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Development and utilization of a landscape scale GIS model to identify potential bat habitat features in the Desert Southwest: Identification and Status of Sensitive Bat Habitat Resources

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Development and utilization of a landscape scale GIS model to identify potential bat habitat features: Identification and Status of Sensitive Bat Habitat Resources

Martin D. Piorkowski (*Arizona Game and Fish Department;* 5000 *W. Carefree Highway Phoenix, AZ 85086*)

Dan P. Sturla (*Arizona Game and Fish Department;* 5000 *W. Carefree Highway Phoenix, AZ 85086*)

Ronald Mixan (*Arizona Game and Fish Department;* 5000 *W. Carefree Highway Phoenix, AZ 85086*)

Joel M. Diamond PhD (*Arizona Game and Fish Department;* 5000 *W. Carefree Highway Phoenix, AZ 85086*)

R. Nathan Gwinn (*Arizona Game and Fish Department;* 5000 *W. Carefree Highway Phoenix, AZ 85086*)

mpiorkowski@azgfd.gov, dsturla@azgfd.gov, rmixan@azgfd.gov, jdiamond@azgfd.gov, rgwinn@azgfd.gov

ABSTRACT

In 2006, the Department of Defense (DOD) signed two agreements emphasizing the need for the conservation of bat species on DoD lands. With increasing military activity across installations in southwestern Arizona, there is an increase in disturbance near mines and caves that may be destructive to roosting bat populations. It is therefore imperative that roost site locations be identified to avoid potential conflicts between bats and the military mission. By collecting data and combining the efforts of previous work within our study area, we are able to present data on features and potential bat roosts on DoD lands. We implemented a sampling design that can be used for future work in these areas and potentially applied across military installations throughout the desert southwest. Our first objective identified 153 potential bat roosts across our study area. From these data we prioritized and revisited bat features (n=46) to determine species specific occupancy and type of roost (i.e., day, night, hibernacula or maternity). Most common across this landscape are various *Myotis* species, pallid bat (*Antrozous pallidus*), California leaf-nosed bat (*Macrotus californicus*), and potentially Townsend's big-eared bat (*Corynorhinus townsendii*) and lesser long-nosed bats (*Leptonycteris curasoae*). Our second objective focused on development of a spatially explicit predictive model to identify high probability areas across this landscape that may harbor bat species testing the null hypothesis that bat roosts are homogeneous across the landscape. The model rejected the null hypothesis in support of a heterogeneous bat roost distribution. This model can be used as a tool to inform resource managers and streamline future surveys to identify potential roosts specifically as it relates to sensitive bat species.

KEYWORDS

Arizona, bat habitat, bat roosts, Desert Southwest, landscape scale, military disturbance, *Macrotus californicus*, *Myotis*

INTRODUCTION

The United States (U.S.) Marine Corps, U.S Air Force and U.S. Army are responsible for the management and environmental compliance of Barry M. Goldwater Range West (BMGR West), Barry M. Goldwater Range East (BMGR East) and Yuma Proving Ground (YPG) respectively (Fig. 1). Continued and future activities on installations require the three branches of the DoD to minimize operational impacts on any federal or state sensitive species, as declines in these species have a potential to prompt listing or delay de-listing under the Endangered Species Act (ESA). Determining the amount of use as well as the temporal and spatial distribution of bat roosts on DoD lands will help develop more cost-effective solutions for wide-scale management and allow for the continuation of training exercises.

Twenty-seven of the 45 bat species in the United States are known to roost in mines, and for several of these species, mines may represent critical habitat (Tuttle and Taylor 1998). The lesser long-nosed bat, Arizona's only endangered bat species (Shull 1988), appears to be heavily dependent on abandoned mines for roosting sites (USFWS 1995). Mines share several characteristics with caves (Tuttle and Taylor 1998) that make them high-quality bat habitat, including stable temperature and humidity, low light levels, and protection from predators. As with caves, certain mine structures may create cold or warm air traps providing appropriate microclimate for roosting bats. Multiple mine entrances may create air flow, which may also affect the variety of microclimates available. Similar to caves, mines may be used as day roosts (i.e., maternity, bachelor, or transitory), night roosts, courtship sites, and hibernacula. However, mines may also be susceptible to greater disturbance than caves due to proximity to roads and increased human activities (Kunz 1982).

The importance of abandoned mines and caves for bats is their potential to provide a variety of roosting sites; (maternity, hibernacula, day, night, and interim roosts Sherwin et al. 2000). Maternity roosts provide a secure location for females to give birth and rear their young throughout the summer season (Humphrey 1975). Hibernacula provide a winter refuge for non-migratory bats (Johnson et al. 1998, Kuenzi et al. 1999, Raesly and Gates 1986). Day roosts are used by non-reproductive individuals of both sexes while night roosts are utilized by all bats, regardless of reproductive status, as a place to rest and to digest their prey between foraging bouts (Lacki et al. 1994, Kerth et al. 2001). Night roosts are generally in different locations than day roosts and are used primarily at dawn and dusk (Anthony et al. 1981). Interim roosts are used in the spring before the young are born and again in the fall before retreating to the hibernacula roost (Dobkin et al. 1995, Twente 1955). Abandoned mines and natural caves may act as all of these roost types (Tuttle and Taylor 1998), thus accurate surveys of bat activity are essential in identifying and preserving these bat roosts.

There are an estimated 80,000 to 100,000 mines in Arizona, but not all mines are equally suitable for bats. Of the Arizona mines surveyed by the Arizona Game and Fish Department Bat Project, about one-third showed evidence of bat use, and approximately 10% appeared to be significant roosts (Hinman and Snow 2003). However, most surveys for this project involved one-time visits to the roosts and may not reflect actual mine usage. P. Brown (Brown-Berry Biological Consulting) has found 75-80% bat use (i.e., bats or guano) in Arizona mines with 10% showing “significant” usage. Knowledge of which factors characterize appropriate roosting habitat is sorely lacking. It is quite possible that many mines that are not currently used by bats could become appropriate roosts if protected from disturbance (Hinman and Snow 2003, AZGFD 2006). Thus, effective prediction models are especially valuable if validated with site visits that determine bat use. Because of low fecundity, high juvenile mortality, and long generational turnover, many bat populations may be vulnerable to human-induced pressures. Entering roosts at sensitive times of the year, camping in or near caves and mines, releasing environmental toxins and destroying roost sites are all human-induced pressures known to be threats to bats (O'Shea et al. 2001). The threat of human disturbance to bats living in mines is similar to the threat of disturbance to cave-roosting bats. Human visitors can intentionally or unintentionally disturb and even cause mortality to roosting bats. As military readiness includes mission activities that may utilize caves and mines for training or are in close proximity to these features, it is important to minimize the impact of these activities on bat roosts in these features. Military activities have the potential to impact the federally listed lesser longed-nosed bat (Shull 1988, Cockrum 1991) observed foraging on military lands and roosting in adjacent federally managed lands (Sidner and Davis 1988). Military activities may additionally affect the pallid bat (*Antrozous pallidus*), California myotis (*Myotis californicus*), cave myotis (*Myotis velifer*), Yuma myotis (*Myotis yumanensis*), Mexican free-tailed bat (*Tadarida brasiliensis*), Townsend's big-eared bat (*Corynorhinus townsendii*) and California leaf-nosed bat (*Macrotus californicus*).

We recognized that the first step in preventing any potential bat and military activity conflicts is to identify where these conflicts may exist. These bat species roost colonially and depend on mines, caves and crevices to provide roost habitat. While bats all utilize mines and caves, they prefer different habitat characteristics such as varying structure and climatic conditions within the feature.

We aimed to identify, map, and describe potential bat roost features on BMGR East, BMGR West and YPG and quantify specific characteristics to inform a spatially explicit model to test the null hypothesis that bat roosts are homogeneously distributed. This model may have application to other geographical areas around the globe and throughout desert regions typical of the southwestern U.S.

MATERIALS AND METHODS

STUDY AREA

Diurnal bat roost surveys were conducted within BMGR East, BMGR West and YPG in southwestern Arizona (Fig. 1). Each installation is divided into sections for aerial systems training, live – fire training and ground maneuvers. The ranges together cover approximately 12,690 km^2 of Sonoran Desert, Lower Colorado River desert scrub. Steep mountain ranges are surrounded by expansive, sparsely vegetated valleys and wide, shallow washes. Dominant vegetation includes creosote bush (*Larrea tridenta*), white bursage (*Ambrosia dumosa*), foothills palo verde (*Parkinsonia microphylla*), mesquite (*Prosopis* spp.), ironwood (*Olneya tesota*) and various cactus species. Survey efforts were focused within the Trigo, Tank and Muggins Mountains on YPG; the Mohawk and Granite Mountains, Crater Range, and White Hills on BMGRE; Mohawk, Gila, Copper, and Tinajas Altas Mountains, and the Wellton Hills on BMGRW.

Barry M. Goldwater Range (BMGR East, BMGR West) - The Barry M. Goldwater Range is located in southwestern Arizona in portions of Yuma, Maricopa, and Pima counties. BMGRW is located entirely in Yuma County; portions of BMGR East are located in each of the three counties. Of the BMGR's 7,017 km^2, about 60 percent is in BMGR East and about 40 percent is on BMGRW. The range is about 214km across on its longest, east-west axis. The BMGR's north-south axes vary in width; at the western end, the north-south axis is about 24 km wide, is generally 29 to 45 km wide through much of the length of the range, and then narrows to about 6 km at its eastern end. (BMGR 2012). The Range is bounded to the south by Mexico and Cabeza Prieta National Wildlife Refuge, to the north by Interstate 8 and a mix of private and public properties, and to the east by the Tohono O'odham Nation and Bureau of Land Management lands. Elevations range from below 61 m on western portions of the range to 1,128 m in the Sand Tank Mountains (BMGR 2012). Temperatures on BMGR can range from below 0 °C to 49 °C, with an average annual rainfall of approximately 12.7 cm (BMGR 2012). The Lower Colorado River Subdivision of the Sonoran Desert is the predominating vegetative community and is characterized by extremely drought-tolerant plant species such as creosote bush, bursage (*Ambrosia spp.*), paloverde (*Parkinsonia spp*.) and cacti (e.g., prickly pear [*Opuntia spp.*], chollas [*Cylindropuntia spp*]. and saguaro [*Carnegiea gigantea*]) (Brown 1994, Marshall et al. 2000). The broad, flat and sparsely vegetated desert plains of BMGR are dissected by numerous incised washes that harbor ironwood, smoketree (*Psorothamnus spinosus*), cat-claw acacia (*Acacia greggii*), mesquite, ocotillo (*Fouquieria splendens*) and numerous shrub species.

Yuma Proving Ground (YPG) - YPG lies within La Paz and Yuma counties near Yuma, Arizona and totals approximately 3,450 km² (YPG 2012). Kofa National Wildlife Refuge is adjacent to YPG for 93 km. Lower Colorado River subdivision of the Sonoran Desert is the predominating vegetative community within YPG. This vegetative community is characterized by extremely drought-tolerant plant species such as creosote bush, bursage, palo verde and cacti(Brown 1994, Olson and Dinerstein 2002). The broad, flat and sparsely vegetated desert plains of YPG are dissected by numerous incised washes that harbor ironwood, smoketree, acacia, mesquite and numerous shrub species. More elevated hills and mountain slopes contain vegetation consisting of Arizona Upland Subdivision of the Sonoran Desert with stool (*Dasylirion wheeleri*), cacti and agave (*Agave spp.*).. Elevation ranges from sea level to 878 m.

The average temperatures on YPG are between 16 °C (December) and 30 °C (July) (Atmospheric Sciences Laboratory, YPG Central Meteorological Observatory), with average annual rainfall of approximately 8.8 cm.

SAMPLING DESIGN

We implemented a sampling design to systematically sample across the landscape of the three military installations. The sampling framework consists of 1-km^2 spatially balanced survey plots weighted by statistical output covariate results (see Piorkowski et al. 2014 for detailed information on development and implementation of this sampling framework). We selected spatially balanced survey plots (n=401) across the gradient of bat roost probability developed in Piorkowski et al. (2014) to conduct our surveys.

Field Surveys – To survey each military installation, we randomly selected 1-k m^2 study plots using ArcGIS using the "select random points" tool. To conduct a survey, plot centroids were marked at distances of 500 m in each cardinal direction to determine the outer boundaries of the survey. This allowed us to delineate 1-km^2 survey plots on the ground. A preliminary scan of the site by a group of 2-3 surveyors was completed using 10 X 42 mm Vortex™ binoculars to determine if obvious features existed. Plots with uniformly flat topography did not receive further investigation. Once the preliminary scan was completed, transect surveys were conducted and any potential roosting features within the plot were recorded with a Global Positioning Systems Unit (GPS) using the North American Datum 1983 (NAD83). Upon finding a potential feature the location was documented, and portal/collar temperature, internal temperature, portal height and width, and length/depth, bat presence/absence, bat guano present/absent in high, medium or low quantities, general description and photo number(s) were recorded. At each plot, all identified features were summarized with an identification name, time, observer(s), and GPS location. Once all data was collected at a plot, we removed any and all markers (flagging) used to visualize the plot boundaries and the areas was left in the same condition as our arrival. *Revisit Surveys* - During the field season, we revisited sites that were difficult to fully assess for potential bat features. Features were selected for a revisit for one of three reasons: 1) potentially high bat use, 2) clarification of bat species utilizing the feature, and 3) documentation of roost type (e.g., day, night, maternity, etc.). Revisits were completed by two observers. At least one observer was skilled at determining bat species by guano while the second observer assisted in precise data collection/measurements and a more detailed description of the feature than was previously collected.

Predictive Model (Potential likelihood of bat features across the study area) - We combined feature detections from the plot surveys, historic feature use (i.e., previously collected data) and bat roost observations to develop a model that identified the likelihood of bat roosts in areas not sampled. The initial sampling grid dataset was included as a refinement mask for model consistency. We imported known feature locations and bat roosts from the field surveys along with historic survey efforts (Dalton and Dalton 1994, Dames and Moore. 1996, Dalton and Dalton 1999, Lowery and Ingraldi 2005, Lowery et al. 2012) and spatially joined them to the sample grid dataset. The resulting grid dataset was then related to a list of variables describing terrain and physical habitat variables along with categories of remotely sensed climate data including: elevation, landcover, landform, road distance, stream distance, stream length, disturbance distance, average temperature across plot, isothermality, terrain ruggedness, rock type, soil type and annual precipitation (Sappington et al. 2007). We modeled derivatives of elevation, including aspect, hillshade, and slope using the spatial analyst extension in ArcGIS and included our descriptive variables. We summarized and spatially joined continuous datasets with the zonal statistics function for minimum, mean and maximum values describing each grid cell using Geospatial Modeling Environment (GME, version 0.7.2.0 RC2; isectpolyrst). Categorical datasets were also summarized with GME (isectpolyrstr), describing the total area of each class. We summarized a roads and perennial water layer dataset (ASLD 1993), describing the total length in each grid cell. The resulting comprehensive dataset was exported as a table for analysis.

Prior to analysis, we examined the dataset for collinearity and removed variables that demonstrated ≥0.5 correlations with others. Using the Statistical Analysis Software version 5.0 (SAS Institute, Cary, North Carolina), we completed logistic regression analyses with a best-fit model parameter (Hosmer and Lemeshow 2000) and determined which covariates, and their associated influence, contributed to the likelihood of a feature and/or bat roost. We ranked the resulting models by Akaike's Information Criterion (AIC; Hosmer and Lemeshow 1989) and selected the top ranking model. For graphical interpretation, we imported the model into ArcGIS where we transformed the resulting logit function to the natural log of odds (probability) using raster math [ArcGIS (Spatial Analyst Extension; Map Algebra)]. Spatial resolution reflecting the most appropriate fit for use during analysis was selected as each covariate was converted to a 30-m pixel dataset (Fisher and Tate 2006). Using the Jenks optimization method (Jenks 1967), we defined the color ramp for display purposes.

RESULTS

Our field effort resulted in the completion of 83 spatially balanced 1-km^2 survey plots to identify features and/or bat roost presence. These survey plots were visited between 7 December 2012 and 19 February 2013 with 46 revisits from 4 February to 14 March 2014. By combining historic datasets, we examined a total of 1,345 survey plots with 158 survey plots containing features and 149 of those with evidence of bat use. From the identified features containing evidence of bats, 15 contained evidence of California leaf-nosed bats, 1 contained evidence of Townsend's big-eared bats, and all contained some evidence for *Myotis* spp. We also detected three bats using a rock crevice that could not be positively identified due to the nature of the structure. We located six features being utilized as a day roost for California leaf-nosed bats and the above mentioned feature being utilized as a day roost for either a *Myotis* spp. or big brown bats (*Eptesicus fuscus*). Several features showed high intensity use (day and night roost) based on guano and culled arthropod evidence.

From all surveys completed, we informed a GIS model with 1,345 survey plots. Our top regression model selected 4 predictive covariates (i.e., landform, road distance, slope and soil types) from a set of 16. The probability of feature likelihood increased with proximity to roads, rocky soil associations and level plateaus or terraces. Feature likelihood decreased with close proximity to moderately steep slopes. This regression and its coefficients are represented as follows:

$$Y = (-0.002630) moderately\ steep\ slopes\ -\ (0.000267) distance\ to\ road + (0.1385) rocky\ soil\ association + (0.001590) level\ plateaus\ or\ terraces$$

Figure 2 graphically displays the results of these analyses across our study area. Based on this model output, less than 5% of the total study area has the highest category likelihood of bat features (YPG = 3.57%, BMGR = 4.84%; Table 1).

DISCUSSION

Mines and caves are important habitats for many bat species that occupy DoD installations in southern Arizona. Our study showed that at least three different species of bats (*M. californicus, C. townsendii*, *Myotis* spp.) occupy abandoned mines and other roosts on all three installations. As such, there is relatively little area across theses large areas in which bats can rest, hibernate, or rear young. With the loss of traditional roosts (e.g., caves) due to disturbance, habitat modification and other factors, mines may become more important habitat features for roosting bats. Our survey efforts highlighted the distribution of roost sites for bats across DoD lands in southwestern Arizona, and the importance of mine sites for bats on the installations. We determined that only 5% of the land area that we surveyed was likely to contain features that could be utilized as bat roosts. Our model thus allows land managers and base commanders to restrict or alter their activities in these areas to keep disturbance at these sites to a minimum, As many of the mines we surveyed occurred in public areas where they could be hazardous to people, the bases may enact programs to close mines. Programs that result in closures intended to safeguard humans can be incompatible with mine-roosting bats and should therefore be carefully considered. There are various methods tested for human exclusion and bat roosting habitat compatibility (e.g., bat gates; White and Seginak. 1987), and all developed methods should be scrutinized based on bat activity and species use.

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TABLE 1. Area likelihood of bat features for Yuma Proving Ground and the Barry M. Goldwater Range in southwestern Arizona determined from field surveys and regression modeling, 2013.

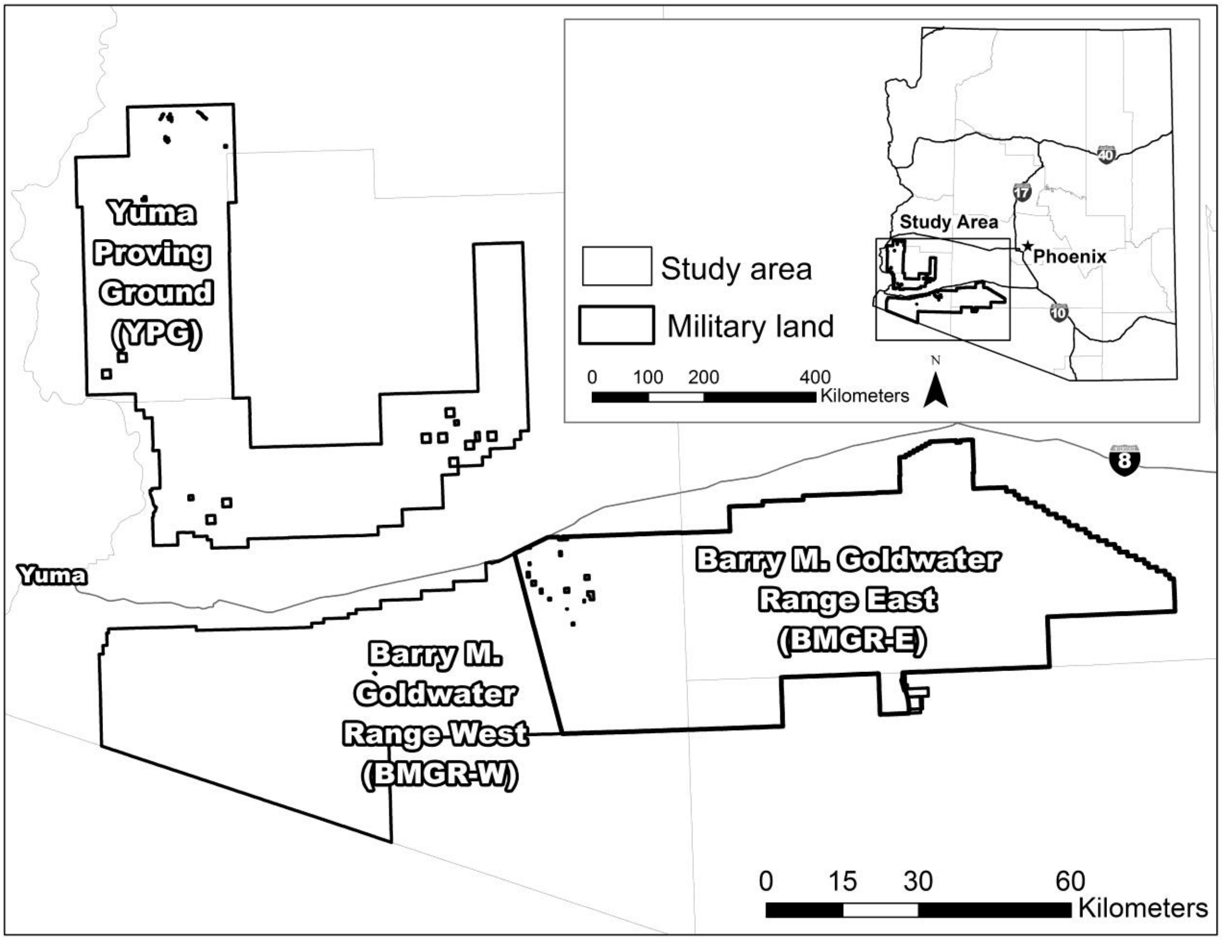
FEATURE LIKELIHOOD (*p*)

Location	*48-66%*	*26-48%*	*11-26%*
YPG (335,985 ha)	12,000 ha	577,504 ha	95,517 ha
BMGR (707,200 ha)	34,248 ha	781,209 ha	122,124 ha

FIG. 1. Study area of Yuma Proving Ground and Barry M. Goldwater Range East and West in southwestern Arizona, 2013.

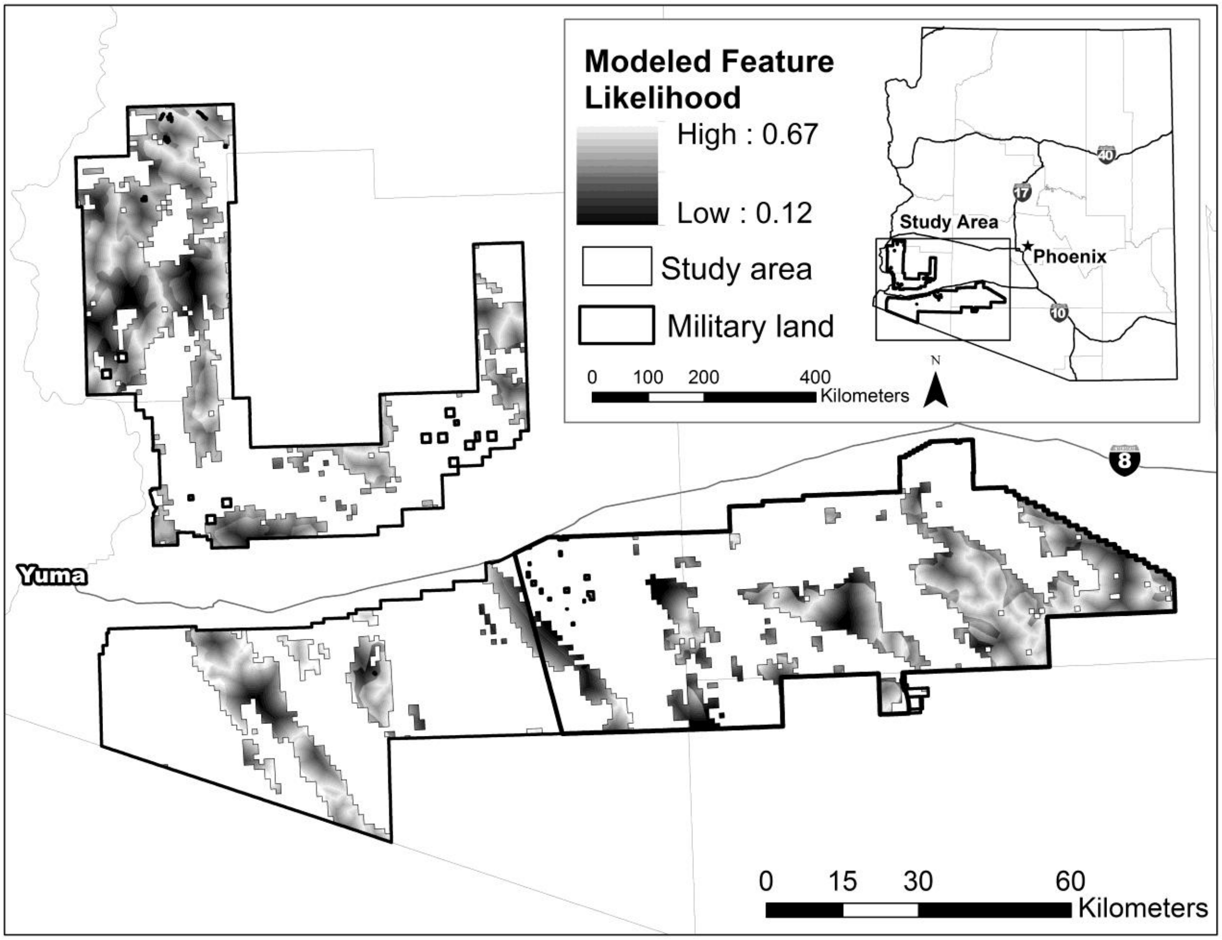
FIG. 2. Modeled GIS output of significant covariates describing the likelihood (*p*) of potential bat features across the Yuma Proving Ground and Barry M. Goldwater Range in southwestern Arizona, 2013. Light shading indicates higher likelihood while darker shading indicates lower likelihood of potential features. Areas outside of the shading were not modeled based on sampling framework described in Piorkowski et al. (2014).

FIG. 1.



Yuma Proving Ground (YPG)
Yuma
Barry M. Goldwater Range West (BMGR-W)
Barry M. Goldwater Range East (BMGR-E)
8
0 15 30 60 Kilometers
Study area
Military land
Study Area
Phoenix
40
17
10
0 100 200 400 Kilometers
N

FIG. 2.



Modeled Feature Likelihood
High : 0.67
Low : 0.12
Study area
Military land
0 100 200 400
Kilometers
N
Study Area
Phoenix
40
17
10
8
Yuma
0 15 30 60
Kilometers