the ratio of the geometric mean to the arithmetic mean of the squared inter-nest distance) to test whether nests were more evenly distributed than if birds selected the nest sites at random (Brown 1975).

Habitat Suitability Model

Digital raster layers representing independent variables from the final logistic regression model were used to produce the habitat suitability model in MaxEnt (i.e., a map of suitable values represented as probability values). The AUC values were the same (as were the visual maps) of active nests versus combined nest sites. This was surprising, where I had assumed a larger breadth of values (combined nests) would produce a larger area of high probability when compared to a model run strictly with active nests.

Slope was shown as the greatest predictor in nest site selection from MaxEnt. This contrasts with the elevation as the greatest predictor shown in the logistic regression analysis. I believe this is due to two separate factors. The first factor is likely that slope was used as a mask to extract features from all other raster layers (coordinate systems, boundaries, number of cells, rows/columns). Because this was the baseline layer it was ultimately shown as the most important. Secondly, I believe (although not tested) that the multi-collinearity of elevation and slope are high, therefore the importance of these variables is interchangeable.

The AUC values are consistent with the assumption that these predictive maps indicate relatively high model performance and are likely a good predictor of where golden eagles might choose to nest. They represent a much broader area of cliffs and canyons than the key habitat initially used by the NNRP. However, as previously discussed models are an approximation or representation of the defined domain and are merely reflections of the true complex nature of golden nesting habits.

REFERENCES

Bergo, G. 1948. Habitat and Nest Site Features of Golden Eagles in Hordaland, West Norway. Fauna Norvegica Series C, Cindus, 7:109-113.

Bittner, J., and J. Oakley. 1999. Status of Golden Eagles in southern California. Golden Eagle symposium. La Paz, Mexico: Raptor Research Foundation Annual Meeting.

Brown, D. 1975. A test of randomness of nest spacing. Wildfowl, 102-103.

Burnham, K., and D. Anderson. 2002. Model selection and multimodel inference: a practival information theoretic approach. New York: Springer-Verlag.

Collopy, M. W., and Jr., T. C. Edwards. 1989. Territory Size, Activity Budget, and Role of Undulating Flight in Nesting Golden Eagles. Journal of Field Ornithology, 60(1):43-51.

Cramp, S., and K. Simmons. 1980. The Birds of Western Palearctic Vol.2. Oxford: University Press.

Donald D D., J. Young, C.L. McIntyre, P.J. Bente, T.R. McCabe, and R. E. Ambrose. 1995. Nesting by Golden Eagles on the North Slope of the Brooks Range in Northeastern Alaska. Journal of Field Ornithology, Vol. 66, No. 3, pp.373-379.

Donazar, J., O. Ceballos, and C. Fernandez. 1989. Factors influencing the distribution and abundance of seven cliff-nesting rapotrs: a multivariates study. In B.-U. Meyburg, & R. Chancellor, Raptors in the Modern World (pp. pp.545-552). Berlin, London, Paris: WGBP.

Driscoll, D. E. 2010. Protocol for Golden Eagle Occupancy, Repoduction, and Prey Population Assessment. Apache Jct. AZ: American Eagle Research Institute.

Dunstan, T. C. 1989-1990. The golden eagle. Audubon Wildlife Report. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Fire Sciences Laboratory.

Ecosphere Environmental Services. 2008. Golden Eagle Monitoring at Carbon Mountain: Final Summary Report for the 2003-2007 Breeding Seasons. Durango, Colorado: U.S. Bureau of Reclamation, Western Colorado Area Office.

Fernandez, C. 1993. Nest Selection for Nesting Golden Eagles: Influence of Accessibility and Human Derangements. Alauda, 61: 105-110.

Fraser, J., F. Martin, L. Frenxeil, and Mathisen, J. 1984. Accounting for measurement errors in Bald Eagle reproduction surveys. Wildlife Society Bulletin, 48:595-598.

Good, R., R. Nielson, H. Sawyer, and L. McDonald. 2004. Population level survey of Golden Eagles (*Aquila chrysaetos*) in the western United States. Arlington, VA: Western EcoSystems Technology, Inc.; Fish and Wildlife Service.

Gulf South Resource Corporation. 2012. Golden Ealge Conservation Plan for Nellis Air Force Base and the Nevada Test and Training Range.

Hawk Mountain. 2007. Conservation Status Report of the Golden Eagle. Retrieved January 2011, from www.hawkmountain.org: www.hawkmountain.org

Hoffman, S., and J. Smith. 2003. Population trends of migratory raptors in western North America, 1977-2001.

Holldenbeck, J. P., V.A. Saab, and R.W. Frensel. 2011. Habitat Suitability and Nest Survival of White-Headed Woodpeckers in Unburned Forests of Oregon. The Journal of Wildlife Management, 75(5):1061-1071.

Hunt, W., R. Jackman, T. Hunt, D. Criscoll, and L.Culp. 1997. A population study of golden eagles in the Altamont Pass Wind Resrouce Area: population tren analysis. University of California, Santa Cruz: Predatory Bird Reserach Group.

Isaacs, F. B. 2011. Golden Eagles Nesting in Oregon. 1st Annual Report. Philomath, OR: Oregon Eagle Foundation, Inc.

Kochert, M., K. Steenhof, C. M., and E. Craig. 2002. Golden Eagles. In The Birds of North America No. 684 (p. 684). Philadelphia, PA: A. Pool and F. Gill.

Lee, D. S., and W.R.Spofford. 1990. Nesting of Golden Eagles in the Central and Southern Appalachians. The Wilson Bulletin, Vol. 102, No.4, pp. 693-698.

Leslie, D. 1992. Population status, habitat and nest-site characteristics of a raptor community in easter Colorado. Master's Thesis, Colorado State University, For Collins.

Mayfield, H. 1961. Nesting success calculated from exposure. Wilson Bulletin, 73: 255-261.

McGahan, J. 1968. Ecology of the Golden Eagle. The Auk, Vol. 85, No. 1, pp 1-12.

Merow, C., M.J. Smith and John A. Silander, J. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography, 1058-1069.

Mosher, J., and C. White. 1976. Directional Exposure of Golden Eagle Nests. Canadian Field Naturalist, 90:356-359.

Murphy, J. 1975. Status of the Golden Eagle in central Utah 1967-1973. Raptor Research Report, 3:91-96.

Nellis Natural Resource Program (NNRP), 2011. GIS data. Las Vegas, NV.

Nevada Department of Wildlife. 2004. Nevada's Wildlife Action Plan.

Newton, I. 1979. Population Ecology of Raptors. T&A.D. Poyser, Calton.

Newton, I. 1989. Population limitation in raptors. Proceedings of the Northeast raptor management symposium and workshop (pp. 3-12). Washington D.C.: National Wildlife Federation.

Nielson, R., L. McManus, T. Rintiz, and L. McDonald. 2014. Monitoring Abundance of Golden Eagles in the Western United States. Jounral of Wildlife Management, Vol. 78, No.4, pp. 721-730.

Olendorff, R., A. Miller and R. Lehman. 1981. Suggested practicies for raptor protection on powerlines: the state of the art in 1981. Raptor Research Report No. 4.

Page, J., and D.J. Siebert. 1972. Inventory of Golden Eagle Nests in Elko County, Nevada. Elko, Nevada: Bureau of Land Management.

Pagel, J. E., D.M. Whittington and A.T. George. 2010. Interim Golden Eagle Technical Guidance: Inventory and Monitoring Protocols; and Other Recommendations in Support of Golden Eagle Management and Permit Issuace. U.S. Fish and Wildlife Service.

Palmer, R. 1988. The handbook of North American Birds, Volume 5. New Haven, Connecticut: Yale University Press.

Phillips, S. J., R.P. Anderson and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling, 231-259.

Predatory Bird Research Group. 1995. A pilot golden eagle population study in the Altamont Pass Wind Resource Area. Golden Colorado: U.S. Department of Energy.

R Development Core Team. (n.d.). R: a language and environment for statistical computing. www.R-project.org. R Foundation for Statistical Computing.

Sancho, J. A., and Olga Ceballos Ruiz, C. F. 1989. Factors Influencing the Distribution and Abundance of Seven Cliff-nesting Raptors: A Multivariate Study. Raptors in the Modern World, 545-552.

Smith, D., and J. Murphy. 1979. Breeding response of raptors to jackrabbit density in the easter Great Basin Desert of Utah. 12(1-14).

Steenhof, K., and I. Newton. 2007. Assessing Nesting Success and Productivity. Raptor Research and Management, 181-191.

Steenhof, K., M. Kochert and T. Mcdonald. 1997. Interactive effects of prey and weather on Golden Eagles reproduction. Journal of Animal Ecology, 66(3): 350-362.

Sugiura, N. 1978. Further analysis of the data by Akaike's Information Criterion and the finite corrections. Communication in Statistics-Theory and Methods, A7:13-26.

Thompson, S. P., R.S. Johnstone and C.D. Littlefield. 1982. Nesting History of Golden Eagles in Malheur-Harney Lakes Basin, Southeastern Oregon. Raptor Research.

Troy, J., J. Veech and M.Green. 2014. Habitat Suitability Modeling for the Newell's Shearwater on Kauai. Journal of Fish and Wildlife Management, 5(2):315-329.

United States Geological Survey (USGS). 2010. Precipitation History in the Mojave Desert from 1893-2001.

United States Geological Survey (USGS). 2015. The National Map. Retrieved 2012, from Map Viewer and Download Platform: http://nationalmap.gov/viewer.html

Watson, A. 1957. The breeding success of golden eagles in the northeast Highlands. Scottish Naturalist, 57:341-344.

Watson, J. 2010. The Golden Eagle. Yale University Press.

Watson, J., and R. H. Dennis. 1992. Nest-site selection by golden eagles in Scotland. British Birds 85(9):469-481.

Watson, J., S. Rae and R. Stillman. 1992. Nesting Density and Breeding Success of Golden Eagles in Relation to Food Supply in Scotland. Journal of Animal Ecology, Vol. 61, No. 3, pp. 543-550.