LOCAL GEOGRAPHIES OF THE COASTAL CACTUS WREN AND THE COASTAL CALIFORNIA GNATCATCHER ON MARINE CORPS BASE CAMP PENDLETON CALIFORNIA

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Jennifer Rebecca Vaughan

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Local Geographies of the Coastal Cactus Wren and the Coastal California

Gnatcatcher on Marine Corps Base Camp Pendleton California

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DEDICATION

This thesis is dedicated to my parents. I want to thank them for immersing me in the natural world and instilling their love of nature in me. It is my passion for the natural world that inspired this thesis and that passion was inspired by my parents. Without their support and love, this would not have been possible.

ABSTRACT OF THE THESIS

Local Geographies of the Coastal Cactus Wren and the Coastal California Gnatcatcher on Marine Corps Base Camp Pendleton California
by
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Master of Science in Geography
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The coastal cactus wren (*Campylorhynchus brunneicapillus couesi*) is a California Species of Special Concern and the coastal California gnatcatcher (*Polioptila californica californica*) is a federally listed threatened species. Both are target species under California's Natural Communities Conservation Program. Habitat loss is the driving force for population decline of both species. This study examines these target species on part of Marine Corps Base Camp Pendleton, California (approximately 41, 118 hectares in area). The purpose of this research is to delineate the local geography for each species and to demonstrate a geographic approach to avian conservation.

This study defines the local geography as a combination of the landscape characteristics, specific habitat requirements, and the identification of core habitat areas for both species. Landscape characteristics refer to the composition and spatial configuration of the vegetation on the Base. Landscape characteristics have been obtained through landscape metric calculations. Specific habitat requirements refer to the habitat features that shape the spatial distribution of both species. Habitat requirements have been obtained through habitat suitability analysis and species distribution modeling. Core habitat areas reflect the landscape characteristics and the habitat features that sustain both avian populations. Lastly, core habitat areas have been identified via kernel density estimation and prioritized by a set of detailed criteria based on requirements for both species on the Base. This study provides information regarding habitat requirements of both species and overall landscape characteristics on the Base, which will aid in conservation and management of these species. On a broad scale, this research supports the regional conservation effort in southern California for the coastal cactus wren and the coastal California gnatcatcher.

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

PAGE

ACKNOWLEDGEMENTS

First I want to thank my advisor, Dr. Li An, for guiding and supporting me throughout my undergraduate and graduate programs at San Diego State University. His support of my research was evident through his confidence in me. In addition, I want to thank the rest of my thesis committee, Dr. John O'Leary, Dr. Rebecca Lewison, and Dr. Eric Kershner, for their great suggestions and willingness to help. I want to give a special thank you to Dr. Eric Kershner because without his guidance and support, this thesis research would not have happened. It was his initial faith in me that facilitated this research and to you I am grateful.

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Lastly, I want to acknowledge the coastal cactus wren and the coastal California gnatcatcher for providing me the impetus for my thesis. Both are charismatic birds that never cease to amaze me.

CHAPTER 1

INTRODUCTION

The lives of birds are inherently geographic. Birds inhabit a variety of ecosystems across the globe. Geographers are able to find connections between various geographies and birds (e.g., global health and ecosystem health indicators) (Steinberg 2010). Ornithologists conduct most avifaunal research. However, geographers can contribute to avian research through a geographic perspective. Geographers view birds at different scales by viewing them as part of the spatial landscape (Steinberg 2010). Geographical research focusing on avian species considers the relationship between the species and their environment and not just the single organism in the environment (Steinberg 2010).

A geographic approach to avian conservation was used in this study to explore the coastal cactus wren and coastal California gnatcatcher populations within the boundary of Marine Corps Base (MCB) Camp Pendleton, California. Through an integration of geographic information science (GIScience) and landscape ecology viewpoints, this research relates the importance of habitat to the spatial distribution of two avian populations. Landscape ecology is important to this study because it deals with an ecological mosaic of landscape patches with continuously varying degrees of connectedness (Noss 1983). This study, focusing on landscape characteristics, specific habitat requirements, and the identification of core habitat areas, will assist in potential management strategies for the coastal cactus wren and the coastal California gnatcatcher on the Base.

The coastal cactus wren (*Campylorhynchus brunneicapillus couesi*) populations in southern California have been declining over the past decades (Figure 1) (Guthrie 1974; Unitt 2004). A lack of research in the demographic and habitat features of the coastal cactus wren has slowed the response of federal, state and local entities in dealing with their population decline in southern California (Solek and Szijj 2004). Another species that has experienced population decline is the coastal California gnatcatcher (*Polioptila californcia californica*) (Figure 2) (Mock 2004). Habitat loss is considered the primary limiting factor for the population decline of both species (Guthrie 1974; Rea and Weaver 1990; Unitt 2004).

Figure 1. Image of the coastal cactus wren by Eric Kershner.

Figure 2. Image of the coastal California gnatcatcher by Peter Knapp.

I choose these species as the subject of my research for several reasons (1) both populations are in decline, (2) the coastal California gnatcatcher is a threatened species under the Endangered Species Act and the coastal cactus wren is a species of special concern, (3) both are considered coastal sage scrub obligates, (4) both are focal species under California's Natural Community Conservation Program (NCCP) (Akçakaya 2000)[1], and most notably, (5) birds are often used to illustrate the fragility of ecosystem health (Sarmiento 2010).

Another benefit arises from studying these two species simultaneously. It is reported that both species share many common features in their habitat requirements (Mock 2004; Solek and Szijj 2004). The coastal cactus wren habitat may be largely contained within the coastal California gnatcatcher habitat. Therefore, joining them in one study will either provide additional evidence to support this insight, or disclose potential differences in their habitat requirements. The knowledge obtained in this study will give us a better understanding of their respective habitat and will facilitate better (likely more efficient) conservation management. For example, if they do share most of their habitat features, if the spatial distribution of one species may be used (or partially used) as a reference to verify information for the other, or as a benchmark to plan conservation activities for the other.

This research will enhance conservation efforts on military installations by following along the continued efforts under the Sikes Act of 1960 and the Executive Order 12186.[2] Information gained from the MCB Camp Pendleton subpopulations of the coastal cactus wren and coastal California gnatcatcher will be important in the regional conservation efforts for both species in southern California (Ferrier and others 2002; Franklin and others 2009). This research supports regional conservation efforts by addressing habitat requirements of both species, which can provide better management direction.

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[1] California's Natural Community Conservation Program (NCCP) was initiated under the passing of the NCCP Act of 1991 (Pollak 2001). The program mission is to protect natural communities at the ecosystem scale.

[2] The Sikes Act of 1960 authorizes the Secretary of Defense to develop corporative plans for conservation and rehabilitation programs on military installations. The Executive Order 13186 was established by former President Clinton, which mandates that all federal agencies conserve migratory birds (Clinton 1997). This Executive Order requires a memorandum of understanding between the USFWS and Department of Defense for the conservation of migratory birds (Clinton 1997).

CHAPTER 2

LITERATURE REVIEW

This chapter is the literature review for this study. This includes information pertaining to the coastal cactus wren and the coastal California gnatcatcher and their associated threats, and a review of the geographic methods used in this research.

COASTAL CACTUS WREN

The coastal cactus wren belongs to the order Passeriformes, family Troglodytidae in the genus *Campylorhynchus*, and is the largest wren in North America (Barker 2007). There are six recognized morphological cactus wren subspecies including *bryanti*, *couesi*, *guttatus*, *brunneicapillus*, *affinis*, and *purus* (Rea and Weaver 1990; Solek and Szijj 2004). There are other proposed sub-species (e.g. *sandiegensis*), but they are not officially recognized at this time (Solek and Szijj 2004). The coastal cactus wren distribution extends through several counties in southern California, including Ventura, Los Angeles, Orange, San Bernardino, Riverside, and San Diego (Solek and Szijj 2004).

Historically, Orange County and MCB Camp Pendleton contained the highest percentage of the coastal cactus wren population in southern California (Rea and Weaver 1990; Solek and Szijj 2004). The coastal cactus wren spatial distribution in southern California is highly fragmented with several populations consisting of only a few pairs (Rea and Weaver 1990).Current population numbers for the coastal cactus wren are unknown and estimates are based on older data. The coastal cactus wren population has declined for various reasons including habitat loss due to urbanization and more recently large fire events.

Population numbers for southern California in 1993 were estimated to be around 1,900 to 2,500 pairs (Mock 1993, 2). The coastal cactus wren populations in San Diego County are centered in four core regions. These regions include MCB Camp Pendleton (and Fallbrook Naval Weapons Station) (estimated 70 pairs in 1993), Lake Hodges/San Pasqual (estimated 90 pairs in 1993), Lake Jennings (estimated 25 pairs in 1993), and Sweetwater/Otay (estimated 80 pairs in 1993) (Mock 1993, 2).

The habitat of the coastal cactus wren is described to be primary on California sage (*Artemisia californica*), California buckwheat (*Eriogonum fasciculatum*) and cactus (Rea and Weaver 1990). The coastal cactus wren is a habitat specialist of coastal sage scrub. They require cactus patches (e.g. coastal cholla (*Cylindropuntia prolifera*) and/or prickly pear (*Opuntia littoralis* and *Opuntia oricola*)) for nest building (Rea and Weaver 1990; Solek and Szijj 2004; Mitrovich and Hamilton 2007). The coastal cactus wren prefers to build nests in mature stands of cacti (Mitrovich and Hamilton 2007). Nest sites can vary in regards to slope, aspect, and cacti availability in different regions throughout southern California (Solek and Szijj 2004). The most favorable locations for nest placements are on south-southwesterly slopes where cacti tend to flourish (Solek and Szijj 2004; Cooper 2009).

Little information is known about the coastal cactus wren's diet, mobility and its average territory size; much of what is known is from the demographic characteristics of the desert cactus wren (e.g. *C.b. anthonyi*) (Anderson and Anderson 1973; Solek and Szijj 2004). Research about the desert cactus wren provides some basis for the understanding of the coastal cactus wren. Coastal cactus wrens forage on the ground for insects (Anderson and Anderson 1973; Solek and Szijj 2004) and supplement their insect-dominant diet by feeding on the fruit of cacti (Rea and Weaver 1990). The average territory of the coastal cactus wren in San Diego County is highly variable. The average territory size of the coastal cactus wren ranges from 0.5 to two ha (Rea and Weaver 1990). Coastal cactus wrens are non-migratory with low dispersal rates (Solek and Szijj 2004). They form permanent pair (male and female) bonds, and defend their territory year round. The average clutch size ranges from three to five eggs, and both sexes attend the brood (Anderson and Anderson 1973; Rea and Weaver 1990).

The survival of the coastal cactus wren is considered one of the greatest challenges in avian conservation that southern California has ever experienced (Unitt 2004). Coastal cactus wrens are vulnerable due to their small fragmented populations, specialization in their habitat, low dispersal rates, and their underrepresentation in habitat reserve designs. The coastal cactus wren is included in several conservation priority lists. The coastal cactus wren is a California Bird Species of Special Concern, a legal designation determined by the California Department of Fish and Game (Shuford and Gardali 2008). The species is a target species for the California Natural Communities Conservation Program, and is covered under the Multiple Species Conservation Program in San Diego County (Franklin and others 2006). The coastal cactus wren is protected under the Migratory Bird Treaty Act and is a United States Fish and Wildlife Service (USFWS) Bird of Conservation Concern for Bird Conservation Region 32. In 1990, the San Diego subpopulation of the coastal cactus wren was petitioned as an endangered sub-species (San Diego coastal cactus wren) in accordance to the 1973 Endangered Species Act (Beattie 1994). The petition failed due to disagreements on the classification of the species as a sub-species (Beattie 1994).

COASTAL CALIFORNIA GNATCATCHER

The coastal California gnatcatcher, also known as the California gnatcatcher, belongs to the order Passeriformes, family Sylviidae in the genus *Polioptila*, and is the sub-species of *Polioptila californica californica.* In the genus *Polioptila*, there are three recognized morphological subspecies including *californica, pontilis* and *margaritae* (Atwood and Bontrager 2001). Their distribution extends from northern Baja California, Mexico to Ventura County in southern California (Mock 2004). The highest densities occur in coastal Orange and San Diego Counties (Mock 2004). Core population areas supporting 30 or more pairs of coastal California gnatcatchers include Orange County, MCB Camp Pendleton, Oceanside, Carlsbad, San Marcos, Rainbow/Pala, Lake Hodges/San Pasqual, Poway, Upper San Diego River, Mission Trails/Miramar, Lakeside, Sweetwater River Reservoir, Jamul Mountains, Otay Lakes/Mesa, and others (Mock 2004, 2). MCB Camp Pendleton is likely to have the largest population in the region (E. Kershner, July 27, 2010, email message to author).

The habitat requirements for the coastal California gnatcatcher are less restricting than the habitat requirements of the coastal cactus wren. Coastal California gnatcatchers prefer open coastal sage scrub and are highly associated with California sage (Mock 2004; Unitt 2004). Other associated plant species are California buckwheat (*Eriogonum fasciculatum*), California sunflower (*Encilia californica*), broom baccharis (*Baccharis sarothroides*), and laural sumac (*Malosma laurina*) (Kucera 1997; Mock 2004). Patches of prickly pear cactus are particularly favored (Kucera 1997). Nests are typically built in areas with less than 40 percent slope, and are common in gullies and drainages (Mock 2004).

The coastal California gnatcatcher diet consists of insects (Mock 2004). The species is non-migratory with occasional dispersion across modified landscapes, including highways and residential development (Mock 2004). Territory sizes are correlated with distance to coast and are highly variable, ranging from one to nine ha (Mock 2004). Mean clutch size varies among sites and years as climate exerts a strong influence on clutch size; rainfall prior to egg-laying may change the clutch size within a range of three to four eggs (Patten and Rotenberry 1999; Mock 2004; Unitt 2004).

The coastal California gnatcatcher was designated as threatened under the United States Endangered Species Act in 1993 (U.S. Fish and Wildlife Service 1993). The coastal California gnatcatcher is a Species of Special Concern in California and is covered under the Multiple Species Conservation Program in San Diego County (Mock 2004). The species is protected under the Migratory Bird Treaty Act and is a focal species under the California Natural Communities Conservation Planning Program (Mock 2004). The coastal California gnatcatcher is currently being used as keystone species to protect endemic species in southern California from development (Olson and others 2001; Mock 2004).

THREATS

The combination of increased urbanization, habitat fragmentation and a change in the fire regime has made San Diego County a hotspot of endangerment of endemic biota (Dobson and others 1997; Crooks and others 2001). San Diego County has the highest number of species at risk of extinction among any county of equal size in the United States. Most of the land covered by coastal sage scrub has now been developed (Unitt 2004; North American Bird Conservation Initiative 2009). Degradation of coastal sage scrub has resulted in substantial habitat loss for a variety of species, particularly avian species (O’Leary 1990).

Threats concerning the coastal cactus wren and coastal California gnatcatcher arise from the loss or degradation of coastal sage scrub. Current and historic declines in both species can be attributed to both natural and human disturbances (Rea and Weaver 1990; Mock 2004). The largest factor affecting the San Diego populations of both the coastal cactus wren and coastal California gnatcatcher is spreading urbanization. San Diego’s human population has grown tremendously over the last 60 years, resulting in habitat loss and fragmentation (Soulé, Alberts, and Bolger 1992, 39).

Habitat loss can typically increases fragmentation of habitat patches. Displacement of coastal sage scrub in southern California has resulted in the increased isolation of remnant habitat fragments (O'Leary 1990). Fragmentation decreases the connectivity of the landscape while increasing edge and remnant habitats. Edges are defined as where plant communities meet or where vegetation conditions within plant communities interact (Noss 1983). Fragmentation has a greater negative impact on specialist species (e.g., the coastal cactus wren) that have strict vegetation structure and area habitat requirements (Soulé, Alberts, and Bolger 1992). Specialist species have an increased risk of extirpation in isolated habitat remnants because of the loss of their original intact habitat.

Isolated avian populations in coastal sage scrub have been linked to high rates of extinction (Soulé and others 1988). Coastal cactus wrens are known as interior species and edge effects can have negative impacts on the population dynamics of interior species (Kristan and others 2003). These species are poorly adapted to cope with edge-related conditions, such as increased predation, that are rarely encountered in their common interior habitats (Temple and Cary 1988).

Edges can alter abiotic processes such as microclimate, light intensity, and hydrology (Kristan and others 2003). In addition, edges are known to modify biotic factors including predator-prey relationships, habitat structure, and food availability (Kristan and others 2003). Potential edge effects in many instances include (1) higher frequency and increased severity of fire, (2) higher intensities of predation, (3) higher probability of nest predation, and (4) higher intensities of browsing and other forms of disturbance that increase the proliferation of non-native vegetation (Soulé 1991).

For the coastal California gnatcatcher, fragmentation-induced edges could possibly increase nest failure because of increased predation (Mock 2004). Edges are in addition more likely to increase brood parasitism. Brood parasitism has been observed directly with the coastal California gnatcatcher. Brood parasitism is the utilization of a host to raise the young of a brood-parasite. It has been witnessed that coastal California gnatcatcher nests have been parasitized by brown-headed cowbirds (*Molothrus ater*), and both abandonment of nests and the raising of young cowbirds have been observed (Mock 2004).

Fire has the potential to be detrimental to both the coastal cactus wren and the coastal California gnatcatcher. It has been documented that coastal cactus wrens have a difficult time re-colonizing burned areas of coastal sage scrub, because of the loss of tall cactus patches (Solek and Szijj 2004). Cacti have slow re-growth after fire events. Cacti residing in the lowlands of coastal sage scrub have the potential to become a flammable material, and grass fires are often more frequent and intense during the dry summer months (Benson 1988). Native cactus species are more likely to be surrounded by non-native grasses, which are more likely to be susceptible to fire. Native cacti tend to be smaller and less dense which allow non-native grasses to overcome the species. An increase in non-native vegetation after large fire events is of concern due to the succession of invasive species in natural areas (Benson 1988). This can lead to conversion of coastal sage scrub to non-native grasslands, which is unsuitable habitat for both the coastal cactus wren and the coastal California gnatcatcher.

The impacts of climate change on avian populations have only been recently addressed (Crick 2004). There is evidence regarding the impacts of climate change on migration, breeding, and population dynamics of many plant and animal populations (Crick 2004; Bolger, Patten, and Bostock 2005). Ecosystems that are particularly vulnerable to climate change are in arid and semi-arid regions because of their high variability in annual precipitation. Reduced reproductive success has been linked to drought conditions (Bolger, Patten, and Bostock 2005). The relationship between rainfall and avian reproduction appears to be mediated by food abundance (Bolger, Patten, and Bostock 2005).

Climate change has potential negative implications for coastal sage scrub birds. The impact of climate change on the avian community of coastal sage scrub is hard to predict, but growing warmer conditions and changes in annual precipitation may influence the reproduction and the availability of food for many avian species (Bolger, Patten, and Bostock 2005; North American Bird Conservation Initiative 2009). It is projected that current climate change witnessed in California may shift cactus wren populations out of their current range (Wiens 2010). It is suggested that shifts among species like the cactus wren may produce unanticipated results, such as new species interactions or increased predation (Wiens 2010). Local species have the potential to be re-shuffled and this may result in species interactions that do not normally occur in their natural habitat and could have detrimental impacts on those species who cannot adapt to changing environmental conditions (Wiens 2010).

GEOGRAPHIC METHODS – HABITAT SUITABILITY ANALYSIS AND SPECIES DISTRIBUTION MODELING

One of the most useful applications of GIScience for planning and management is suitability mapping (McHarg 1969; Makczewski 2004). GIScience based suitability mapping has been applied to many ecological applications for defining suitable habitat for a certain species (Store and Kangas 2001). Habitat suitability analysis is often used to produce probability maps to find the landscape properties of preferred habitats and potential spatial distribution of species (Store and Kangas 2001). This approach to suitability analysis has its roots in overlay analysis.

A common overlay operation in GIScience is weighted linear combination (Makczewski 2004). Weighted linear combination involves standardization of the suitability maps by assigning weights of relative importance to each individual suitability map and then combining the weighted standardized suitability maps to obtain an overall suitability score and map (Makczewski 2004). Habitat suitability is determined by habitat factors, which are characteristics of the habitat. Overall habitat suitability can be measured by a comprehensive habitat suitability index, which is a unitless variable describing the suitability of the habitat with respect to the needs of the focal species (Store and Kangas 2001).

Modeling the geographic distribution of species is critical in conservation. To protect at-risk species, it is important to know what habitat features are required for species survival (Phillips, Dudík, and Schapire 2004). The goal of species distribution modeling is to detect and/or predict areas in a region that fulfill the requirements of the species ecological niche (Anderson and Martínez-Meyer 2004). Species distribution modeling uses species locations and environmental factors to generate statistical functions that allow predictions of the potential spatial distribution of the focal species (Guisan and Zimmermann 2000; Brotons and others 2004).

Environmental factors could be obtained from statistically derived response surfaces (e.g., digital elevation models) and environmental variables (e.g., vegetation, climate, soil). Model components include the dependent variable (e.g., the presence/absence of the species of interest) and the independent variables (e.g., the potential environmental covariates) (Buckland and Elston 1993). There are several statistical techniques used in species distribution modeling, including niche-based modeling, logistic regression, generalized linear modeling, generalized additive modeling, and bayesian modeling (Guisan and Zimmermann 2000; Phillips, Anderson, and Schapire 2006; Austin 2007). One important aspect of species distribution modeling is the need for presence and absence data. For many species, absence data is not always available, reliable, or reported. Many traditional statistical methods used for both presence and absence data should not be used to analyze presence only data (Phillips, Anderson, and Schapire 2006).

Niche-based modeling is considered to approximate a species ecological niche (Phillips, Anderson, and Schapire 2006). An ecological niche refers to both the fundamental and realized niche. The fundamental niche contains all conditions and factors that provide long-term survival for the species (Pulliam 2000; Phillips, Anderson, and Schapire 2006). The realized niche is the subset of the fundamental niche with which the species actually inhabits (Pulliam 2000; Phillips, Anderson, and Schapire 2006). The niche-based model thus represents an estimate of a species realized niche (Phillips, Anderson, and Schapire 2006).

Maximum entropy (MaxEnt) method is a form of niche-based modeling that predicts potential species distribution using presence only data (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006). MaxEnt is a machine learning based method that incorporates maximum entropy for species distribution modeling (Phillips, Anderson, and Schapire 2006). The maximum entropy method estimates a probability distribution by finding the probability distribution of maximum entropy; it is then subjected to a group of constraints that represent incomplete information about the target species spatial distribution (Phillips, Anderson, and Schapire 2006).

CHAPTER 3

RESEARCH OBJECTIVE AND QUESTIONS

One approach towards avian conservation is to delineate local geographies for the target species. A local geography approach is defined in this study as an examination of the landscape characteristics, detection of specific habitat requirements, and the identification of core habitat areas (Figure 3).

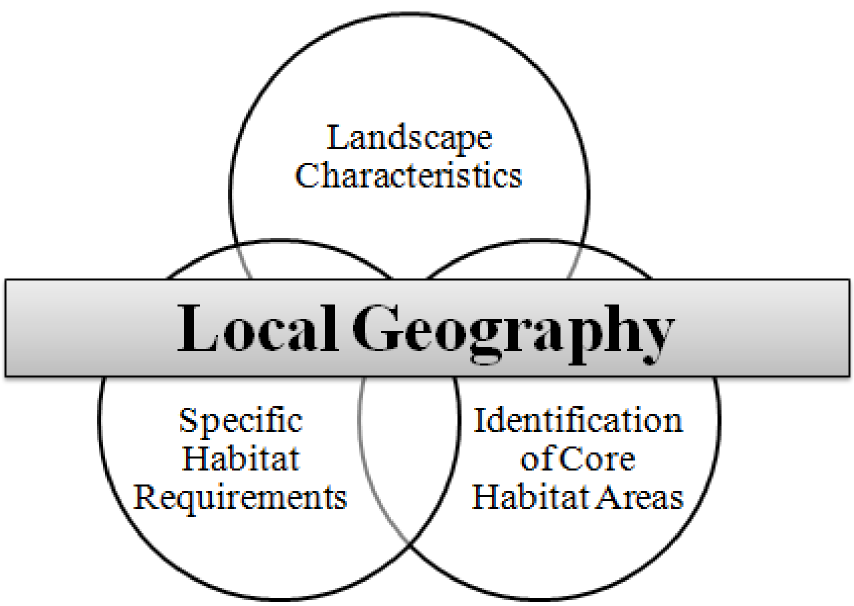

Figure 3. The conceptual model of the local geography.

The main research question for this study is: what elements affect the local geography of the coastal cactus wren and the coastal California gnatcatcher on MCB Camp Pendleton? This broad research question can be broken down into the following three sub-questions:

1. How do the landscape characteristics affect the spatial distribution of these two species on the Base?
2. What is the spatial distribution and suitable habitat of both species on the Base?
3. What are the core habitat areas for the coastal cactus wren and coastal California gnatcatcher on the Base?

CHAPTER 4

METHODS

This chapter details the methods used in this study. This research used geographic methods that relate the importance of habitat to the spatial distributions of both the coastal cactus wren and the coastal California gnatcatcher on MCB Camp Pendleton. The methods include landscape metric analysis, habitat suitability analysis, species distribution modeling, and the identification of core habitat areas using kernel density estimation. This chapter in addition details the study site and the reasons behind why it was selected.

STUDY AREA

Marine Corps Base Camp Pendleton is located in the northwestern section of San Diego County in southern California (see Figure 4). The Base has a total area of 50, 585 ha and is the largest undeveloped region in southern California (MCB Camp Pendleton 2007). This study will focus on approximately 41, 118 ha that encompasses the entire Base with the exception of areas designated as restricted by the United States Marine Corps (Nagel and Pavelka 2006). MCB Camp Pendleton is an active military installation with approximately 40,000-45,000 training events every year (MCB Camp Pendleton 2007). The surrounding land use types include urban, residential and agriculture. The Base resides on the coastal plains of the southern end of the Santa Ana Mountains, which are within the Peninsular Range of southwestern California.

Natural resources within the Base reflect the high diversity of species and habitats found throughout southern California. The Base supports a wide range of vegetation communities including coastal sage scrub, chaparral, grasslands, oak woodlands, dune vegetation, riparian woodlands, and wetland vegetation (MCB Camp Pendleton 2007). Coastal sage scrub on the Base is classified as Diegan Coastal Sage Scrub, a coastal sage scrub association (Holland 1986). Diegan Sage Scrub consists of low, soft, woody sub-shrub vegetation, with many plants that are summer drought-deciduous (Holland 1986).

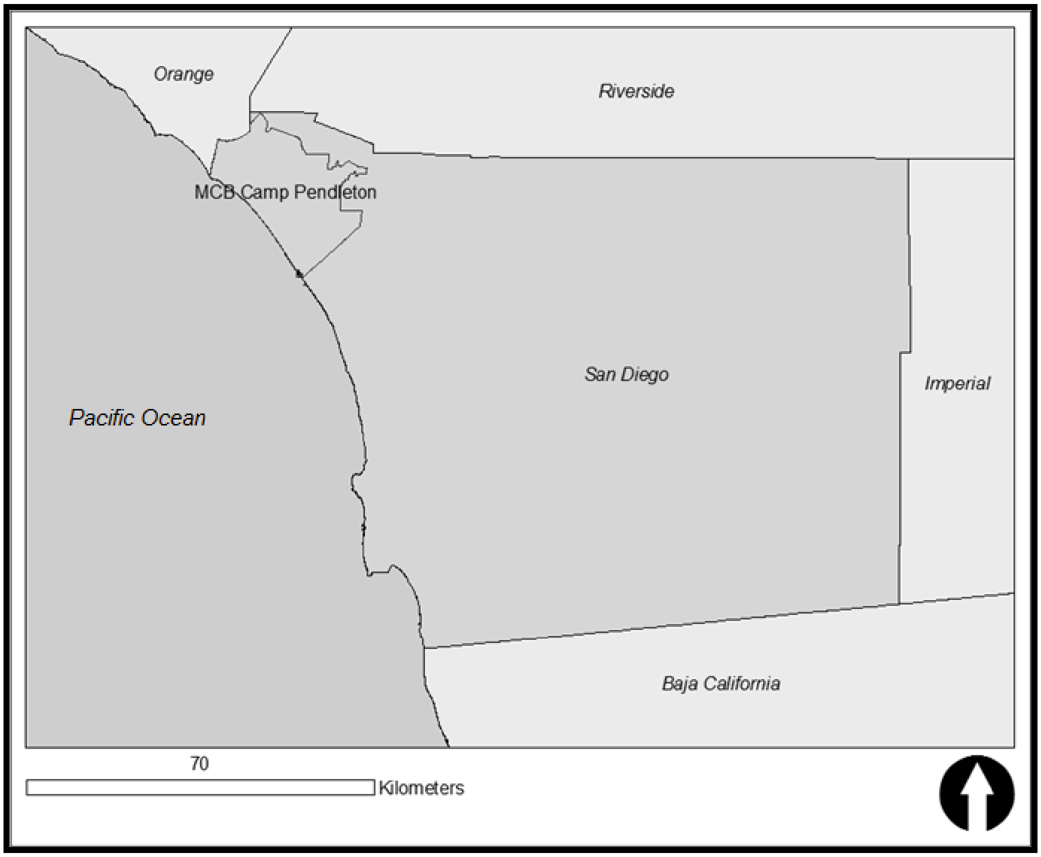

Figure 4. The map of Marine Corps Base Camp Pendleton.

Vegetation communities on the Base range from highly degraded to almost pristine (Nagel and Pavelka 2006). Degradation can be attributed to a variety of factors including but not limited to agricultural practices, frequent intense fires, and other anthropogenic causes (e.g., military training activities). The native vegetation is highly adapted to periodic drought, flooding and fire. Fire has a strong influence on the composition of vegetation on the Base, partly because it is more frequent on the Base than throughout San Diego County due to live-fire United States Marine Corps training.

MCB Camp Pendleton is an ideal study site for several key reasons. The Base is the largest undeveloped region in southern California, and historically has had large populations of both coastal cactus wrens and coastal California gnatcatchers. More importantly, the Base has been designated by Birdlife International as an Important Bird Area, which is defined as a site providing essential habitat for one or more vulnerable species (Birdlife International 2003; National Audubon Society 2008).

This research was permitted under a Sikes Agreement between the Wildlife Management Branch, Environmental Security, Marine Corps Base Camp Pendleton and the Department of Geography at San Diego State University. The GIS digital vector and raster datasets were obtained by permission from Marine Corps Base Camp Pendleton Environmental Security. Additional data were obtained through San Diego Association of Governments. The most complete Base-wide distribution data for the coastal cactus wren in this study were collected in 1989, 1993, 1994, 2007 and 2008. The Base-wide distribution data for the coastal California gnatcatcher in this study were collected in 1998, 2003, and 2006. The data for the coastal cactus wren and coastal California gnatcatcher are in the form of point count (vector) data.

Geographic Methods and Techniques

The landscape was examined through landscape metric calculations. Landscape metrics were used to quantify the landscape patterns that sustain both the coastal cactus wren and the coastal California gnatcatcher on the Base. Landscape patterns can have a large influence on the spatial distribution of species, and knowledge of these patterns will give us a better understanding of how these species interact with their environment. FRAGSTATS software version 3.3 was used to calculate the landscape metrics (McGarigal and others 2002). The landscape metrics were calculated using the 2003 vegetation data provided by the Base (coarse scale, cell size 420 m by 420 m). The vegetation data were created by an environmental consulting firm, AMEC Earth and Environmental, based on aerial imagery and fieldwork validation data (MCB Camp Pendleton 2007).

Twelve land cover types (see Table 1) were used to calculate class-level metrics and 40 land cover types (see Table 2) were used to calculate the landscape-level metrics. Class-level metrics are calculated for every class type (e.g., coastal sage scrub) in the landscape, while the landscape-level metrics are calculated for the entire landscape (McGarigal and Cushman 2002). The twelve land cover types were chosen because they are considered important vegetation communities associated with the coastal cactus wren and coastal California Gnatcatcher. The 40 land cover types for the landscape level calculations include all class types that occur on the Base, based on the 2003 vegetation data. The 40 class types in the landscape level metrics will provide an overall picture of landscape composition.

Table 1. Land Cover Types for the Class Level Landscape Metrics

Land Cover Types
Diegan Coastal Sage Scrub
Valley Needlegrass Grassland
Coastal Sage – Chaparral Scrub
Riparian Scrub
Scrub Oak Chaparral
Coastal Sage Scrub
Southern Mixed Chaparral
Grass-forb Mix
Grassland
Non-native Grassland
Southern Riparian Scrub
Southern Coastal Bluff Scrub

Table 2. Land Cover Types for the Landscape Level Landscape Metrics

Land Cover Types	
Urban/Developed	Southern Sycamore – Alder Riparian Woodland
General Agriculture	Southern Foredune
Disturbed Habitat	Riparian Forests
Dense Engelmann Oak Woodland	Opens Water
Coast Live Oak Woodland	Arundo
Coastal and Valley Freshwater Marsh	Tamarisk
Disturbed/Developed Lands	Southern Coastal Salt Marsh
Open Water/Open Gravel	Eucalyptus Woodland
Coastal Salt Marsh	Mixed Willow Exotic
Sycamore Grassland	Beach
Riparian Woodland	Open Engelmann Oak Woodland
Mixed Woodland	Disturbed Wetland
Freshwater Marsh	Riparian and Estuary
Non-native vegetation	Exotic-other

Seven landscape metrics were calculated for this study; four metrics were calculated for the class-level analysis and three were calculated for the landscape-level analysis (Table 3). The vector vegetation data were converted into ASCII format in ArcGIS software. FRAGSTATS parameters include cell size 420 m by 420 m, background value of 999, 259 rows, 249 columns, and 4-cell rule for the neighborhood definition. The 4-cell rule considers only four adjacent cells that share a side with the focal cell (e.g., orthogonal neighbors), or two cells with the same class that are diagonally touching will be considered as part of separate patches (McGarigal and Cushman 2002).

Table 3. FRAGSTATS Metrics

Percentage of Landscape – The percentage of the landscape comprised of the corresponding class type.
Percentage of Like Adjacencies – The degree of aggregation of the focal class type.
Clumpiness Index – The proportional deviation of like adjacencies involving the parallel class types.
Patch Cohesion Index – The physical connectedness of the corresponding class type.
Contagion – The percentage of clumping in the landscape.
Simpson's Diversity Index – The measure of landscape diversity.
Simpson's Evenness Index – The measure of landscape dominance.

The habitat suitability analysis was executed using ArcGIS 9.3 software. This project used the software's application ModelBuilder to build the appropriate models for the habitat suitability analysis (ESRI 2009). Reclassification and weighted overlay techniques were used to create the final habitat suitability maps. The reclassification technique changes the original cell values to alternative values (ESRI 2009). The original cell values represent either quantitative or qualitative attributes of a certain feature (e.g., elevation value, land cover type). During reclassification, the variables were assigned values of preference (ten values) according to the species habitat characteristics. A common scale (one to ten) of preference was used in this study. The weighted overlay technique overlays several of the environmental variables using a common scale and weights (equal to 100 percent) each according to their importance (ESRI 2009). The weighted overlay technique first enables the reclassification of the variables, weights the variables, and combines them to create the final habitat suitability index and map.

The variables used in the habitat suitability analysis, vegetation, aspect, slope, climate (precipitation and climatic zones), and fire variables, were based on the literature of both species. An important component in southern California's ecological history is fire. Human alteration of the fire regime has become evident, resulting in fires that are more frequent. To incorporate this phenomenon, fire variables were incorporated in the analysis. Fire variables included fire count (the total number of fires in the area of interest) and year of last fire (the year of last fire in the area of interest) throughout the Base from the period of 1972-2008.

Niche-based modeling was performed using the maximum entropy approach (MaxEnt) for the species distribution modeling (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006). This method is suitable for presence only occurrence data, especially when the sample size is small and sampling bias is of concern (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006). MaxEnt was chosen because this technique performed as well or better than other approaches when presence only data were used (e.g., BIOCLIM, DOMAIN and GARP) (Baldwin 2009). Random background locations serve as pseudo-absences in the MaxEnt model (Baldwin 2009). MaxEnt software is relatively insensitive to spatial errors associated with location data, and it can produce useful models with as few as five species locations (Baldwin 2009).

The environmental data used in the species distribution models were elevation, aspect, slope, and vegetation. These environmental variables were chosen based on literature pertaining to both species habitat and spatial distribution characteristics. Elevation was added to the model to see if there was an influence towards the potential distribution of either species. The data were converted in ArcGIS for use in the MaxEnt software (e.g., from raster or vector format into ASCII or CSV files).

The MaxEnt models developed for both species will be validated using a technique of replication–cross validation. Cross validation randomly splits occurrence data into a number of equal sized groups, called folds, and results are given using one fold at a time in the MaxEnt model execution. This technique was used because it is best suited for small data sets and because it uses all the data in each fold for cross validation. The output for each model is a map of potential spatial distribution of the species on the Base. Statistical information was given in regards to model performance including response curves for the environmental variables, environmental variable contribution (jackknife tests), receiver operating characteristic (ROC) curve, and area under the receiver operating characteristic curve (AUC) (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006).

Environmental variable contribution can be assessed using the jackknife approach, which excludes one variable at a time when the model is executed. This provides an assessment of each variable in the model in terms of how important each variable is at explaining the spatial distribution of the species as well as how much important information each variable contains (Baldwin 2009).

The receiver operating characteristic curve is a plot of sensitivity and 1-specificity where sensitivity represents how well the data correctly predicts presence occurrences and 1-specificity is a measure of correctly predicted absences (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006; Baldwin 2009). A well-developed model should be defined by a curve that maximizes sensitivity for low values of the false – positive fraction (Baldwin 2009). The significance of the ROC plot is quantified by the AUC, which ranges from 0.5 (indicating a fit no better than a random prediction) to one (indicating a perfect fit of the model) (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006; Baldwin 2009). A model could have an AUC value less than 0.5, which would indicate that the model fit is worse than a random model (Baldwin 2009). The AUC approach for defining model performance is a ranked approach that determines the probability that a presence location is ranked higher than a random background location (pseudo-absence) (Baldwin 2009).

The identification and prioritization of core habitat areas will be important for maintaining the current and future populations of coastal cactus wrens and coastal California gnatcatchers in southern California. This research followed techniques given by the USFWS for the prioritization of core habitat areas for the coastal California gnatcatcher on MCB Camp Pendleton (Nagel and Pavelka 2006). The method selected for defining core habitat areas was built upon a study done by the USFWS titled “Designation of Core Areas and Potential Restoration Sites for the Coastal California Gnatcatcher, Pacific Pocket Mouse and Stephen’s Kangaroo Rat on Marine Corps Base Camp Pendleton, California” in 2006 (Nagel and Pavelka 2006). The method in this study to define core habitat areas was kernel density estimation, which has been used widely in ecological studies (Nagel and Pavelka 2006).

Kernel density estimation calculates and creates isopleths of utilization intensity by calculating the mean influence of data points at grid intersections (Hemson and others 2005). The isopleths contain a fixed percentage of the utilization density that indicates the amount of time the species spends in the isopleth (Hemson and others 2005). Kernel density estimation was calculated using tools from Hawth’s Anaylsis Tools, an extension for ESRI’s ArcGIS software (Beyer 2004). The tool used calculates a fixed kernel density estimation using a quartic approximation of a true Gaussian kernel function and creates isopleths that represent the percentage by volume of location points (Beyer 2004). The isopleths represent the boundary that the area contains a percentage of the probability density distribution (Beyer 2004). For this study, the percent volume isopleths was based on 85 percent volume upon the request of the Base's Environmental Security (Nagel and Pavelka 2006). The 85 percent volume isopleths contains 85 percent of the points that were used to calculate the kernel density (Beyer 2004).

The core habitat regions were prioritized based on the criteria developed in accordance to the USFWS requirements for the coastal California gnatcatcher (Nagel and Pavelka 2006). The criteria included habitat, historic locations of species, closeness to training areas on the Base, and fire susceptibility. Designated core areas were ranked as high, medium, and low priority according to the multicriteria for each species (Nagel and Pavelka 2006). The highest priority sites would be those that are less subjected to training impacts. The prioritization criteria for the core habitat areas are listed in Table 4.

Table 4. Criteria for Prioritization of Core Habitat Areas

PRIORITY	CRITERIA
HIGH	Both species are present and/or historic locations of species Far from military impact areas Highly suitable habitat according to the habitat suitability analysis Potential geographic distribution according to the species distribution modeling
MEDIUM	Small historic locations of species Close to military impact areas (within 100 m) Adds connectivity on a Base-wide level but are otherwise not high priority Recent fire events Less suitable habitat according to the habitat suitability analysis Potential geographic distribution according to the species distribution modeling
LOW	Core areas in the Base's interior (military impact areas) Frequent and recent fire events Minimal suitable habitat

CHAPTER 5

RESULTS

This chapter details the results from the study. The main research question is what elements affect the local geography of the coastal cactus wren and the coastal California gnatcatcher on MCB Camp Pendleton? The main research question can be broken down into three sub-questions:

1. How do the landscape characteristics affect the spatial distribution of these two species on the Base?
2. What is the spatial distribution of both the species and suitable habitat for each target species on the Base?
3. What are the core habitat areas for the coastal cactus wren and coastal California gnatcatcher on the Base?

LANDSCAPE METRIC ANALYSIS

The percentage of landscape (PLAND) calculates the proportional abundance of each class type (e.g., coastal sage scrub) in the landscape (McGarigal and Cushman 2002). The percentage of landscape metric is a relative measure suitable for understanding landscape composition (McGarigal and Cushman 2002). PLAND approaches zero when the corresponding class type becomes increasingly rare in the landscape and equals 100 when the entire landscape is occupied by a single class type (McGarigal and Cushman 2002). The percentage of landscape is important to avian species because they require a proportion of different class type(s) for survival.

Table 5 details the PLAND results. The highest percentage of landscape was Diegan Coastal Sage Scrub at 44.97 percent. This illustrates a high percentage of Diegan Coastal Sage Scrub that comprises the landscape in comparison to the other class types. Diegan Coastal Sage Scrub was 33.39 percent higher than the next land cover type, Valley Needlegrass Grassland, with the second highest PLAND at 9.58 percent. The lowest PLAND was 0.28 percent for Southern Coastal Bluff Scrub, indicating that this class type is rare in the landscape on the Base.

Table 5. Percentage of Landscape (PLAND) Results

Type	PLAND
Diegan Coastal Sage Scrub	44.97 %
Valley Needlegrass Grassland	9.58 %
Southern Mixed Chaparral	6.64 %
Grassland	5.52 %
Coastal Sage-Chaparral Scrub	4.53 %
Non-native Grassland	3.49 %
Riparian Scrub	2.21 %
Coastal Sage Scrub	0.84 %
Grass-forb Mix	0.76 %
Scrub Oak Chaparral	0.56 %
Southern Riparian Scrub	0.43 %
Southern Coastal Bluff Scrub	0.28 %

The percentage of like adjacencies (PLADJ) is the percentage of cell adjacencies involving the corresponding class type that have like adjacencies (McGarigal and Cushman 2002). The percentage of like adjacencies is a measurement of dispersion of a certain land class in the landscape. PLADJ is zero when the corresponding class type is maximally disaggregated (every cell borders cells of different class types) and there are no like adjacencies (McGarigal and Cushman 2002). PLADJ is 100 when the landscape consists of a single class type and all adjacencies are between the same classes (McGarigal and Cushman 2002). PLADJ increases as the corresponding class type become increasingly clumped (McGarigal and Cushman 2002). A landscape that has a large number of class types and compact shapes will have a higher proportion of like adjacencies than a landscape that has fewer class types (McGarigal and Cushman 2002).

Table 6 details the PLADJ results. The highest percentage of like adjacencies calculation was Diegan Coastal Sage Scrub at 76.21 percent. The high percentage for Diegan Coastal Sage Scrub indicates that this land cover type is contiguous throughout the landscape. The percentage of like adjacencies ranged from 9.39 to 76.21 percent, and Southern Riparian Scrub had the lowest percentage at 9.40 percent indicating that this land cover type is more disconnected in the landscape. Southern Mixed Chaparral (67.19 percent) and Valley Needlegrass Grassland (64.10 percent) are in addition highly connected throughout the landscape on the Base.

Table 6. Percentage of Like Adjacencies (PLADJ) Results

Type	PLADJ
Diegan Coastal Sage Scrub	76.21 %
Southern Mixed Chaparral	67.19 %
Valley Needlegrass Grassland	64.10 %
Grassland	56.00 %
Coastal Sage-Chaparral Scrub	54.40 %
Non-native Grassland	49.82 %
Scrub Oak Chaparral	36.78 %
Riparian Scrub	35.54 %
Grass-forb Mix	24.47 %
Coastal Sage Scrub	21.54 %
Southern Coastal Bluff Scrub	18.82 %
Southern Riparian Scrub	9.40 %

The clumpiness index (CLUMPY) is the proportional deviation of the proportion of like adjacencies involving class types that are expected under a spatially random distribution (McGarigal and Cushman 2002). CLUMPY equals negative one when the focal class type is maximally disaggregated or a uniform pattern in the landscape (McGarigal and Cushman 2002). CLUMPY equals zero when the focal class type is distributed randomly, and approaches one when the class type is maximally clumped (McGarigal and Cushman 2002). The clumpiness index can be used to determine the potential of fragmentation in class types, i.e., if they are disaggregated in the landscape.

Table 7 details the CLUMPY results. The highest clumpiness index (CLUMPY) was for Southern Mixed Chaparral with 0.66. The clumpiness index ranged from 0.09 to 0.66, and Southern Riparian Scrub has the lowest index value. Southern Mixed Chaparral (0.66), Valley Needlegrass Grassland (0.62), and Diegan Coastal Sage Scrub (0.58) are considered by the clumpiness index to be maximally clumped throughout the landscape in comparison to the other land cover types. An interesting note was that the differences from the first six of the highest clumpiness index values were within 0.02-0.04 points of each other. This highlights again that these class types are highly aggregated among their class types within the landscape on the Base. Highly clumped class types are important to interior species (e.g., coastal cactus wren) because they require intact habitat that have low fragmented habitat remnants.

Table 7. Clumpiness Index (CLUMPY) Results

Type	CLUMPY
Southern Mixed Chaparral	0.66
Valley Needlegrass Grassland	0.62
Diegan Coastal Sage Scrub	0.58
Grassland	0.56
Coastal Sage-Chaparral Scrub	0.54
Non-native Grassland	0.50
Scrub Oak Chaparral	0.40
Riparian Scrub	0.36
Grass-forb Mix	0.26
Coastal Sage Scrub	0.22
Southern Coastal Bluff Scrub	0.21
Southern Riparian Scrub	0.10

The patch cohesion index (COHESION) measures the physical connectedness of the corresponding class type (McGarigal and Cushman 2002). COHESION approaches zero as the proportion of the landscape comprised of the focal class decreases becomes less physically connected. COHESION increases as the proportion of the landscape comprised of the focal class increases until an asymptote is reached near the percolation threshold (McGarigal and Cushman 2002).

Table 8 details the COHESION results. The highest patch cohesion index was Diegan Coastal Sage Scrub with 95.43. The patch cohesion index ranges from 13.71 to 96.43, and Southern Riparian Scrub had the lowest index value. Diegan Coastal Sage Scrub (95.43), Southern Mixed Chaparral (93.03), and Valley Needlegrass Grassland (87.74) are clumped in their class type throughout the landscape on the Base. Non-native grassland had a relatively high index value at 77.11 indicating that this type is also clumped throughout the landscape.

The clumping nature of non-native grasslands likely represents the pattern of disturbance that resulted in the aggregation of the invasive species. This high compilation of non-native grasslands may reflect the high usage of the landscape by the military on the Base. The patch cohesion index supports the results from the clumpiness index with Diegan Coastal Sage Scrub, Southern Mixed Chaparral, and Valley Needleland Grassland having a large presence within the landscape on the Base.

Table 8. Patch Cohesion Index (COHESION) Results

Type	COHESION
Diegan Coastal Sage Scrub	95.43
Southern Mixed Chaparral	93.04
Valley Needlegrass Grassland	87.75
Grassland	78.35
Non-native Grassland	77.11
Coastal Sage-Chaparral Scrub	76.73
Riparian Scrub	56.09
Scrub Oak Chaparral	55.01
Grass-forb Mix	39.17
Coastal Sage Scrub	29.94
Southern Coastal Bluff Scrub	28.17
Southern Riparian Scrub	13.71

The contagion (CONTAG) metric quantifies the degree of clumping in the entire landscape. CONTAG approaches zero when the class types across the landscape are maximally disaggregated (McGarigal and Cushman 2002). The metric equals 100 when all the class types are maximally aggregated (McGarigal and Cushman 2002). The contagion metric for the entire landscape was 49.92. This result is relatively marginal indicating that the edge density in the landscape is neither high nor low. No single land cover type completely dominates the landscape, whereas edge density throughout is consistent with the variety of land cover types.

The Simpson's Diversity Index (SIDI) is a measure of diversity. SIDI equals zero when the landscape contains one class type (i.e. no diversity) and increases as the number of class types increases (e.g., class types richness) (McGarigal and Cushman 2002). The Base's landscape has a Simpson's Diversity Index of 0.77, indicating that the landscape is relatively diverse. Simpson's Evenness Index (SIEI) is measure of dominance. SIEI equals zero when the landscape contains one class type (McGarigal and Cushman 2002). The metric approaches zero when the distribution of area among the different class types becomes increasingly uneven (McGarigal and Cushman 2002). The Base's landscape has a Simpson's Evenness Index of 0.79 indicating a more even proportion of class types across the landscape. The land cover types are distributed in proportion in their abundance on the Base.

Habitat Suitability Analysis

The environmental variables, i.e., vegetation, slope, aspect, climate (precipitation and climatic zone), and fire (year of last fire and fire count), were reclassified based on the preference of both species (see Appendix A for the reclassified variables). The variables were reclassified on a common scale of one to ten, which is often used in suitability analysis for clearer interpretation (see Table 9). One is considered low unsuitable habitat, while five and six are considered marginal habitat, and ten is considered high suitable habitat. Similarly, there are specific habitat requirements or other suitability scores under the one to ten gradients.

Table 9. Habitat Suitability Index

Index Value	Habitat Suitability
1	Low Suitable Habitat
2	
3	
4	
5	Marginal Habitat
6	Marginal Habitat
7	
8	
9	
10	High Suitable Habitat

The standard for the habitat suitability index was based on the on the literature on specific habitat requirements for the coastal cactus wren and the coastal California gnatcatcher (Mock 2004; Solek and Szijj 2004). The ideal suitable coastal cactus wren habitat features would include (1) Diegan Coastal Sage Scrub, (2) south-southwestern slopes, (3) 36-42.52 percent slopes, and (4) habitat areas that have burned less frequently. The ideal suitable habitat features for the coastal California gnatcatcher habitat would include (1) Diegan Coastal Sage Scrub, (2) 0-3.7 percent slopes, (3) annual precipitation of 0.36 m in a coastal/or maritime zone, and (4) areas that have burned less frequently.

After the environmental variables were reclassified, the variables were then assigned weights of importance (according to each species) (see Appendix B for the weighted variables and the reasoning behind the weights for the percent influences). The weights are assigned a percent influence in the weighted overlay technique. This percent influence total is equal to 100 percent. The higher weighted variable percentages in the weighted overlay technique were determined from the literature on the species habitat requirements (e.g., vegetation had a high percentage because both species are coastal sage scrub obligates). The final products for the habitat suitability analysis were habitat suitability maps (see Appendix C for the habitat suitability maps).

The environmental variables used to predict suitable habitat for the coastal cactus wren were vegetation types, aspect and slope. The habitat suitability index was from two to ten. The total area calculated from the habitat suitability analysis is 50,874 ha. The next analysis for the coastal cactus wren included not only the environmental variables but also fire variables. The habitat suitability index was from three to ten. The total area calculated from the habitat suitability analysis with the inclusion of fire is 40,445 ha. The inclusion of fire decreased the total area by 10,429 ha.

The variables used to predict suitable habitat for the coastal California gnatcatcher were vegetation, slope, and climate (included precipitation and climate zones). The habitat suitability index was from one to eight. The total area calculated from the habitat suitability analysis is 50,244 ha. The next analysis for the coastal California gnatcatcher included not only the environmental variables but also fire variables. The habitat suitability index was from two to eight. The total area calculated from the habitat suitability analysis with the inclusion of fire is 40,272 ha. The inclusion of fire decreased the total area by 9,972 ha

The final habitat suitability analysis was examined to consider both the coastal cactus wren and coastal California gnatcatcher. The variables used to predict suitable habitat for both species were vegetation, aspect, slope, and climate (including precipitation and climatic zones). The habitat suitability index was from one to eight. The total area calculated for both species was 50,126 ha. The next analysis for both species included not only the environmental variables but also the fire variables. The habitat suitability index was from two to eight. The total area with the inclusion of fire is 40,199 ha. The inclusion of fire decreased the total area by 9,927 ha.

SPECIES DISTRIBUTION MODELING

The dependent variable was the presence of the species, and the independent variables included aspect, elevation, slope, and vegetation. Cross-validation was used to assess the predictive power of the models. This method allows the models to execute multiple runs for the same species (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006). The presence data for both species were randomly split into a number of equal sized groups called folds in the MaxEnt software (Phillips, Dudík, and Schapire 2004, Phillips, Anderson, and Schapire 2006). A fold contains both the training and testing data for the model. The folds for the coastal cactus wren model consisted of 64-65 presence locations for training and 21 for testing. The folds for the coastal California gnatcatcher model consisted of 982-983 presence locations for training and 327 presence locations for testing. Ten folds were created for each species in the cross-validation.

MaxEnt produces three important results: the predictive map, jackknife test of variable importance and the relative contribution of environmental variables to the species distribution model. The omission rate and predicted area for the coastal cactus wren and coastal California gnatcatcher were averaged in the cross-validation. The omission rate and predicted area graph shows the mean predicted area, the mean area plus and minus one standard deviation, the mean omission rate for the test data on the model, the mean omission rate plus and minus one standard deviation and the predicted omission rate. The MaxEnt software applies a threshold so that the model performance can be validated. The analysis used a threshold to make a binary prediction, such that suitable areas are those with values predicted above the threshold and unsuitable areas below the threshold (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006).

The omission rate is the fraction of the test points that falls into pixels not predicted as suitable for the species, and the proportional predicted area is the fraction of all the pixels that are predicted as suitable for the species among the actually known habitat pixels (Phillips, Anderson, and Schapire 2006). Low omission rate is an optimal condition for a good model, and that the model is not missing known species locations (Phillips, Anderson, and Schapire 2006).

The average omission rate and predicted area for the coastal cactus wren are shown in Figure 5. There is some variability in the omission rates based on the standard deviation. This highlights that the model has a low potential of predicting presence points in unsuitable conditions for the coastal cactus wren.

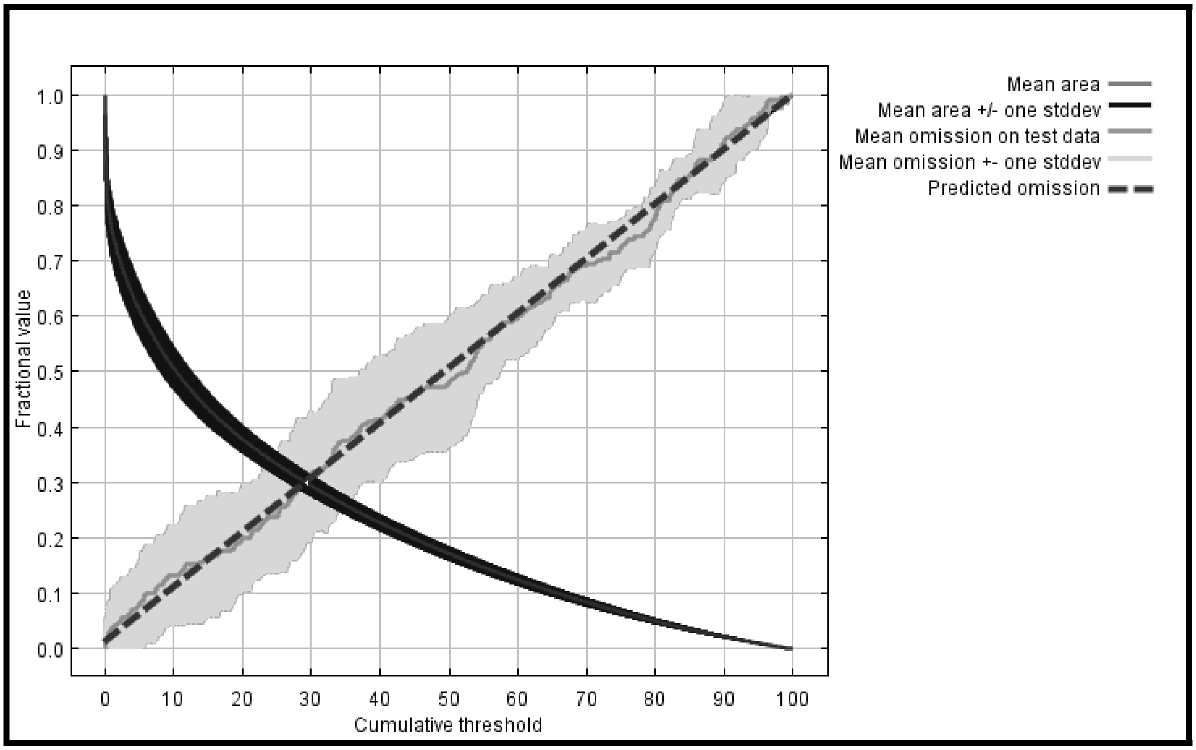

Figure 5. Coastal cactus wren omission rate and predicted area graph.

The omission rate and predicted area for the coastal California gnatcatcher are shown in Figure 6. There is also minor variability in the omission rates based on the standard deviation as the omission rates fluctuate around the mean omission rate. The model has a low potential of predicting presence points in unsuitable conditions for the coastal California gnatcatcher. The models predicted a low potential of occurrence locations at unsuitable conditions, thus the models are considered robust for analysis and predicting the species' spatial distributions (Phillips, Dudík, and Schapire 2004; Phillips, Anderson, and Schapire 2006).

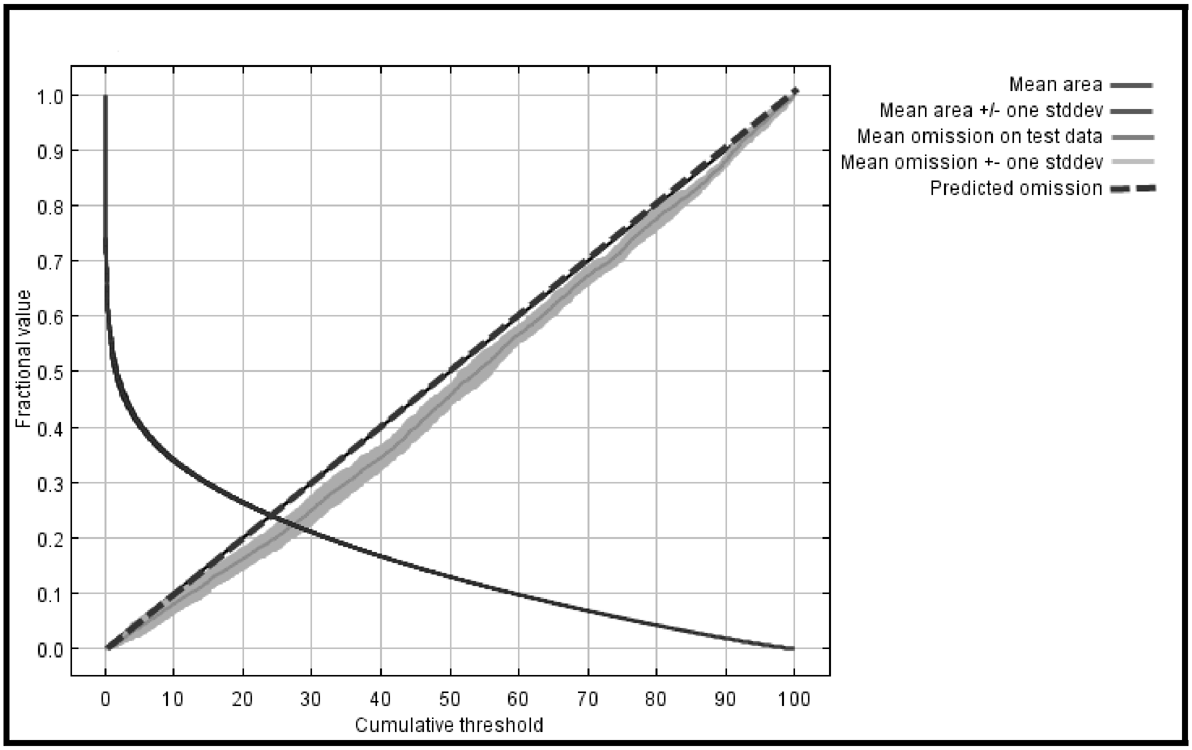

Figure 6. Coastal California gnatcatcher omission rate and predicted area graph.

The receiver operating characteristic (ROC) curve was given for both species and was averaged over the replicate runs from the cross-validation (Figures 7 and 8). The gray line is the mean value for the area under the ROC curve, and the surrounding black line area is the mean area under the ROC curve plus and minus one standard deviation. The black dashed line is the random prediction that the model would execute if the model were no better than random. The ROC curve plots sensitivity against 1-specificity (Pearson 2007). Sensitivity and specificity are used because they incorporate all the true and false presences and pseudo-absences in relation to species spatial distribution (Pearson 2007). The ROC describes the relationship between the proportion of observed presences correctly predicted and the proportion of observed pseudo absences incorrectly predicted. The ROC curve with presence only data interprets the negative samples with all grid cells with no occurrence localities, background points (pseudo-absences), even if they have good environmental conditions for the species (Phillips, Dudík, and Schapire 2004).

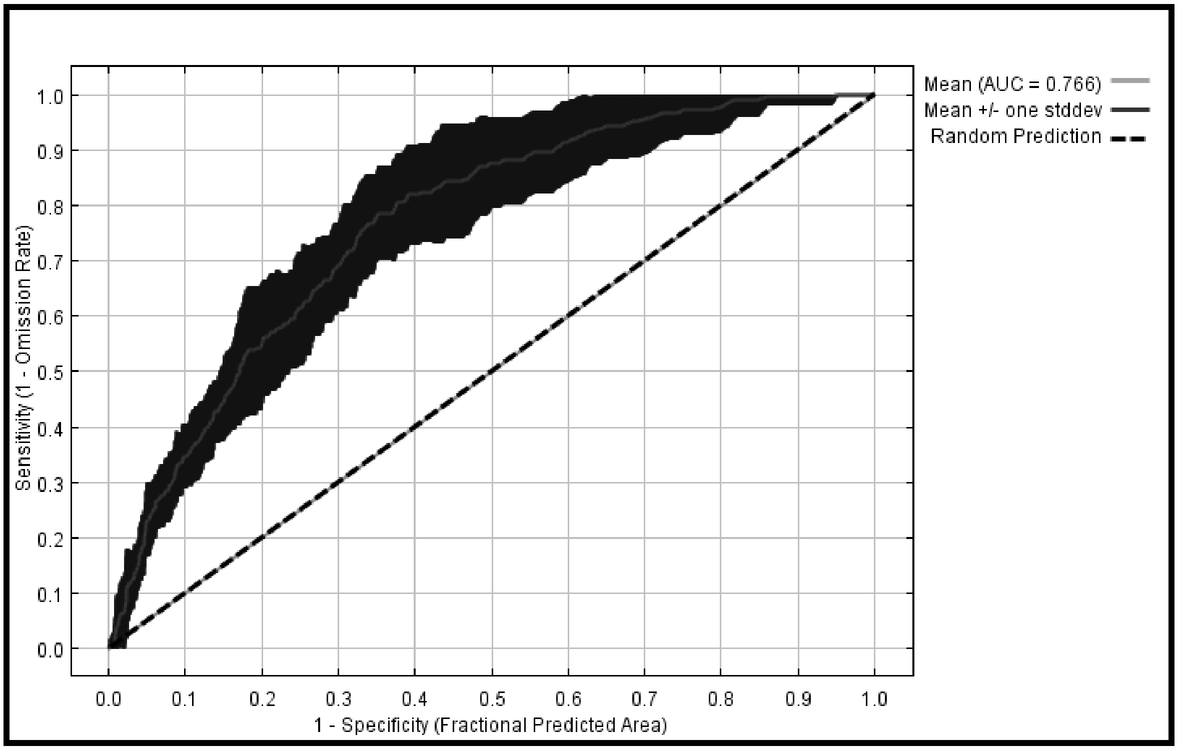

Figure 7. Coastal cactus wren ROC graph.

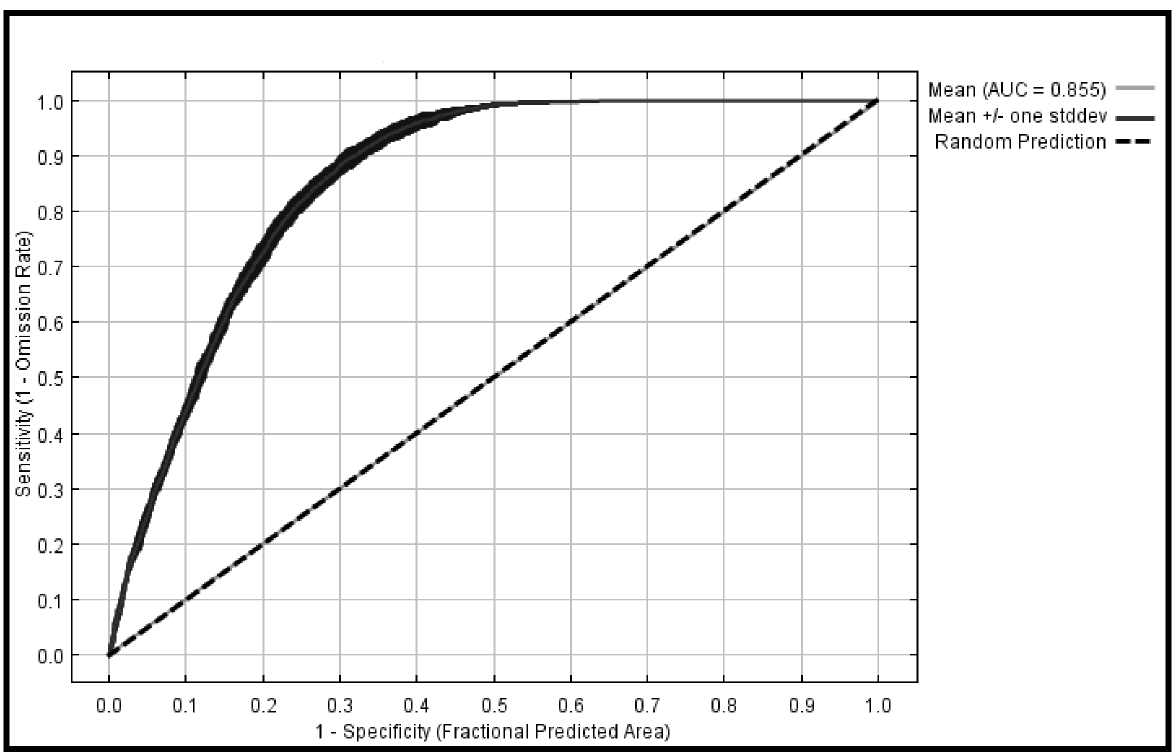

Figure 8. Coastal California gnatcatcher ROC graph.

High AUC values indicate that the model can discriminate between locations at which the species is present or is just pseudo-absences (Pearson 2007). The AUC ranges from 0.5 (models no better than random) to 1.0 (models have perfect predictive power).The mean AUC value for the coastal cactus wren model was 0.77 and the standard deviation was 0.04. The mean AUC value for the coastal California gnatcatcher was 0.86 and the standard deviation was 0.004. The AUC values can be interpreted as the probability that a record selected at random from the set of presences will have a predicted value greater than a record selected at random from the set of background points (Pearson 2007). Both models produced high AUC values indicating that the models have high predictive capacity (Phillips, Dudík, and Schapire 2004: Phillips, Anderson, and Schapire 2006).

The potential distribution of the coastal cactus wren and coastal California gnatcatcher on MCB Camp Pendleton was determined by averaging the outputs from the cross-validation. The MaxEnt model displayed a potential spatial distribution map in a logistic format; this format was inputted into ArcGIS and reclassified. The classification was adapted from the logistic predictions of probabilities of presence based on equal interval classification in ArcGIS. Figures 9 and 10 are detailed maps of the potential spatial distribution of the coastal cactus wren and the coastal California gnatcatcher on the Base. The gradient was constructed on a 0 to 100 percent probability scale. The warmer (lighter) colors show a higher probability of predicted occurrences while cooler (darker) colors indicate a lower probability of predicted occurrences.

The visual inspection of the predicted spatial distribution of the coastal cactus wren suggested that there are better-predicted occurrences on south – southwestern facing low elevation slopes on the Base. Minimal occurrences were found to be at central portions of the Base correlating with higher elevations. The visual inspection of the predicted spatial distribution of the coastal California gnatcatcher suggested that there is a similar trend to that of the coastal cactus wren’s spatial distribution on the Base. Better-predicted occurrences were on the lower slopes and near the coastline. Minimal occurrences of the coastal California gnatcatcher are correlated with central portions of the Base. The visual inspections of both potential distribution maps are similar in terms of the high and low probability of presence.

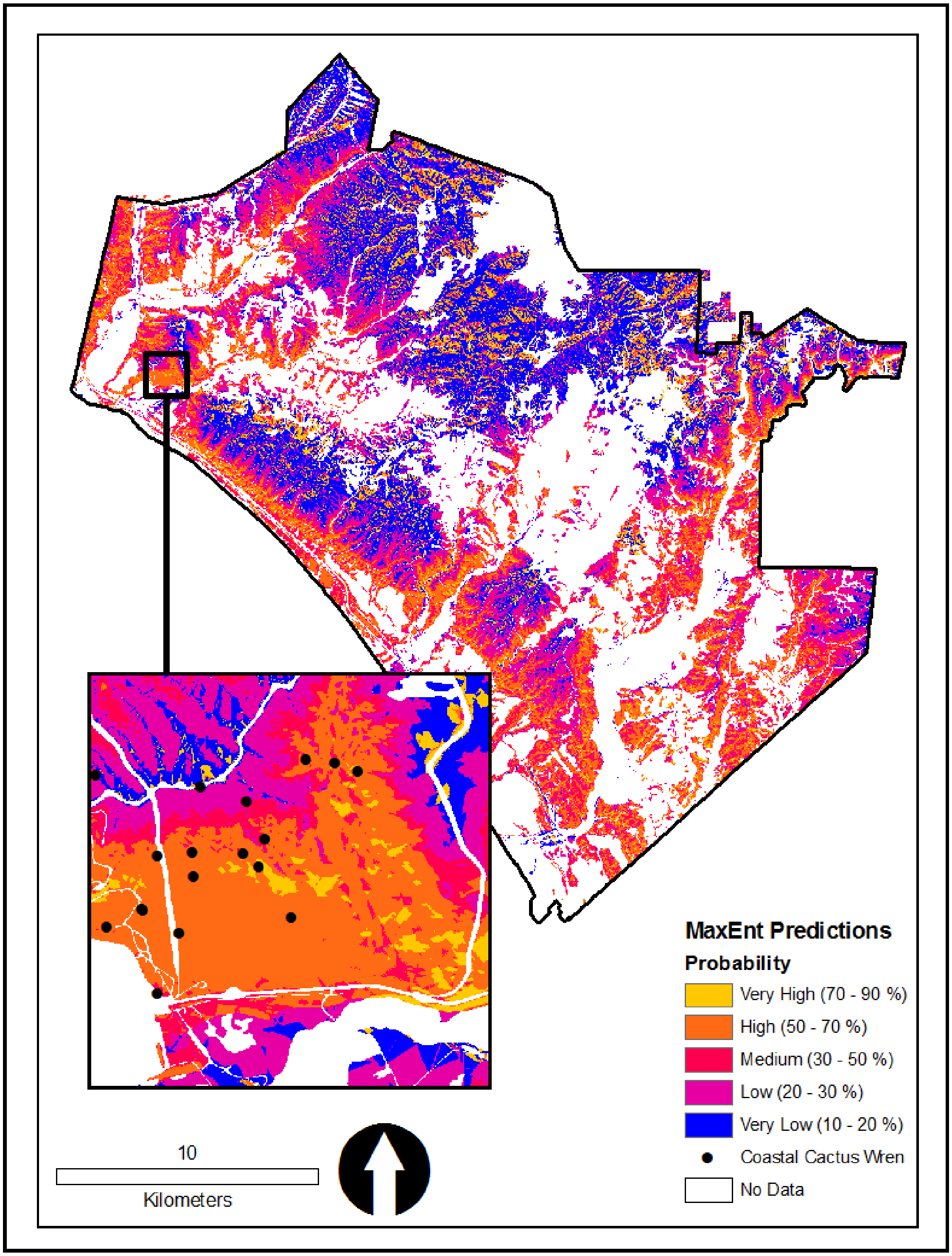

Figure 9. Predicted coastal cactus wren distribution map.

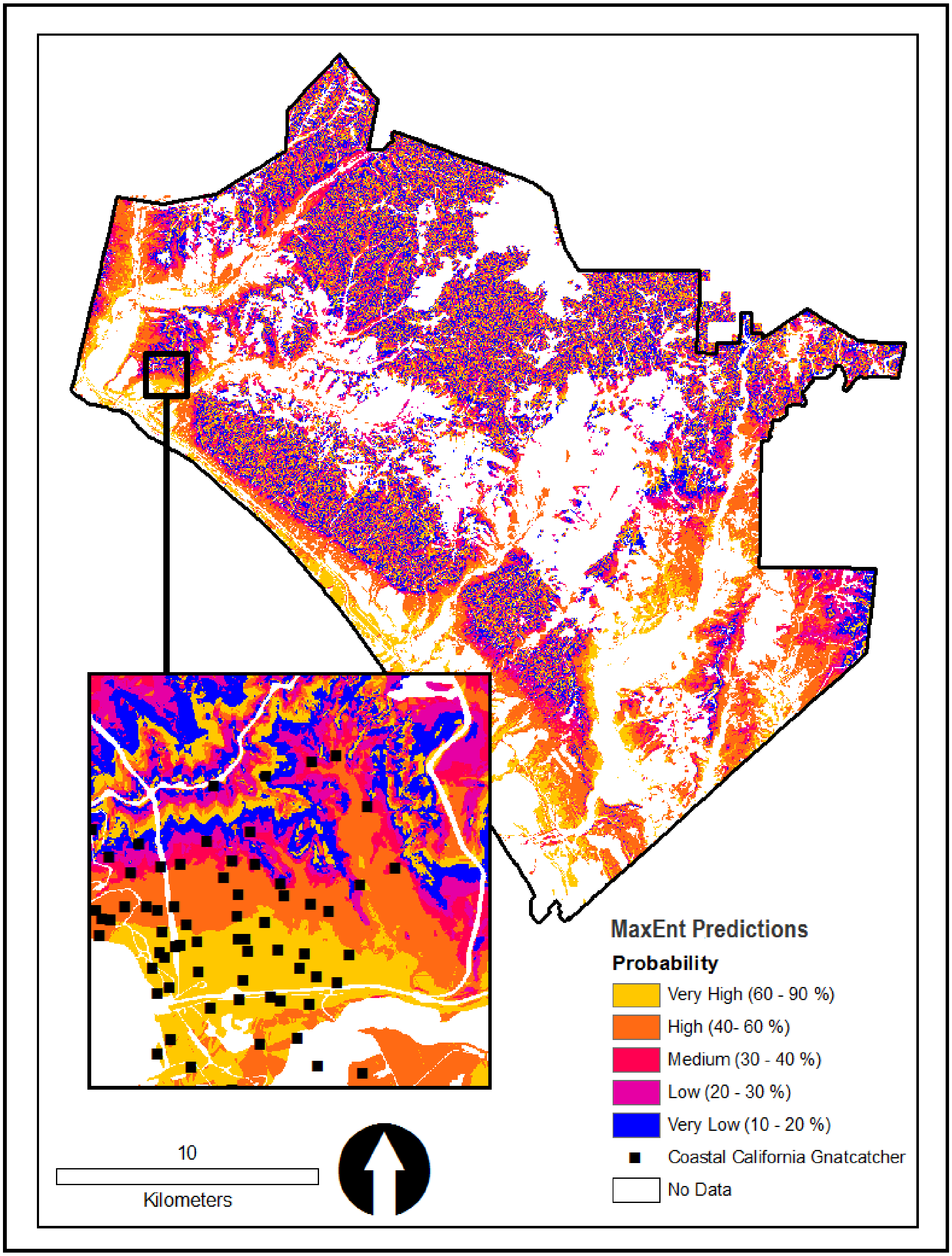

Figure 10. Predicted coastal California gnatcatcher distribution map.

Tables 10 and 11 give a heuristic estimate of the relative contributions of the environmental variables to the coastal cactus wren and coastal California gnatcatchers models. MaxEnt determines the estimate in each of the iterations of the training algorithm, whereas the increase in regularized gain is added to the contribution of each of the corresponding variables, or is subtracted from, if the change is negative (Phillips, Dudík, and Schapire 2004). The variable contributions were averaged in the cross-validation. For both species, elevation had the highest overall variable contribution to the models. The coastal cactus wren model had a 53.2 percent elevation contribution while the coastal California gnatcatcher model had a significantly higher elevation contribution, 91.1 percent. The coastal cactus wren model in addition had a high contribution from vegetation type at 30.6 percent. The lowest contribution for the coastal cactus wren model was slope at 7.4 percent and for the coastal California gnatcatcher model was aspect at 1.6 percent.

Table 10. Variable Contribution Percentage for the Coastal Cactus Wren

Environmental Variable	Contribution Percentage
Elevation	53.2 %
Vegetation	30.6 %
Aspect	8.8 %
Slope	7.4 %

Table 11. Variable Contribution Percentage for the Coastal California Gnatcatcher

Environmental Variable	Contribution Percentage
Elevation	91.1%
Slope	5.5%
Vegetation	1.8%
Aspect	1.6%

The jackknife test results for both the coastal cactus wren and the coastal California gnatcatcher concluded that the environmental variable with the highest gain in the model when used in isolation is elevation, and it appears to have the most useful information by itself and the most important information not present in the other variables (Figures 11 and 12). Vegetation (types) was the second environmental variable in the coastal cactus wren model with the highest gain.

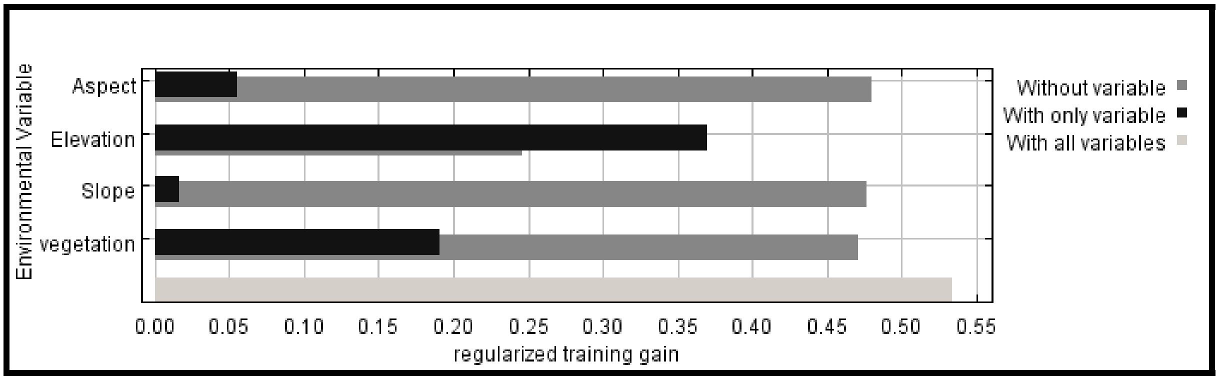

Figure 11. The jackknife analysis for the coastal cactus wren model.

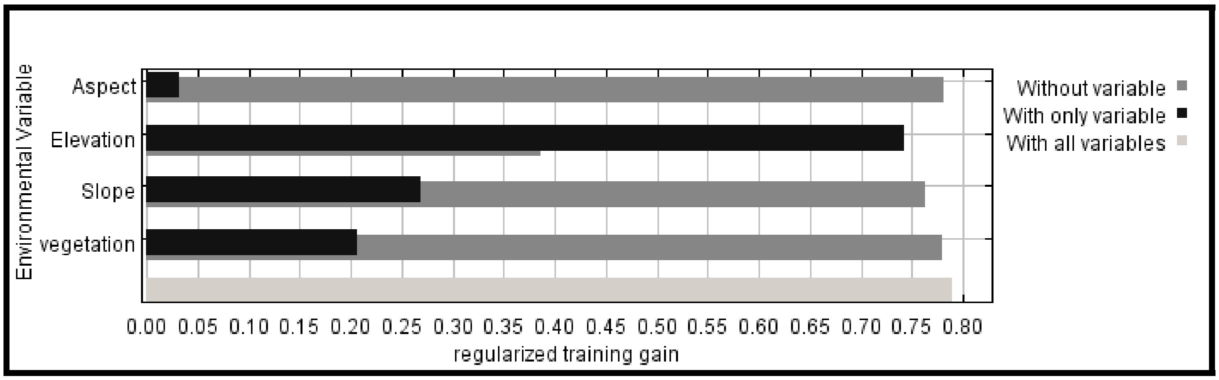

Figure 12. The jackknife analysis for the coastal California gnatcatcher model.

Elevation was considered the most important variable in the MaxEnt models for the coastal cactus wren. The response curves illustrates the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their corresponding values (Figure 13) (Phillips, Dudík, and Schapire 2004). The response curve shows the ten replicate model runs (gray line) and the mean plus and minus one standard deviation (black line) (Phillips, Dudík, and Schapire 2004). The high probability of presence of the coastal cactus wren corresponded with elevations from zero to 400 m. The logistic output (probability of presence) drops dramatically at about 500 m. The vegetation response curve indicated that Diegan Coastal Sage Scrub had the highest probability of presence for the coastal cactus wren (Figure 14). The second highest probability presence was coastal sage scrub – chaparral scrub, indicating a potential for cactus scrub in the vegetation type.

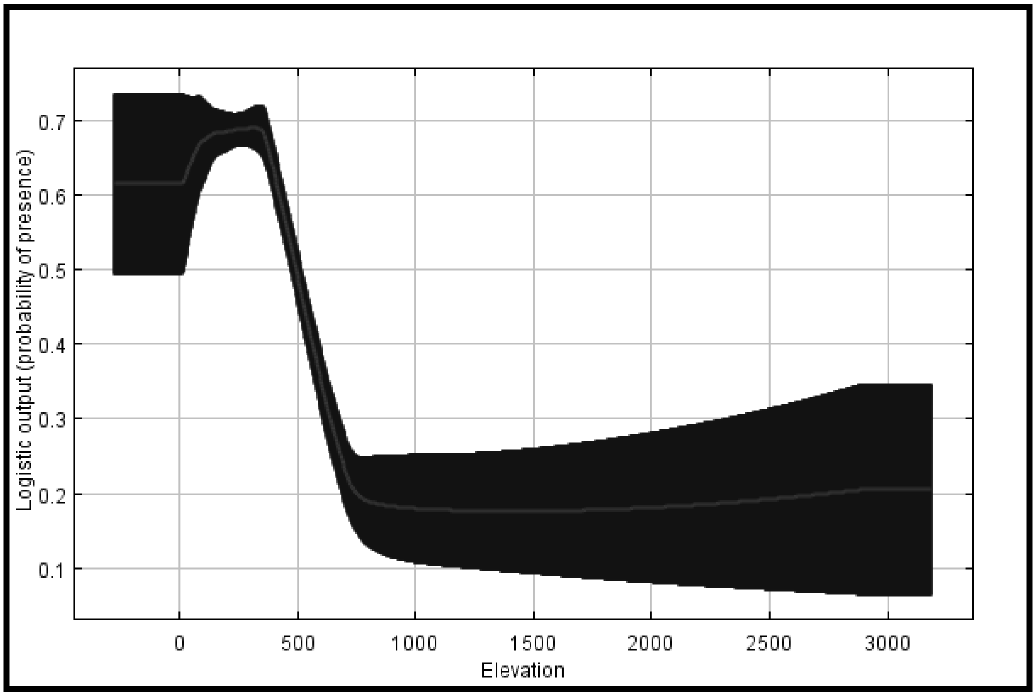

Figure 13. Response curve of elevation for the coastal cactus wren.

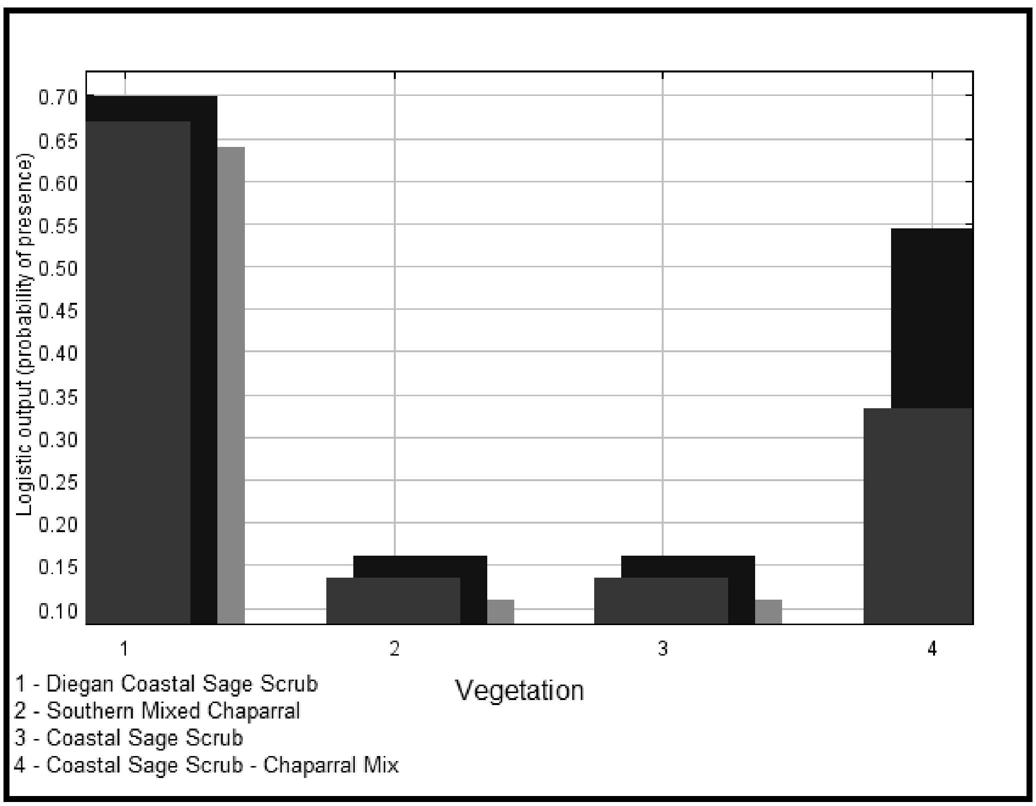

Figure 14. Response curve of vegetation for the coastal cactus wren.

Elevation was considered the most important variable in the MaxEnt models for the coastal California gnatcatcher. Response curves illustrate how the logistic prediction changes as each environmental variable is varied, keeping all environmental variables at their corresponding values (Figure 15) (Phillips, Dudík, and Schapire 2004). The response curve shows the 10 replicate model runs and the mean plus and minus one standard deviation (Phillips, Dudík, and Schapire 2004). High probability of presence of the coastal California gnatcatcher was correlated with the low elevation (e.g., less than 50 m). The logistic output (probability of presence) decreases with elevation and drops to zero at the higher elevations.

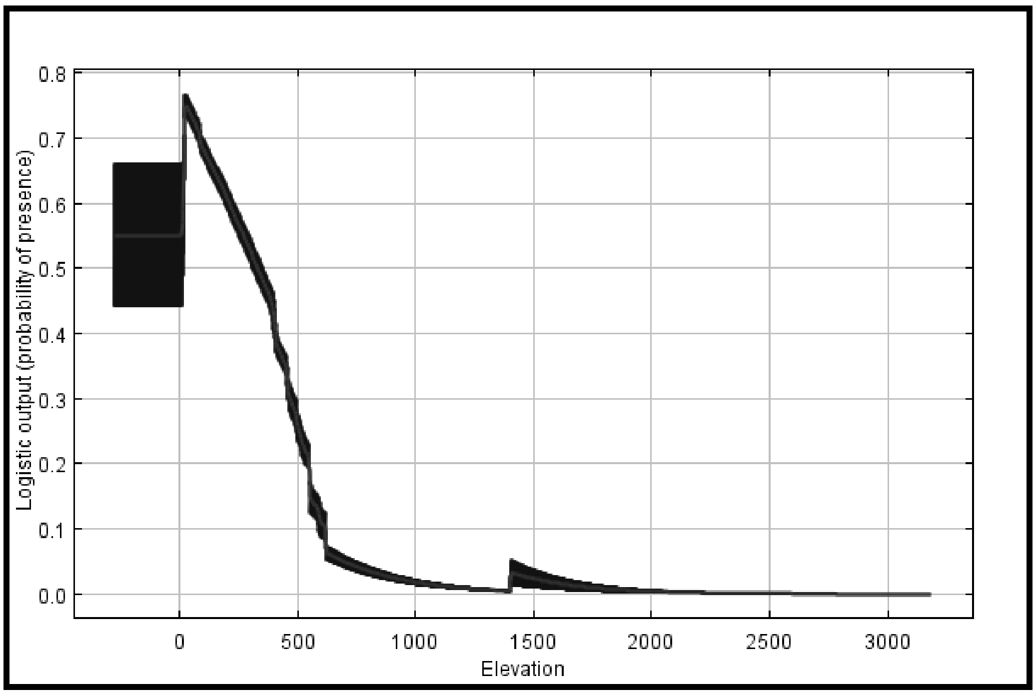

Figure 15. Response curve of elevation for the coastal California gnatcatcher.

High probability of presence for the coastal California gnatcatcher occurs on slopes between 0 to 10 percent (Figure 16). The probability of presence decreases with slopes greater than 10 percent. The probability of presence is 50 percent at 25 percent slope. This supports the literature which states that coastal California gnatcatchers prefer to build their nests on slopes with less than 40 percent (Mock 2004). These results indicate that the coastal California gnatcatcher may be more specialized in their preference of slope in the landscape.

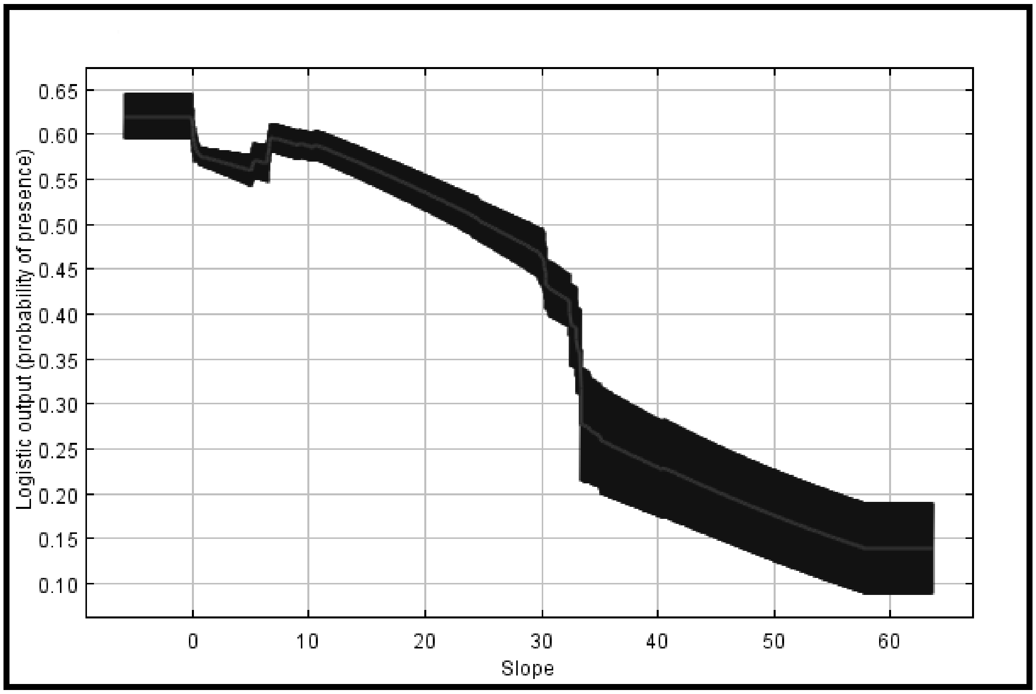

Figure 16. Response curve of slope of the coastal California gnatcatcher.

IDENTIFICATION OF CORE HABITAT AREAS

The identification of core habitat areas was delineated using kernel density estimation. The isopleths that did not have presence locations of either species were deleted and were not considered in the core habitat delineation. The calculation produced 34 isopleths for the coastal cactus wren and 38 isopleths for the coastal California gnatcatcher. Overlapping isopleths were considered core habitat for both species (see Appendix D for maps of the core habitat areas) and then were prioritized based on the criteria that was developed for this study. Eight core habitat areas were delineated, three were considered high priority and five were considered medium priority. After the delineation of core habitat areas, site visits were conducted at random sites to document the habitat quality.

The first core habitat area is located in the northwestern edge of the Base. This core area is located near the boundary between MCB Camp Pendleton and San Clemente, California. The core habitat also resides in San Onofre State Park and is adjacent to agricultural fields. This core habitat area is consistent with the core habitat areas identified for the coastal California gnatcatcher by the USFWS (Nagel and Pavelka 2006). This core habitat area was identified to have high priority based on the ranking criteria. The site visits documented good habitat quality in terms of intact coastal sage scrub and presence of cactus species (Figure 17). The intact coastal sage scrub is associated with the site not witnessing fire since the early 1970s. However, there was presence of invasive species, which could be a potential impact left from the early fires or human alteration from military training. Table 12 describes core habitat area one in more detail.

Figure 17. Example site in core habitat area 1.

Table 12. Description of Core Habitat Area 1

Core Habitat Area 1	Total area-693 ha Coastal California gnatcatcher habitat is 693 ha Coastal cactus wren habitat overlap is 129 ha Fire-1972 Presence of cactus and invasive species

The second core habitat area is located in the northwestern edge of the Base. San Onofre Housing Community is within this area and is composed of two separate housing areas and an elementary school. This core area is consistent with the core habitat areas identified for the coastal California gnatcatcher by the USFWS (Nagel and Pavelka 2006). This core habitat area was identified to have high priority. The site visits documented good habitat quality in terms of presence of cactus species and intact coastal sage scrub (Figure 18). During the site visits in early 2010, both coastal cactus wrens and coastal California gnatcatchers were observed (visually and/or heard). This site had not been impacted by documented fires since the 1980s, thus, the relatively high quality coastal sage scrub. Table 13 describes core habitat area two in more detail.

Figure 18. Example site in core habitat area 2.

Table 13. Description of Core Habitat Area 2

Core Habitat Area 2	Total area-1,081 ha Coastal California gnatcatcher habitat is 936 ha Coastal cactus wren habitat is 345 ha Fire-1980s Presence of cactus and invasive species

The third core habitat area is located on the western edge of the Base. This core habitat resides in several active training areas used by the Marine Corps (Tango, Papa I and Oscar II Training Areas). Core habitat area three was the third largest area selected in this study. This core habitat area is consistent with the core habitat areas identified for the coastal California gnatcatcher by the USFWS (Nagel and Pavelka 2006).

This core habitat area was identified to have medium priority based on the ranking criteria (Figure 19). The site visits documented marginal quality habitat due to a high presence of invasive grasslands and minimal cactus. This site was severely impacted by fire that occurred in 2007; however, there was documentation of cactus species at the site but many species were singular cactus. Table 14 describes core habitat area three in more detail.

Figure 19. Example site in core habitat area 3.

Table 14. Description of Core Habitat Area 3

Core Habitat Area 3	Total area-1,521 ha Coastal California gnatcatcher habitat is 1,427 ha Coastal cactus wren habitat is 80 ha Fire-2007 Presence of cactus and invasive species

The fourth core habitat area is located on southern end of the Base. This core habitat area resides in an active training area (Oscar I Training Area) and the Santa Margarita River crosses through this core area. Core habitat area four is the second largest identified in the study. This core habitat area is consistent with the core habitat areas identified for the coastal California gnatcatcher by the USFWS (Nagel and Pavelka 2006).

This core habitat area was identified to have medium priority based on the ranking criteria (Figure 20). The site visits in this core habitat area documented marginal habitat in terms of a large presence of invasive species. The site did hold a large presence of cactus and in large clusters, which is ideal for coastal cactus wrens. Table 15 describes core habitat area four in more detail.

Figure 20. Example site in core habitat area 4.

Table 15. Description of Core Habitat Area 4

Core Habitat Area 4	Total area-1,638 ha Coastal California gnatcatcher habitat is 1,568 ha Coastal cactus wren habitat is 136 ha Fire-2006 Presence of cactus and invasive species

The fifth core habitat area is located in the southern end of the Base. Core habitat area five resides in Pueblitos Canyon and is near the air station. This core habitat area resides in several training areas (Mike and November Training Areas). This core habitat area is consistent with the core habitat areas identified for the coastal California gnatcatcher by the USFWS (Nagel and Pavelka 2006).

This core habitat area was identified to have medium priority based on the ranking criteria (Figure 21). The site visits documented as marginal due to presence of invasive species. The site was largely impacted by the fires in 2008 on the Base. However, some of the hillsides were not impacted by the fires and had a large presence of cactus. Table 16 describes core habitat area five in more detail.

Figure 21. Example site in core habitat area 5.

Table 16. Description of Core Habitat Area 5

Core Habitat Area 5	Total area-271 ha Coastal California gnatcatcher habitat is 228 ha Coastal cactus wren habitat is 236 ha Fire-2008 Presence of cactus and invasive species

The sixth core habitat area is located on the eastern side of the Base. This core area is located within a relatively active portion of the Base. The De Luz Homes Housing Community and Mainside are located on its western edge. Fallbrook Naval Weapons Station borders the north side of the site. The core habitat area is located in a training area (Juliet Training Area).

The core habitat area is within the areas identified for the coastal California gnatcatcher as core habitat by the USFWS (Nagel and Pavelka 2006). This core habitat area was identified to have medium priority based on the ranking criteria (Figure 22). The site visits documented marginal habitat with high presence of invasive species, which likely from military training since the last documented fire occurred in the site in the 1970s. Table 17 describes core habitat area six in more detail.

Figure 22. Example site in core habitat area 6.

Table 17. Description of Core Habitat Area 6

Core Habitat Area 6	Total area-305 ha Coastal California gnatcatcher habitat is 305 ha Coastal cactus wren habitat is 42 ha Fire-1972 Presence of cactus and invasive species

The seventh core habitat area is located at the eastern side of the Base. O’Neill Heights Housing Community and O’Neill Lake are located within the area. The core habitat area resides in active training areas (India and Kilo II Training Areas). This core habitat area is consistent with the core habitat areas identified for the coastal California gnatcatcher by the USFWS (Nagel and Pavelka 2006). This core habitat area was identified to have high priority based on the ranking criteria (Figure 23). The site visits documented good habitat quality with intact coastal sage scrub and high abundance of cactus. There was minimal presence of invasive species. The site was largely affected by fires that have been documented on the Base since 1972. The most recent documented fire only affected a small section of the site in 2002. Table 18 describes core habitat seven in more detail.

Figure 23. Example site in core habitat area 7.

Table 18. Description of Core Habitat Area 7

Core Habitat Area 7	Total area 571 ha Coastal California gnatcatcher habitat is 571 ha Coastal cactus wren habitat is 61 ha Site largely unaffected by fires Presence of cactus and invasive species

The final (eighth) core habitat area is located on the eastern/southeastern side of the Base. This site is located in an active part of the Base. The MCB Camp Pendleton golf course is located within the site. The core habitat area incorporates several active training areas (Lima, November, Juliet, and Mike Training Areas). Core habitat area eight is the largest area that was identified in this study. This core habitat area is consistent with the core habitat areas identified for the coastal California gnatcatcher by the USFWS (Nagel and Pavelka 2006). The core habitat was identified to have medium priority based on the ranking criteria (Figure 24). The site visits documented marginal habitat with a presence of invasive species. This core habitat was impacted by the fires in 2008; however, regrowth of cactus and other species was present during the site visit. Table 19 describes core habitat area eight in more detail.

Figure 24. Example site in core habitat area 8.

Table 19. Description of Core Habitat Area 8

Core Habitat Area 8	Total area-2,067 ha Coastal California gnatcatcher habitat is 1,951 ha Coastal cactus wren habitat is 626 ha Fire-2008 Presence of cactus and invasive species

CHAPTER 6

DISCUSSION

This research used a geographic approach towards avian conservation. This was achieved through a delineation of the local geographies for the coastal cactus wren and the coastal California gnatcatcher on MCB Camp Pendleton. The delineation of the local geography was comprised of an examination of the landscape characteristics, analysis of specific habitat requirements, and identification of core habitat areas for the focal species. The study has provided an insight into their spatial distribution and habitat requirements, which will likely facilitate better conservation management practices on the Base.

SUMMARY

The landscape metric analysis concluded that Diegan Coastal Sage Scrub has a dominant presence throughout the landscape. This land cover type is highly connected on the Base. Previous research estimates 15,338 ha of coastal sage scrub and its subtypes including Diegan Coastal Sage Scrub on the Base (MCB Camp Pendleton 2007). The coastal cactus wren and the coastal California gnatcatcher are coastal sage scrub obligates and a high presence of Diegan Coastal Sage Scrub is important component to their environment (Mock 2004; Solek and Szijj 2004). Highly connected vegetation is significantly important for interior species that thrive on intact connected vegetation. Intact and well-connected Diegan Coastal Sage Scrub is critical for the survival of the coastal cactus wren.

Another land cover type that had a significant contribution to the landscape included a high presence of Valley Needleland Grassland (native perennial grassland). A high presence of grasslands is supported by previous research with an estimation of over 30 percent of the Base covered by grasslands, or approximately 16,187 ha (MCB Camp Pendleton 2007). Previous research indicates that the coastal California gnatcatcher more abundance near the interface of coastal sage scrub and grassland interface rather than the where the sages scrub integrates into chaparral vegetation (Mock 2004).

Landscape metrics become a useful tool when examining ecological phenomena at broad spatial scales because it is often necessary to quantify patterns and structure for testing relationships or making predictions about the landscape and the phenomena in focus (Hargis, Bissonette, and David 1997). Landscape metrics provide a unique perspective in understanding the configuration and composition of the area of study. This study only briefly explored the potential of landscape metrics and their usefulness in avian research. Further research on the coastal cactus wren and the coastal California gnatcatcher may provide important links in their relationship to their environment. Landscape metrics have the potential to understand the influence of coastal sage scrub on avian species in different landscapes. Other potential applications could be to use landscape metrics to compare landscape associations with avian communities in terms of restored and disturbed habitats.

The habitat suitability analysis provided useful information pertaining to both the coastal cactus wren and the coastal California gnatcatcher. The final products from the analysis are habitat suitability maps that provide general suitable and unsuitable habitat trends for both species on the Base (see Appendix C for the habitat suitability maps). The most significant finding from the habitat suitability analysis was the influence of fire on the habitat for both species on the Base. The total area of potential habitat decreased with the inclusion of fire (e.g. coastal cactus wren decreased 10,455 ha, the coastal California gnatcatcher decreased 9,972 ha, and for both species decreased 9,927 ha). This is supported by previous literature, with fire being a major impact to both species populations by decreasing suitable habitat (Mock 2004; Solek and Szijj 2004).

The species distribution modeling has resulted in potential spatial distribution maps of both the coastal cactus wren and the coastal California gnatcatcher on the Base. The model results for both species indicated that elevation had the highest contribution and the most useful information by itself in comparison to the other variables (e.g. vegetation, aspect and slope). This illustrates a potential elevational limit to both species' spatial distribution. This corresponds to the characteristics of coastal sages scrub vegetation community, which ranges in elevation from sea level to 600 m in more inland areas (O'Leary 1990). Vegetation had a significant contribution to the coastal cactus wren model, which is concurrent to the idea that the wren is a coastal sage scrub specialist that depends on this habitat component and more specifically on coastal sage scrub-cactus scrub.

Eight core habitat areas were identified for both the coastal cactus wren and the coastal California gnatcatcher on the MCB Camp Pendleton. An interesting aspect to the delineation of the core areas was the overlap of coastal cactus wren habitat within coastal California gnatcatcher habitat. Coastal cactus wren habitat overlapped coastal California gnatcatcher habitat in all eight identified core habitat areas (see Table 20).

Table 20. Habitat Area Overlap

Core Habitat	Total Area (ha)	Coastal Cactus Wren Habitat (ha)	Coastal California Gnatcatcher Habitat (ha)
1	693	129	693
2	1,081	345	936
3	1,521	80	1,427
4	1,638	136	1,568
5	271	236	228
6	305	42	305
7	571	61	571
8	2,067	626	1,951

The habitat overlap of both species is important in terms of conservation management. The coastal California gnatcatcher is legally protected under federal laws pertaining to the Endangered Species Act and currently the coastal cactus wren is minimally protected. Federal monies are given towards the protection of the coastal California gnatcatcher, thus, the likelihood for habitat mitigation is high and habitat acquirement may occur for the species. The protections afforded to the coastal California gnatcatcher may provide essential protection for the coastal cactus wren. Thus, the potential linkage may provide essential conservation management for the coastal cactus wren.

All core habitat areas that were delineated in this study were consistent with the coastal California gnatcatcher core habitat areas in the USFWS study in 2006 (Nagel and Pavelka 2006). USFWS delineated 13 core habitat areas in comparison to eight that were delineated in this study. The methods utilized in this study went beyond just using kernel density estimation, of which the USFWS used in their study, by incorporating landscape characteristics, habitat suitability analysis, and species distribution modeling. The use of habitat suitability analysis and species distribution modeling details important information in regards to the species habitat requirements, spatial distribution, and trends in suitable habitat. By utilizing these geographic methods, we are given a broad spatial perspective on these two species.

A review of the literature indicates that the coastal cactus wren and the coastal California gnatcatcher share similar habitat features (Mock 2004; Solek and Szijj 2004). Linking these two species together provides an interesting insight into this notion about them. The results from the species distribution modeling illustrated several insights towards both species. Elevation played a significant role in the spatial distribution of both species on the Base. Coastal cactus wrens are known to occur in coastal low elevation cactus scrub within coastal sage scrub (Cooper 2009). Coastal California gnatcatchers are limited to lower elevations (less than 500 m) in coastal sage scrub (Atwood 1992; Mock 2004). The potential spatial distributions are seen in the spatial distribution maps of both species. The spatial distributions are largely contained within each other; it appears that the coastal cactus wren is more contained with the coastal California gnatcatcher's spatial distribution on the Base.

The local geographies of both the coastal cactus wren and the coastal California gnatcatcher on MCB Camp Pendleton are affected not only by the chosen elements (e.g., vegetation, terrain, and climate) but also by a multitude of other physical attributes within their environment as well as significant anthropogenic influences such as fire. Information gained in this research has illustrated the potential linkage of both species in terms of their habitat and spatial distribution on the Base. The coastal California gnatcatcher spatial distribution could serve to be used as a reference to verify the distribution of the coastal cactus wren because of their overlap in habitat characteristics. This research also highlighted the important use that geographic methods can be used in avian conservation efforts.

STUDY LIMITATIONS

Fieldwork was conducted in late spring of 2009 to collect presence data for the coastal cactus wren. No observations were documented for the coastal cactus wren. The aim of this initial fieldwork was to obtain the most recent presence data to be used in the species distribution modeling. To validate historic presence locations, more fieldwork was conducted in early spring of 2010. Both coastal cactus wrens and coastal California gnatcatchers were observed and heard at some of the core habitat areas. The failure to observe coastal cactus wrens during the initial field efforts could have been attributed to many factors including weather conditions (e.g., drought) or the ability of the species to disperse.

Coastal cactus wrens depend on coastal cholla and coastal prickly pear cactus for their survival. This research could not identify cactus patches from the landscape analysis, species distribution modeling, or the habitat suitability analysis. The scale of this research was executed through a coarse spatial scale; thus, the individual cactus could not be identified. To overcome the limitation site visits were conducted in reference to the identification of core habitat areas and their availability of cactus in the core habitat areas.

Previous research suggested that landscape metric calculation has some inherent limitations (McGarigal and Cushman 2002). Area metrics (e.g., the percentage of like adjacencies) are affected by the scale of investigation (McGarigal and others 2002). This limitation should be regarded in terms of how the area metrics are being used and must be weighted in relation to the organism under investigation (McGarigal and others 2002). The resolution of the investigation study area is coarse; therefore, the results from the landscape analysis should be interpreted cautiously. The choice of metrics should reflect the hypothesis and research questions about the observed landscape pattern and the constraints or processes that are creating that pattern (McGarigal and others 2002).

Several criticisms have arisen from previous research in regards to presence-only species distribution modeling (Phillips, Anderson, and Schapire 2006; Franklin and others 2009). A main issue is that occurrence locations may be biased due to the collection method (e.g., survey route, close to the transportation network) (Phillips, Anderson, and Schapire 2006). This limitation was examined by viewing the presence data for both species on the Base. Most data collected in this study came from Base biologists; it was understood that their methods were of less bias due to their professional backgrounds. A major criticism in the overlay approach in habitat suitability analysis is related to using inappropriate methods for standardizing suitability indices/maps and unverified assumptions of independence among the suitability criteria (Makczewski 2004). This criticism was recognized when standardizing of the suitability indices. The choice of standardization of suitability indices were based upon the literature of habitat requirements for both species.

Another aspect important to landscape analysis, habitat suitability analysis and species distribution are the dependency on scale (extent and grain). The scale of a study affects patterns found in the landscape (Wiens 1989). The selection of the appropriate scale for a study is influenced by either the organism or the scale at which the landscape patterns are apparent (Mayer and Cameron 2003). A limitation that can arise is if the resolution is coarser than the level at which the species perceives the landscape, this can obscure important habitat relationships between the species and their environment (Mayer and Cameron 2003). This study used a broad scale (coarse grain and small extent) in the landscape analysis, habitat suitability analysis, and species distribution modeling. A coarse scale is appropriate for correlative modeling (species distribution modeling) (Wiens 1989). Mayer and Cameron found that studies on birds are often studied through larger grain sizes (2003). The real-world data used in the study was limited by scale of the available data provided by the Marine Corps.

A limitation that arose came during the interpretation of the results from the species distribution modeling. The variables that were found to be significant for both the coastal cactus wren and the coastal California gnatcatcher models were elevation. Elevation may play a role in their spatial distribution but understanding the species known habitat requirements it should not be the most significant. Vegetation, more specifically coastal sage scrub, should play the largest significant role in the determination of their spatial distribution. The limitation arises from the quality of the vegetation data that was provided by the Base; this limitation was a delimitation of the study.

The vegetation used in this study was created in 2003; several major fires have affected the Base, as a result, the vegetation may have been altered significantly. The resolution of the data could have influenced the results of the modeling efforts and the quality of the elevation data may have been of a better quality thus their variable contribution was higher. The methods used in the study were considered correct; however, the quality of the data may dramatically influence the results from the methods. This highlights the importance of high quality of data and the problem in acquiring high quality data.

RECOMMENDATIONS

Recommendations are given, in response to my findings from this research, to Marine Corps Base Camp Pendleton in efforts to conserve these species on the Base and to support the regional conservation efforts in southern California. The purpose is to inform the MCB Camp Pendleton officials about the efforts that they can contribute to the conservation of both the coastal cactus wren and the coastal California gnatcatcher on the Base.

Core habitat areas were delineated for the coastal cactus wren and the coastal California gnatcatcher. These core habitat areas could be used for conservation of habitat for the coastal cactus wren and the coastal California gnatcatcher on MCB Camp Pendleton. However, conserving the entire recommended habitat (e.g., the eight core habitat areas) is not always a feasible action due to the priorities of the U.S. Marine Corps and MCB Camp Pendleton. If habitat is maintained on the Base, there is a high potential benefit for the Marine Corps in terms of public relations and training activities on the Base. By maintaining habitat for conservation, a positive perception may be given towards the Marine Corps for their conservation activities by environmental organizations (e.g., The Nature Conservancy) and federal agencies (e.g., USFWS). The maintained habitat will allow the coastal cactus wren, the coastal California gnatcatcher, and other species that inhabit the coastal sage scrub to persist, which could mitigate possible future legal action, pertaining to these species and their habitat.

The conservation of habitat on training areas has the potential to provide realistic training opportunities for the Marine Corps (Gorsira, Belfit, and Cantrell 1996; Benton, Ripley, and Powledge 2008). Conserving habitat for combat training has resulted in the retention of habitat that supports a variety of threatened and endangered species throughout military installations across the United States (e.g., Army Base, Fort Bragg, North Carolina and the red-cocked woodpecker (*Piciodes borealis*)) (Gorsira, Belfit, and Cantrell 1996). Intact coastal sage scrub can provide the Marine Corps with good training exercises in concealment and camouflage because the existing vegetation is not tall enough to hide individuals or vehicles (MCB Camp Pendleton 2007).

Habitat restoration and invasive species control should be considered if possible in the core habitat areas. Restoration will help to establish a healthier coastal sage ecosystem allowing all species to persist. Restoration of habitat would also facilitate more enhanced availability and longevity of military training areas. Restored habitat would have less erosion potential, which could inhibit training by limiting access by transportation (e.g., tank and humvee access). Core habitat areas three, six, and eight would be ideal sites for restoration of habitat. Habitat restoration would not only help the status of both species but also would benefit other coastal sage scrub species (Nagel and Pavelka 2006).

Fire management would be encouraged in these core habitat areas. The habitat suitability analysis illustrated the significant influence that fire has on the total vegetation on the Base. Many of the core habitat areas have not been significantly impacted by fires since the 1970s and 1980s. If the core habitat areas are managed in terms of fire frequency, the retention of habitat would decrease the potential of new invasive species spread, and encourage the growth of cactus species.

Many of the core habitat areas are within military housing areas (e.g., San Onofre, De Luz Homes and O'Neill Heights Housing Communities). Community outreach for coastal sage scrub conservation could be initiated in the military housing areas. These housing areas are ideal locations for conservation education programs because many are centrally located within or surrounding the habitat areas. The creation of education programs that focus on some or all of the core habitat areas could facilitate community (both civilian and military personnel) involvement in potential restoration efforts of some sites, such as weed abatement and trash removal. This would highlight the beneficial role the Marine Corps has in environmental issues, and could be a positive environmental public relation campaign.

The situation for the coastal cactus wren is significantly more complicated due to limited knowledge about the species. I would encourage more surveys of the coastal cactus wren to gain a better understanding of their demography, dispersion behavior, and habitat requirements. Detailed cactus surveys would be beneficial to understand the distribution and abundance of cactus in the landscape. Mapping cactus patches would help in understanding the microhabitat characteristics for the coastal cactus wren. Mapping cactus would give us a better understanding of the spatial distribution of the cactus and cactus abundance on the Base.

The core habitats that were delineated would provide useful study areas for the coastal cactus wren as well as the coastal California gnatcatcher. The core habitat areas are diverse and are located on different locations throughout the Base. More information in regards to the coastal cactus wren will help to obtain more insight upon the potential association with the coastal California gnatcatcher. The regional management direction for this species in southern California is leading towards the potential translocation of the coastal cactus wren throughout their range in southern California. Before translocation can be implemented, more information needs to be known about the bird, because inbreeding could occur in these isolated populations.

CONCLUSIONS

Mapping species distribution is a key issue in ecology and conservation (Brotons and others 2004). Conservation management plans for focal species at risk often rely on accurate knowledge of where species are located. In this study, this critical issue is addressed through examining the local geographies of the coastal cactus wren and the coastal California gnatcatcher populations within the boundary of Marine Corps Base Camp Pendleton.
The potential linkage of the coastal cactus wren and the coastal California gnatcatcher in terms of their habitat may assist in their management (e.g., conservation efforts and habitat restoration) on the Base and regionally in southern California. The use of geographic methods offers another direction in understanding species habitat characteristics and spatial distribution.

The status of the coastal cactus wren and coastal California gnatcatcher in southern California is of concern. This concern is heightened by the recent fire events and changes in climate patterns (e.g., drought) in southern California. This concern could potentially lead to another attempt to list the coastal cactus wren as a threatened species like the coastal California gnatcatcher. More research is needed to address the situation with the coastal cactus wren. Such research would help to facilitate better management practices, or provide evidence to list the coastal cactus wren as a threatened species. More research may find that the coastal cactus wren as another umbrella species, like the coastal California gnatcatcher, for coastal sage scrub conservation in southern California (Fleury, Mock, and O'Leary 1998).

Delineation of a local geography for both the coastal cactus wren and the coastal California provided important information in regards to their habitat requirements and their spatial distribution on Marine Corps Base Camp Pendleton, California. Landscape characteristics, specific habitat requirements, and identification of core habitat areas provided important insights to these two avian populations in terms of supporting a potential linkage in their distribution and habitat requirements. A geographic approach provided a different perspective for avian conservation effort by utilizing geographic methods.

The use of geography in avian conservation offers a different viewpoint in understanding the relationship that avian species have with their environment. The combination of geographic methods and traditional biological methods provides a diverse approach to avian conservation by incorporating many different perspectives to answer research objectives and questions. Geography enables a spatial perspective that may provide essential information for not only avian conservation but for conservation efforts in general.

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APPENDIX A

RECLASSIFIED VARIABLES

Table 21. Reclassification of Aspect

10	28.729409-239.666646
7	239.666646-277.890173
6	277.890173-317.529385
5	317.529385-359.999969
2	-1-28.729409
1	-1

Note: The reclassification of aspect was based on the literature on the coastal cactus wren, with south- southwestern slopes being favorable for cactus growth.

Table 22. Reclassification of Climate Zone

3	Coastal, Maritime
1	Interior

Note: The reclassification of climate zones was based on the literature for the coastal California gnatcatcher; the species is known to occur in coastal and maritime areas in southern California.

Table 23. Reclassification of Precipitation

4	13
3	13.01-13.968627
2	13.9686271-17.992157
1	17.9921571-22.5

Note: The reclassification of precipitation was based on the literature on the coastal California gnatcatcher and their reproductive cycle. There is a high correlation between precipitation and the number of eggs laid.

Table 24. Reclassification of Year of Last Fire

10	1972-1989
7	1990-1999
5	2000-2002
2	2003-2005
1	2006-2008

Note: The reclassification of year of last fire was constructed so older fires would have the highest classification, 10, while more recent fires would have a lower classification, one.

Table 25. Reclassification of Fire Count

10	1-4
7	5-9
4	10-19
2	20-23
1	24-28

Note: The reclassification of fire count was constructed so smaller fire count would have a higher classification, while numerous fires would have a lower classification.

Table 26. Reclassification of Slope for the Coastal Cactus Wren

10	36.004151- 42.519188
9	15.087454 – 87.438652
8	0-15.087454

Note: The reclassification of slope was based on the literature on the coastal cactus wren, with their nests found on areas with zero to 45 percent slope gradient.

Table 27. Reclassification of Slope for the California Gnatcatcher

9	0-3.7771863
8	3.7718631-9.25821
7	9.258211-15.087454
6	15.0874541-20.5738
5	20.57381-25.717251
4	25.7172511-30.860701
3	30.8607011-36.004151
2	36.0041511-42.519188
1	42.5191881-87.438652

Note: The reclassification of slope was based on the literature on the coastal California gnatcatcher, with nests found on areas with less than 40 percent slope gradient.

Table 28. Reclassification of Vegetation

10	Diegan Coastal Sage Scrub, Coastal Sage Scrub
9	Coastal Sage-Chaparral Scrub, Southern Coastal Bluff Scrub
8	Southern Mixed Chaparral
7	Southern Riparian Scrub, Riparian Scrub, Scrub Oak Chaparral
6	Valley Needleland Grassland, Grassland, Sycamore Grassland, Grass-forb Mix
5	General Agriculture
4	Distributed Habitat, Non-native Vegetation, Non-native Grassland, Exotic-other, Arundo, Tamarisk
3	Dense Engelmann Oak Woodland, Coast Live Oak Woodland, Riparian Woodland, Mixed Woodland, Southern Sycamore–Alder, Eucalyptus Woodland, Mixed Willow Exotic, Open Engelmann Oak Woodland
2	Coastal and Valley Freshland Marsh, Open Water, Open Gravel, Coastal Salt Marsh, Freshwater Marsh, Southern Foredune, Riparian Forests, Southern Coastal Salt Marsh, Beach, Disturbed Wetland, Riparian and Estuary
1	Urban and Developed, Distrusted and Developed Lands

Note: The reclassification of vegetation was based on the literature on the coastal cactus wren and the coastal California gnatcatcher; both species are coastal sage scrub obligates.

APPENDIX B

WEIGHTED VARIABLES

Table 29. Coastal Cactus Wren Habitat Suitability Analysis Variables

Vegetation Reclass	65%
Aspect Reclass	25%
Slope Reclass	10%

Notes: The weighted percent influence total equals 100 percent. Vegetation was weighted the highest based on the habitat requirements of the species. Aspect has the second highest weight because cactus species growth favorable on south-southwestern slopes.

Table 30. Coastal Cactus Wren Habitat Suitability Analysis including Fire Variables

Vegetation Reclass	36%
Aspect Reclass	16%
Slope Reclass	16%
Fire Count Reclass	16%
Year of Last Fire Reclass	16%

Notes: The weighted percent influence total equals 100 percent. Vegetation was weighted the highest based on the habitat requirements of the species. The other variables were equally weighted due the weighting criteria in the weighted overlay technique.

Table 31. Coastal California Gnatcatcher Habitat Suitability Analysis Variables

Vegetation Reclass	56%
Climate Zone Reclass	5%
Slope Reclass	10%
Precipitation Reclass	20%

Note: The weighted percent influence total equals 100 percent. Vegetation was weighted the highest based on the habitat requirements on the species. Precipitation was the second highest weighted variable because annual precipitation influences the reproduction of the coastal California gnatcatcher.

Table 32. Coastal California Gnatcatcher Habitat Suitability Analysis including Fire Variables

Vegetation Reclass	20%
Climate Zone Reclass	16%
Slope Reclass	16%
Precipitation Reclass	16%
Year of Last Fire Reclass	16%
Fire Count Reclass	16%

Notes: The weighted percent influence total equals 100 percent. Vegetation was weighted the highest based on the habitat requirements of the species. The other variables were equally weighted due the weighting criteria in the weighted overlay technique.

Table 33. Both Species Habitat Suitability Analysis Variables

Vegetation Reclass	36%
Climate Zone Reclass	16%
Slope Reclass	16%
Precipitation Reclass	16%
Aspect Reclass	16%

Notes: The weighted percent influence total equals 100 percent. Vegetation was weighted the highest based on the habitat requirements of both species. The other variables were equally weighted due the weighting criteria in the weighted overlay technique.

Table 34. Both Species Habitat Suitability Analysis including Fire Variables

Vegetation Reclass	20%
Climate Zone Reclass	12%
Slope Reclass	12%
Precipitation Reclass	12%
Aspect Reclass	12%
Year of Last Fire Reclass	16%
Fire Count Reclass	16%

Notes: The weighted percent influence total equals 100 percent. Vegetation was weighted the highest based on the habitat requirements of both species. The fire variables were weighted high to reflect the impact that fire is known to have on both species populations on the Base.

APPENDIX C

HABITAT SUITABILIY MAPS

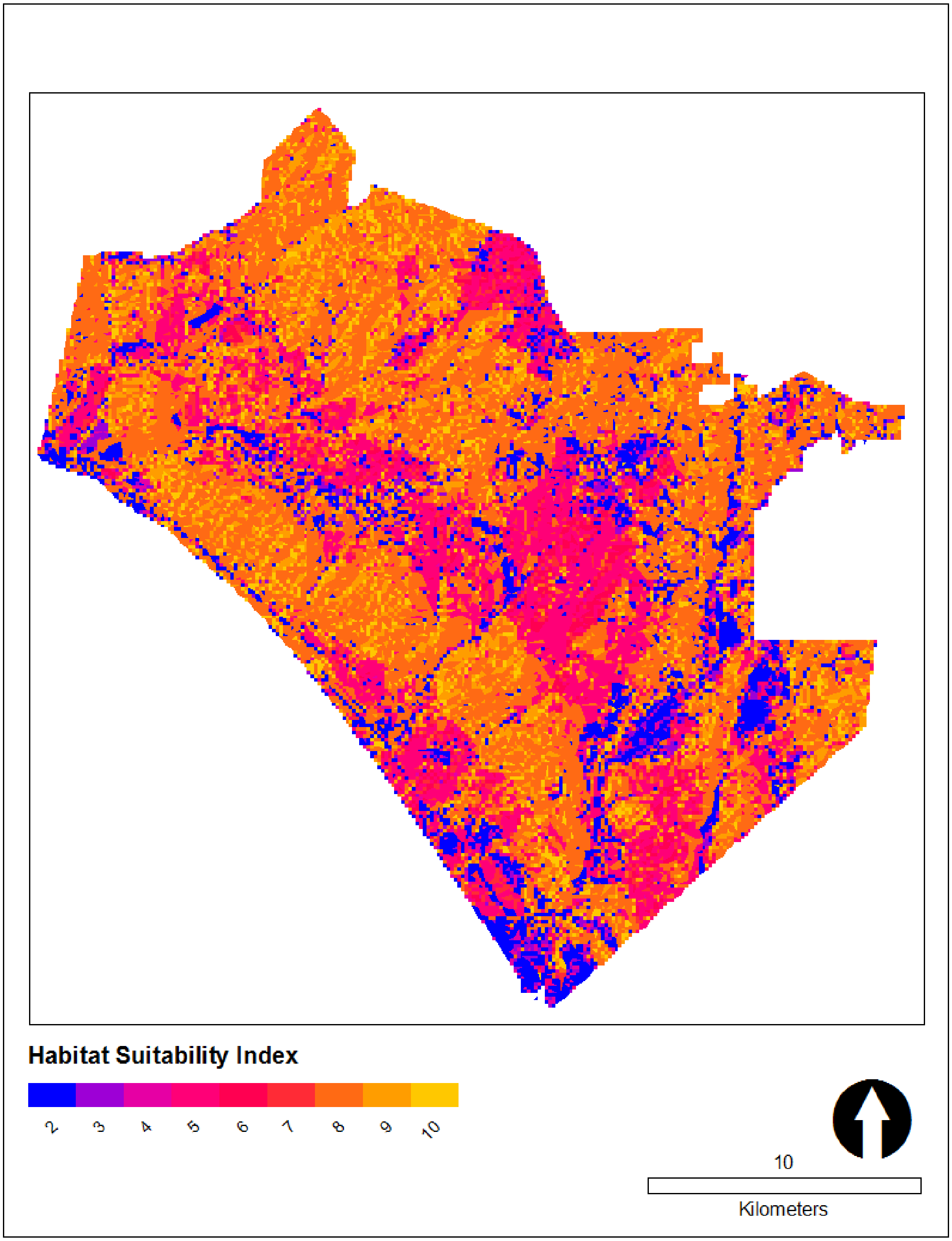

Figure 25. Habitat suitability map for the coastal cactus wren.

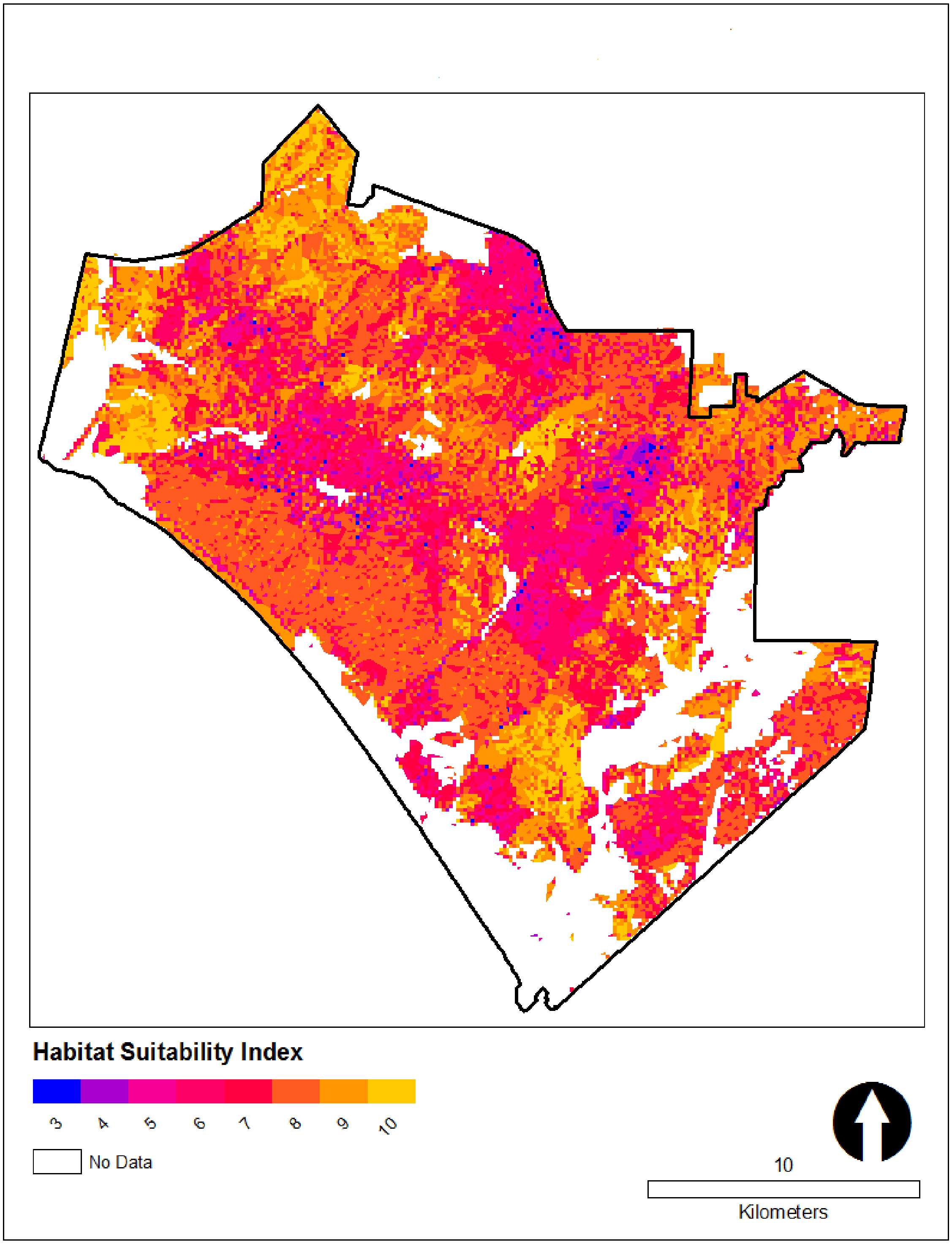

Figure 26. Habitat suitability analysis map for the coastal cactus wren including fire variables.

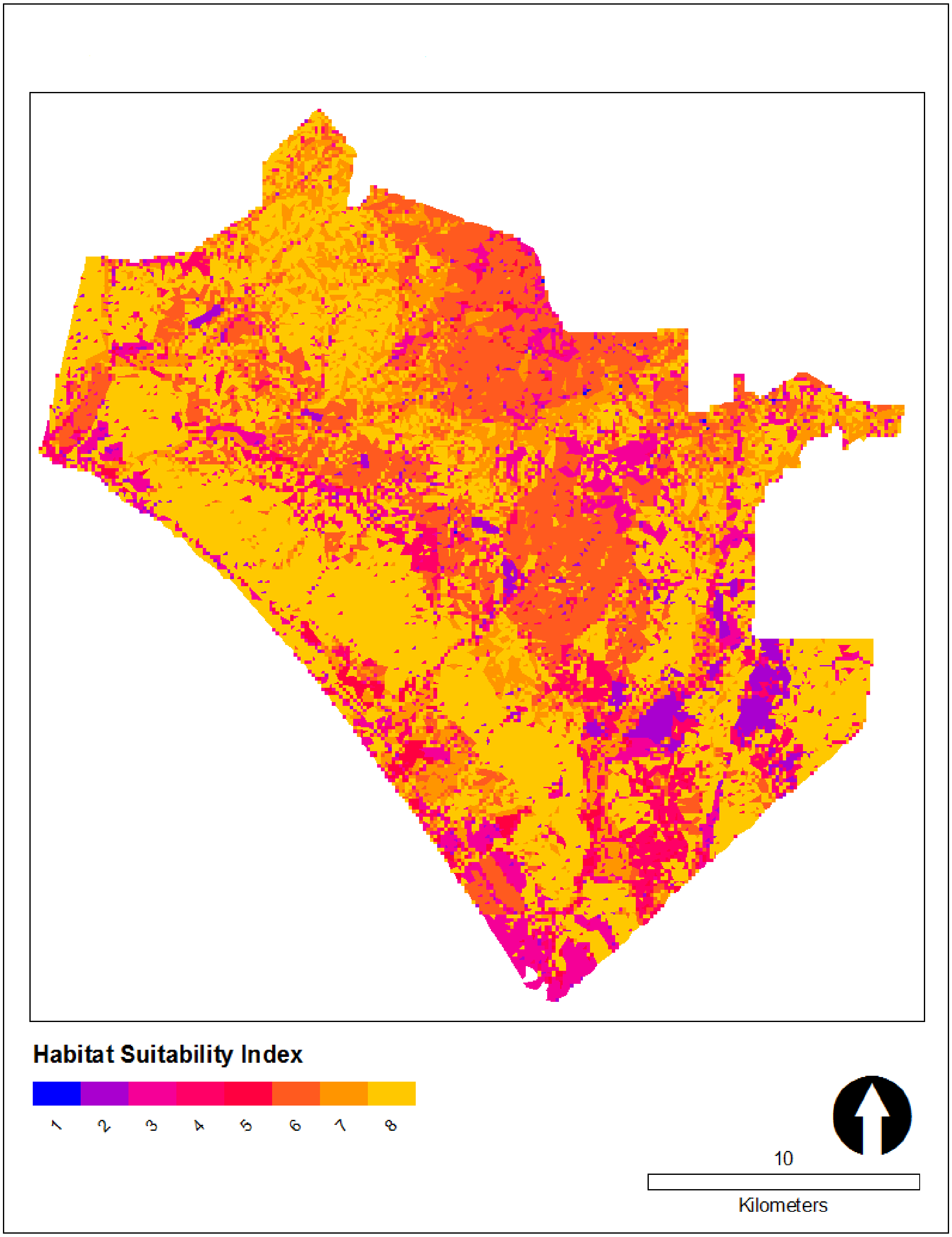

Figure 27. Habitat suitability map for the coastal California gnatcatcher.

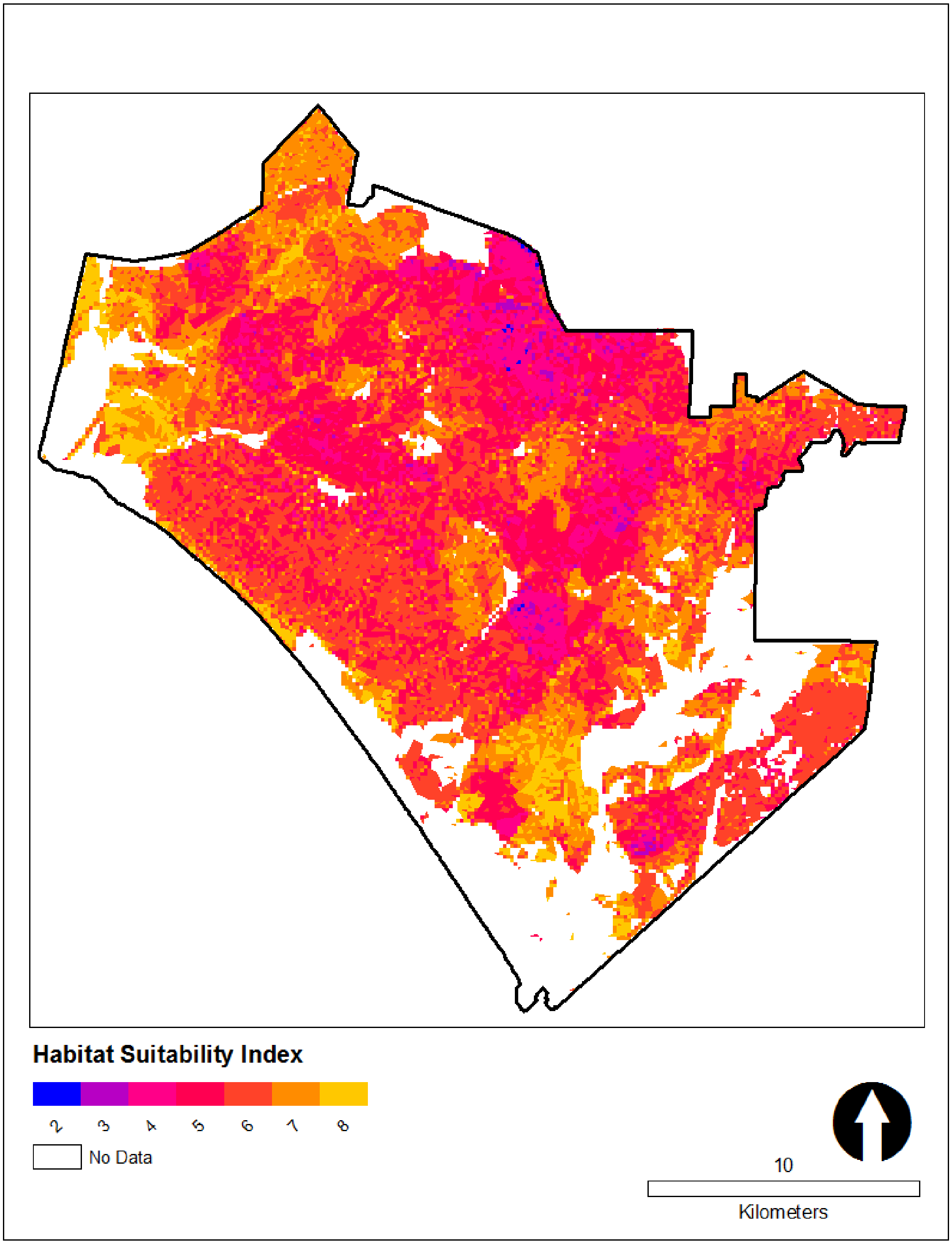

Figure 28. Habitat suitability map for the coastal California gnatcatcher including fire variables.

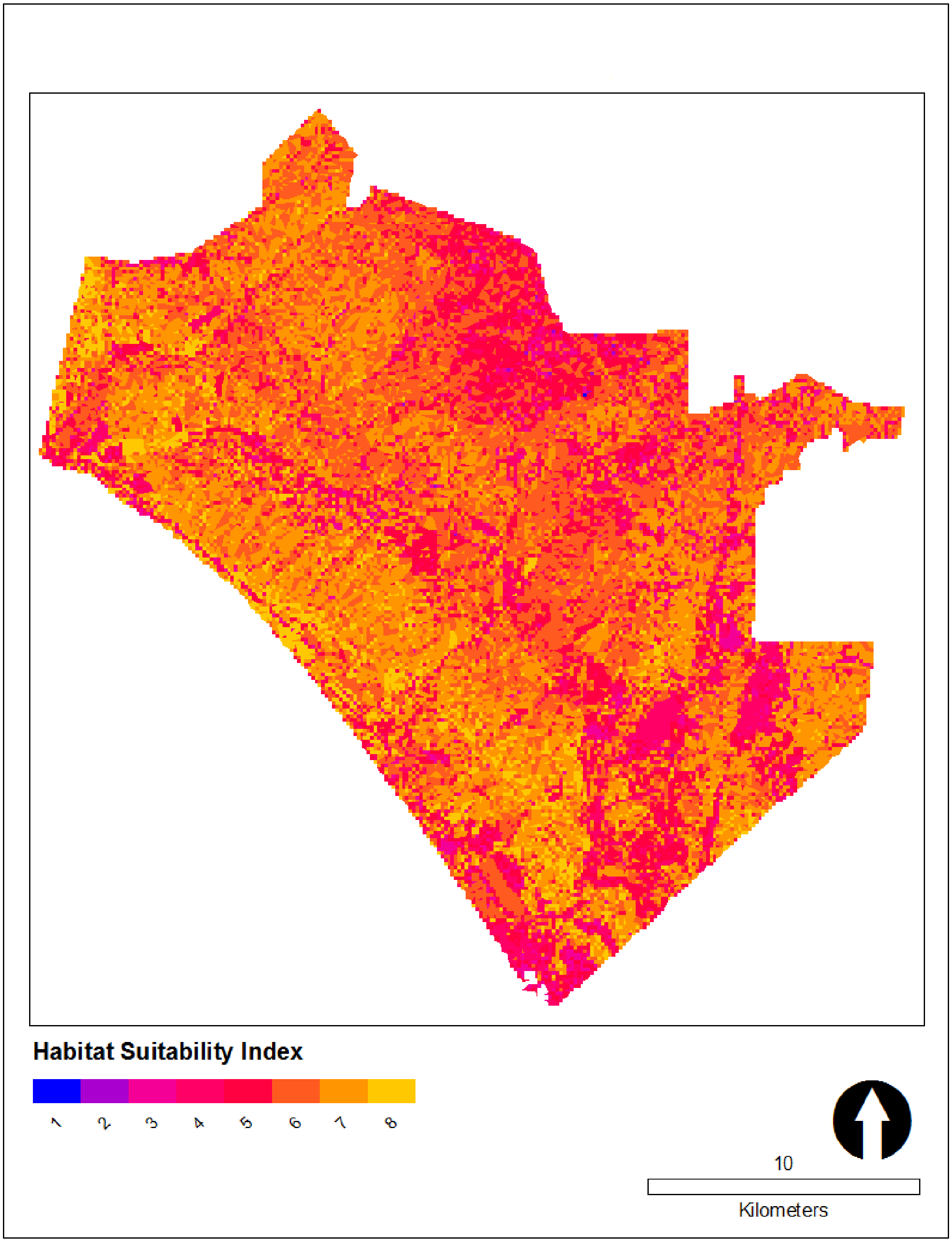

Figure 29. Habitat suitability map for the coastal cactus wren and the coastal California gnatcatcher.

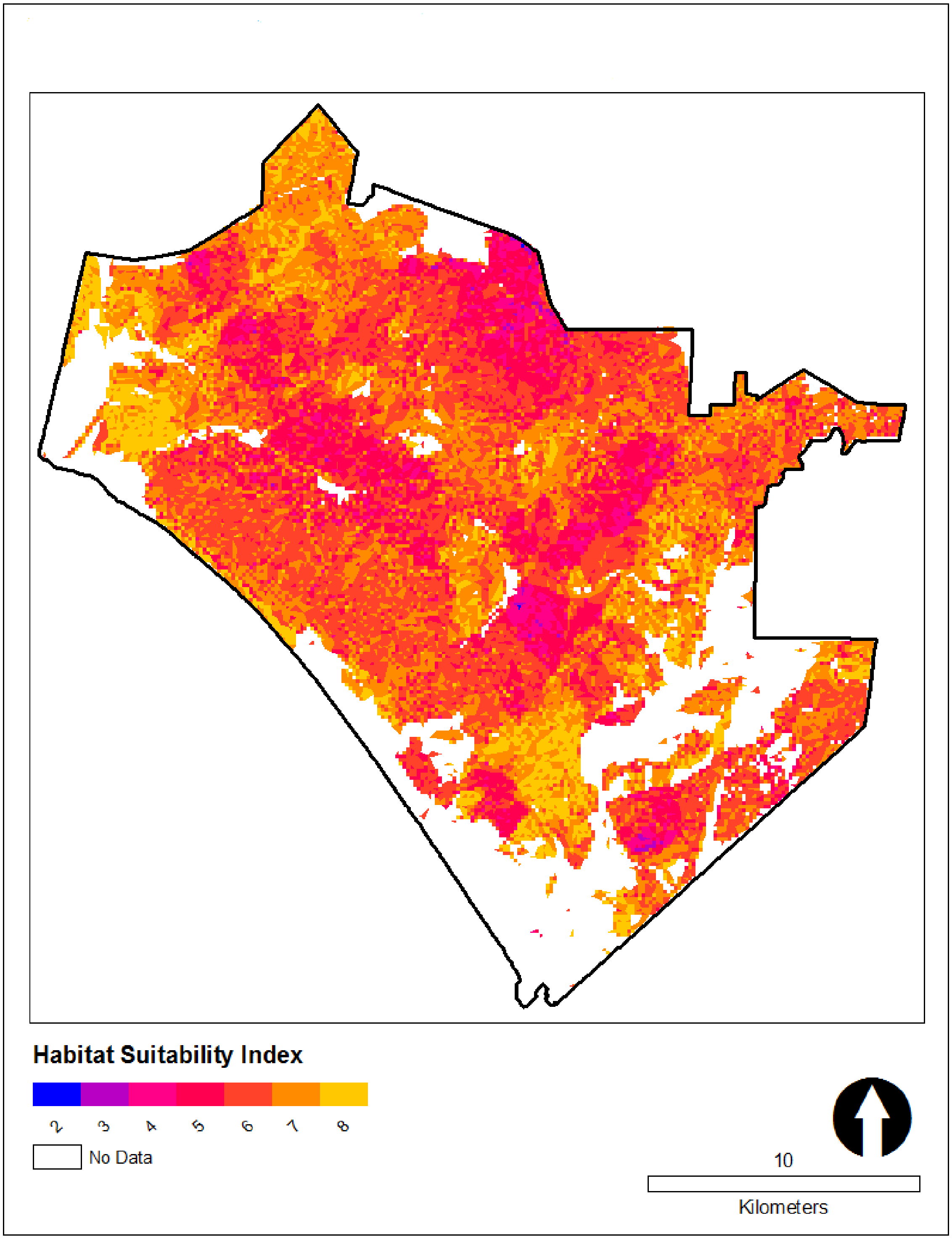

Figure 30. Habitat suitability map for the coastal cactus wren and the coastal California gnatcatcher including fire variables.

APPENDIX D

CORE HABITAT AREAS

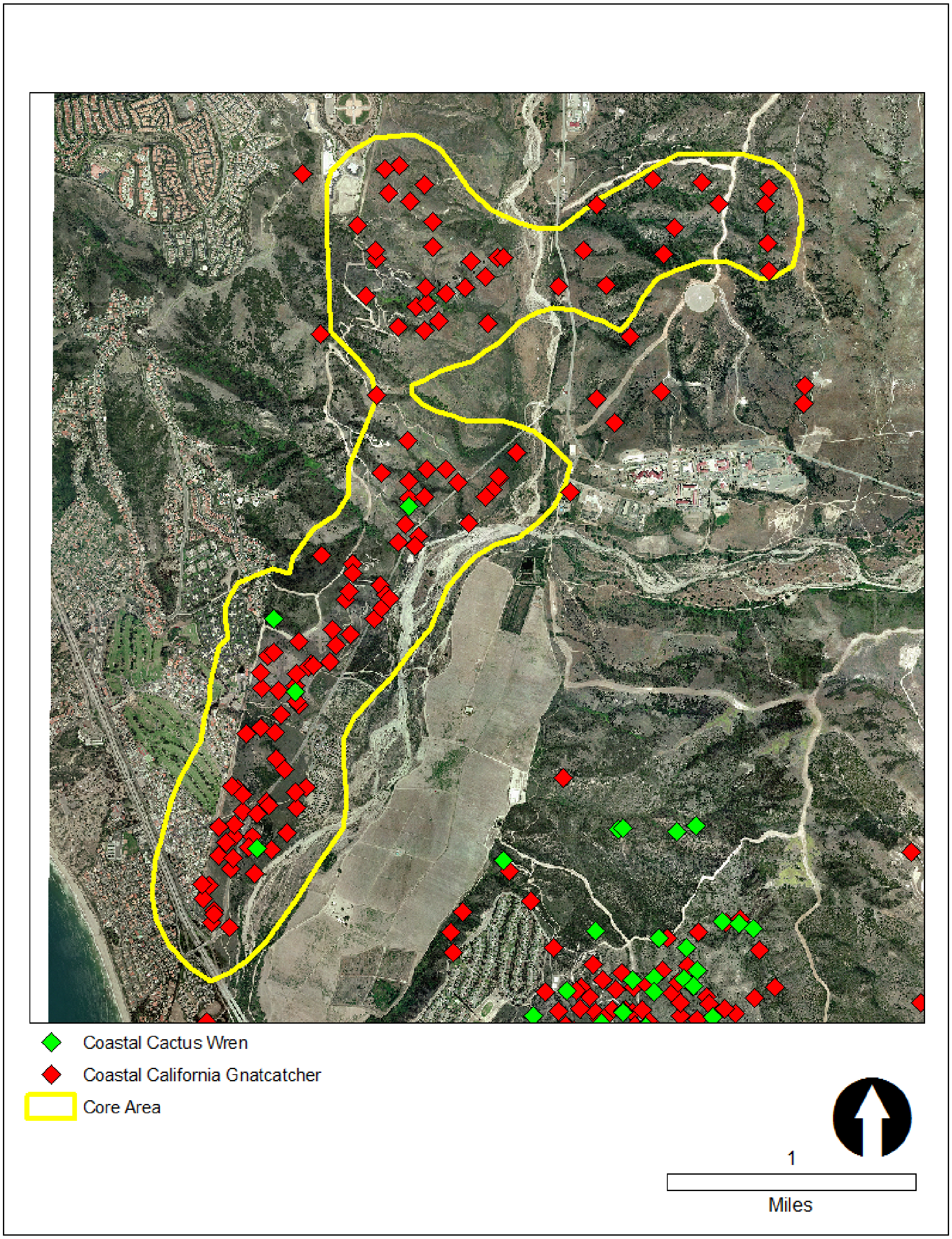

Figure 31. Core habitat area 1 map.

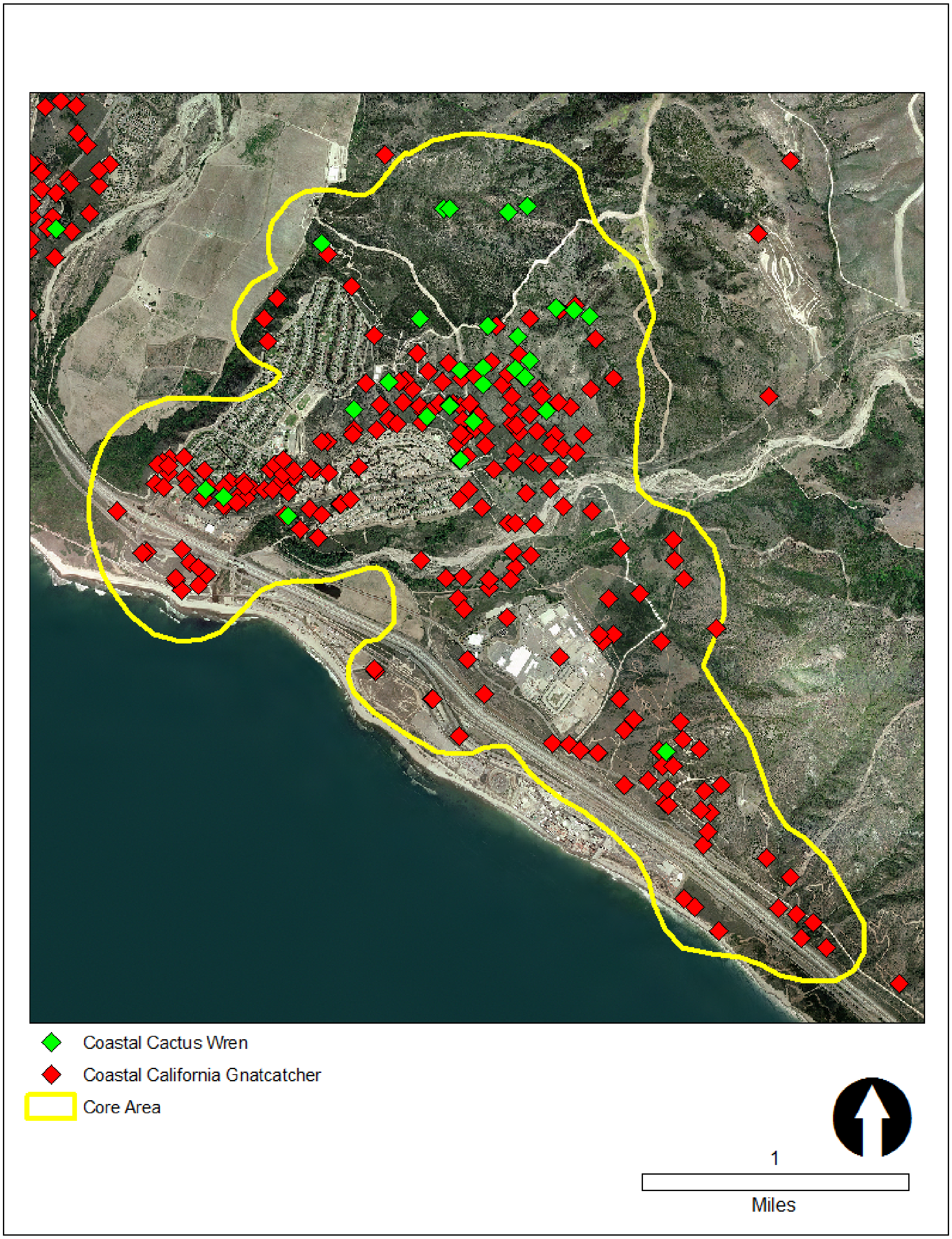

Figure 32. Core habitat area 2 map.

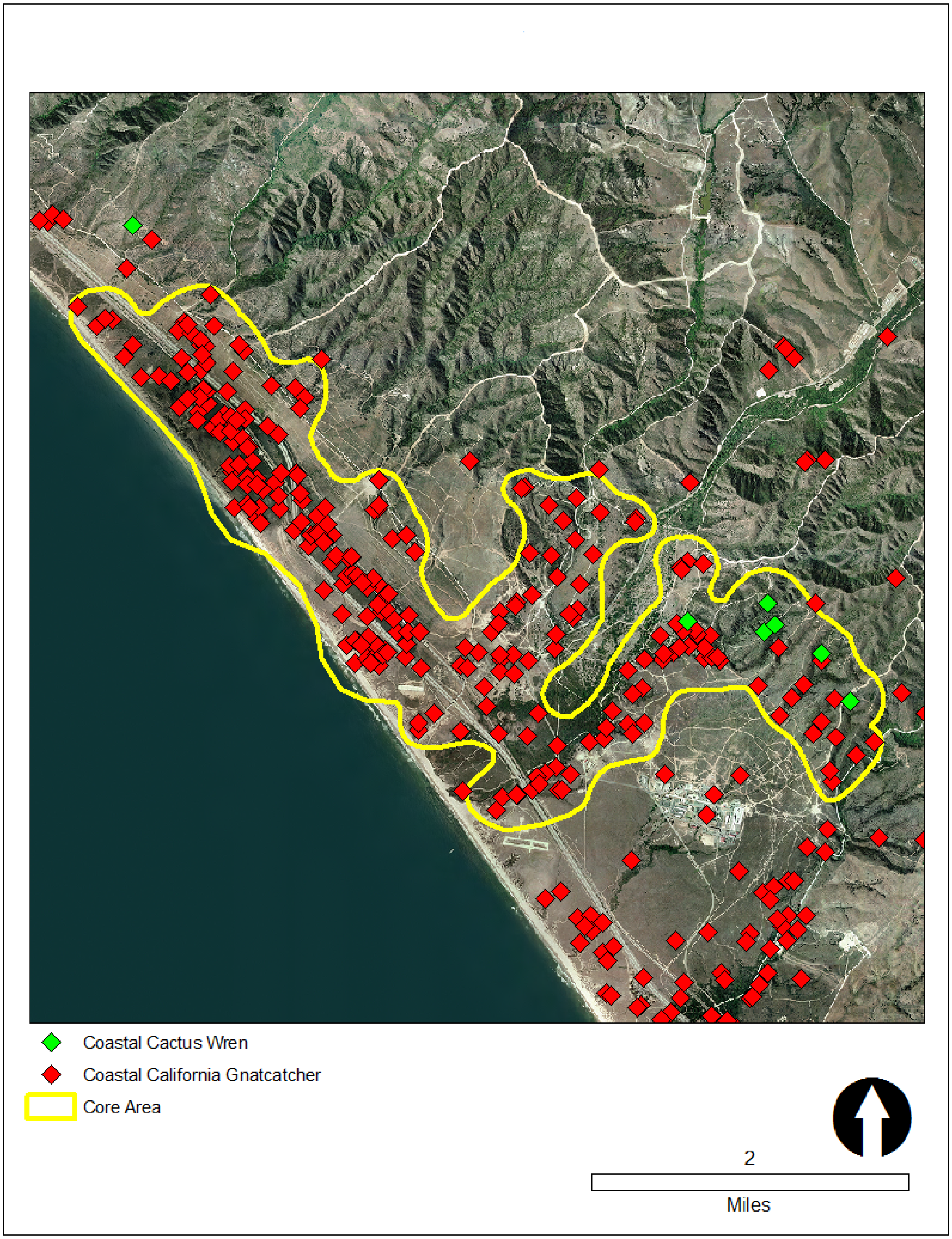

Figure 33. Core habitat area 3 map.

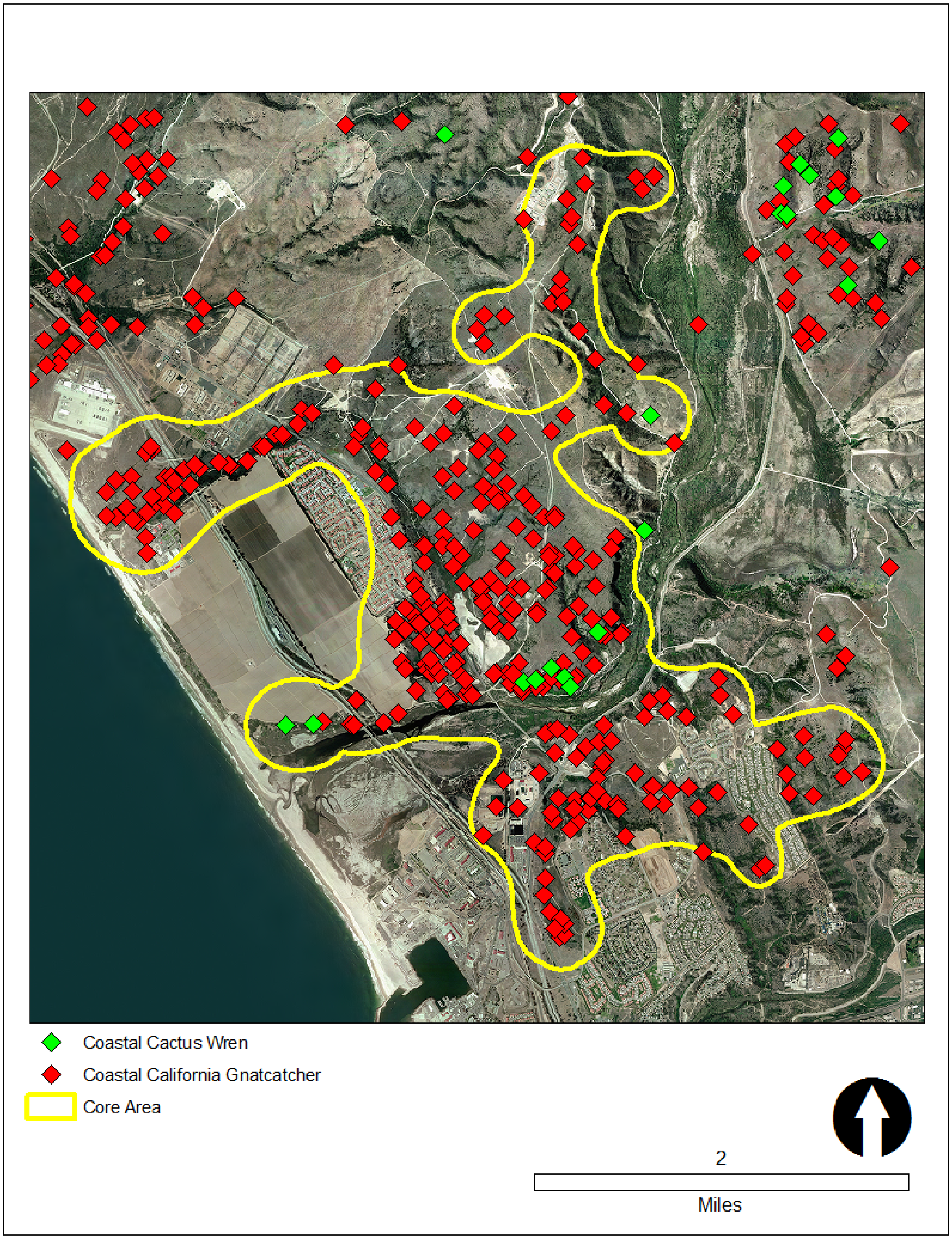

Figure 34. Core habitat area 4 map.

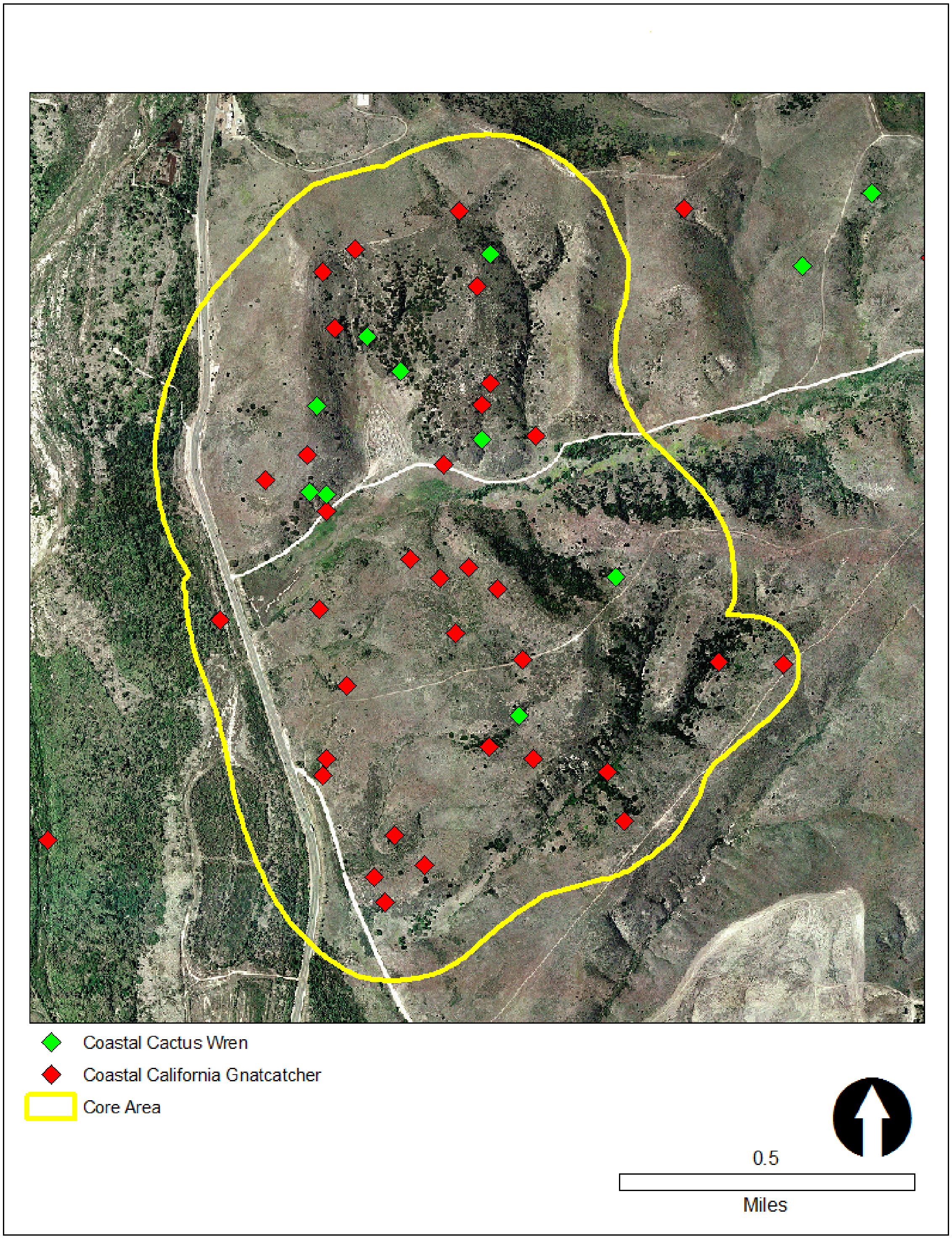

Figure 35. Core habitat area 5 map.

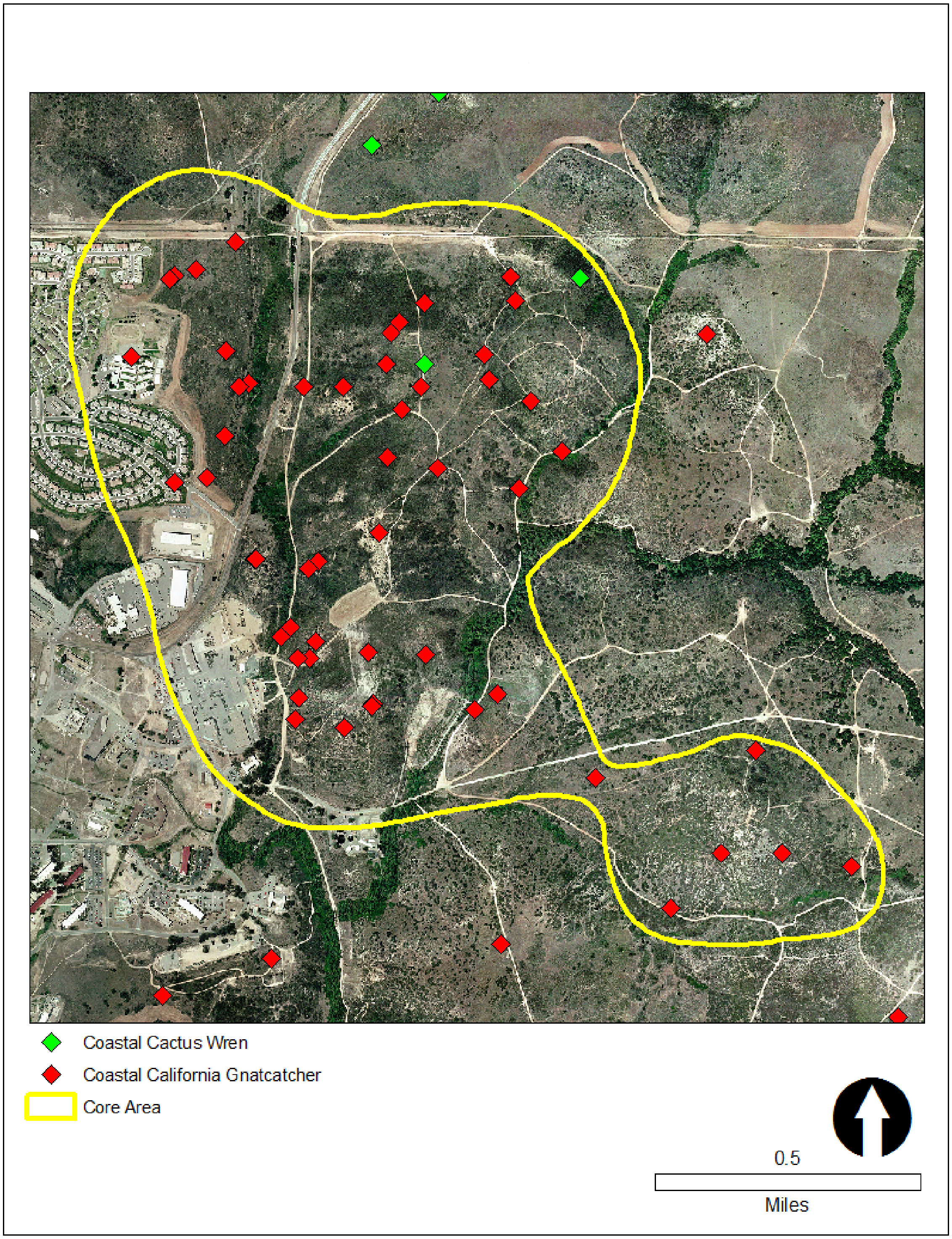

Figure 36. Core habitat area 6 map.

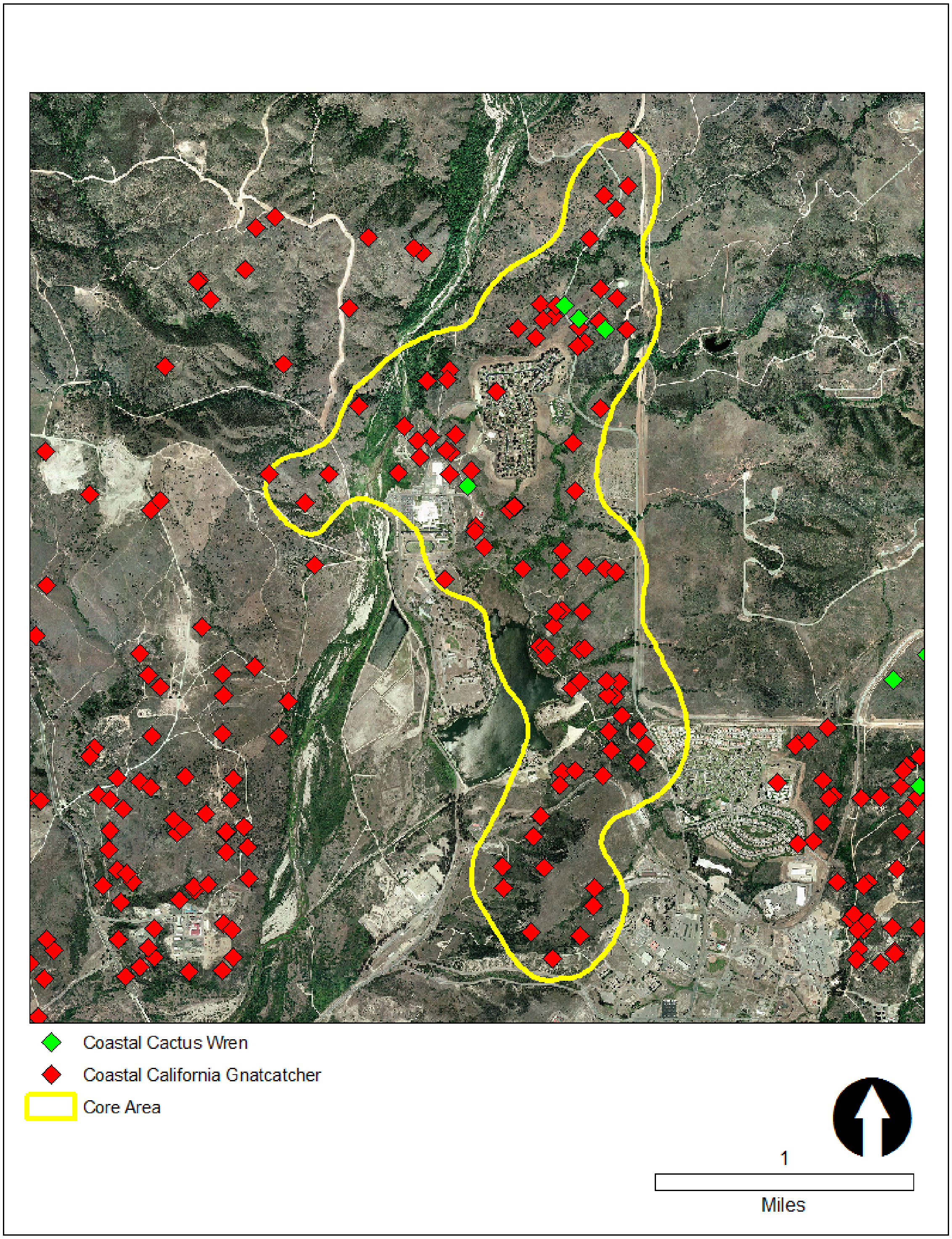

Figure 37. Core habitat area 7 map.

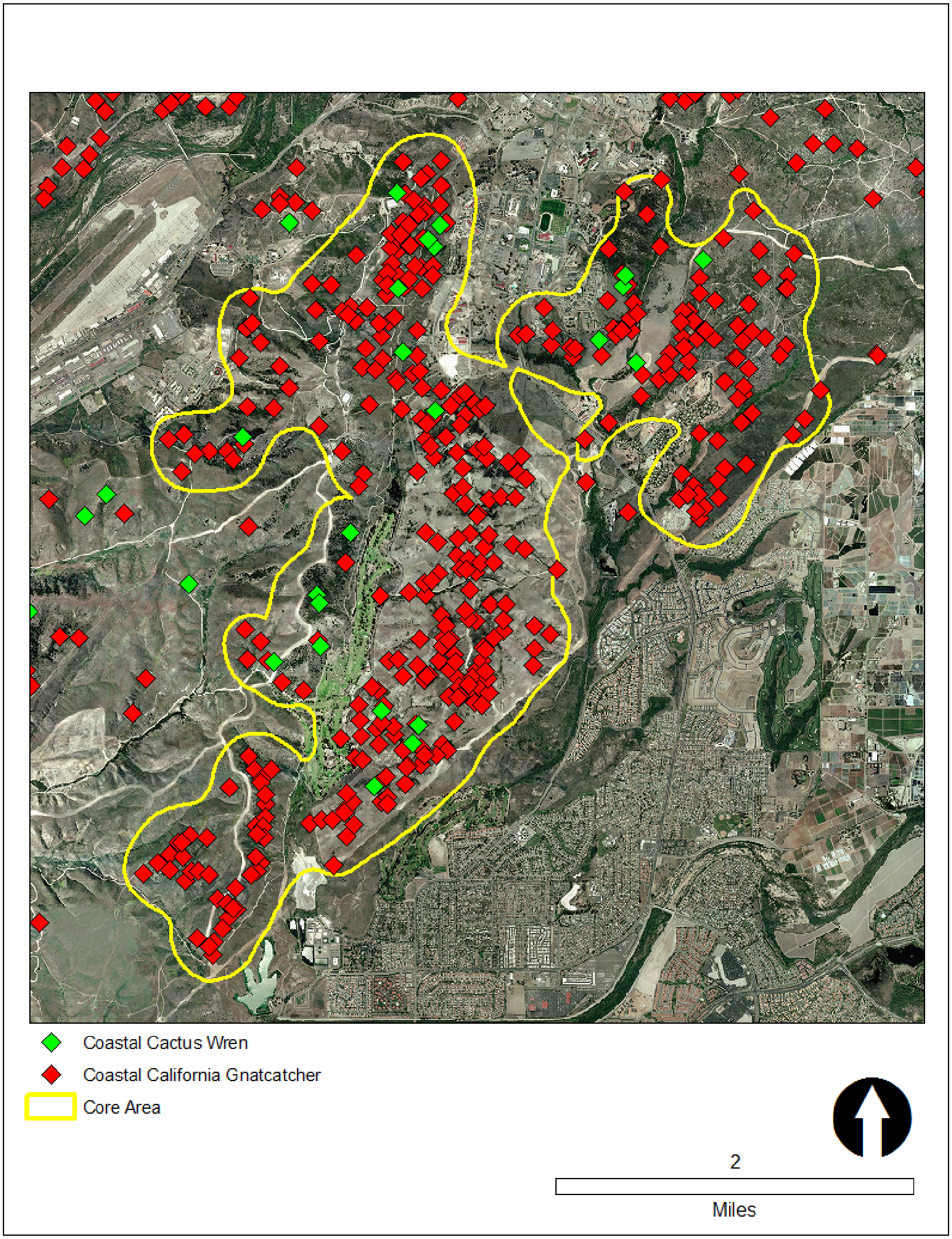

Figure 38. Core habitat area 8 map.