ARCHAEOLOGICAL SITE LOCATION SUITABILITY MODELING THROUGH GIS
FOR THE IMPACT AREAS AT MARINE CORPS BASE CAMP PENDLETON

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Since the establishment of Camp Pendleton as a military installation, ordnance has regularly been fired into designated impact areas. Safety concerns related to unexploded ordnance have precluded archaeological surveys in these areas. In order to comply with Section 106 inventory requirements for prescribed burns proposed within the impact areas, a GIS site location suitability model was developed. Slope and cost weighted distances to streams were used to identify areas where archaeological sites are likely to be located within the impact areas. The model was tested in a previously surveyed study area; the results indicate that the model is effective.

Marine Corps Base Camp Pendleton (MCB Camp Pendleton) is in the process of preparing an Environmental Assessment (EA) to consider the potential environmental consequences resulting from implementing a Wildfire Prevention Plan (WPP). Since the establishment of MCB Camp Pendleton as a military installation in 1942, live ordnance has regularly been fired into designated impact areas located in the center of the base. These impact areas contain high concentrations of unexploded ordnance (UXO) and are therefore unsafe for a traditional intensive pedestrian survey to identify historic properties (Figure 1). Because Portions of the WPP EA are within areas that are off limits to all personnel, MCB Camp Pendleton faces the unique challenge of complying with Section 106 identification requirements without having physical access to perform traditional pedestrian survey. Therefore, MCB Camp Pendleton created a Geographic Information Systems (GIS) based site location suitability model as a reconnaissance level survey in lieu of an intensive pedestrian survey in order to meet identification requirements under 36 CFR 800.4. The goal of the study is to model the most suitable locations for the majority of archaeological site types. The regulatory context, archaeological context, GIS methodology, and results of an internal test of the model are presented below.

REGULATORY CONTEXT

The creation of a site suitability model, also known as a predictive model, is an attempt to satisfy a regulatory requirement not otherwise possible. Section 106 of the National Historic Preservation Act (NHPA) directs federal agencies to take into account the effects of federal undertakings on historic properties, as outlined in the Advisory Council on Historic Preservation’s regulations (36 CFR 800). As defined in 36 CFR 800, an undertaking is “a project, activity, or program funded in whole or in part under the direct or indirect jurisdiction of a Federal agency” (36 CFR 800.16[y]). The Area of Potential Effects (APE) of an undertaking is defined in 36 CFR 800.16(d) as “the geographic area or areas within which an undertaking may directly or indirectly cause changes in the character or use of historic properties, if any such properties exist.” Historic properties include prehistoric and historic sites, buildings, structures, districts, or objects listed or eligible for listing in the National Register of Historic Places (National Register), as well as artifacts, records, and remains related to such properties (NHPA, as amended [54 USC 12 300101 et seq.]).

The goals of the WPP include managing wildland fuels, reducing the frequency and intensity of wildfires, and improving grassland habitat through prescribed burns and weed abatement (Leidos 2017). The EA considers three methods of managing fuels: prescribed burning, maintaining a system of firebreaks, and thinning fuels. As such, the WPP meets the definition of an undertaking.
Figure 1. Impact Areas and Training Areas at MCB Camp Pendleton.
Potential Effects to Historic Properties

The APE includes the areas where project activities, such as prescribed burns, firebreaks, and fuel thinning zones, may have an effect on historic properties. Prescribed burns could affect cultural resources, primarily by exposing surface artifacts and features to elevated heat, but also through the active management of the prescribed burn. The effects of heat exposure to cultural resources depend on the temperature and duration of the fire and can range from negligible to extreme (Leidos 2017). Another direct effect of managing prescribed burn activities is the potential for damage to historic properties by vehicles, equipment, and personnel managing the prescribed burn. However, most of the prescribed burn management activities would occur around the perimeter of the burn area and, unlike wildfire suppression activities, can be carefully planned in advance to minimize impacts to cultural resources.

Firebreak maintenance through the use of graders, dozers, tractors, and heavy-duty trucks can also affect cultural resources. Most of these firebreaks have existed for several decades and their maintenance would occur within areas that are already highly disturbed. Archaeological surveys of existing firebreaks at MCB Camp Pendleton (Reddy 1999, for example) have documented extensive ground disturbance from bulldozing, and therefore it is unlikely that previously unrecorded historic properties are within the extant firebreaks. As described by Reddy (1999:7), “Wherever these bulldozed swaths occur the chances of finding archaeological sites have been effectively eliminated due to the severe disturbance of the ground surface and the removal of surface sediments.”

Finally, fuel thinning zones have the potential to affect historic properties because they are maintained using tractors with mowers, grass string trimmers, and chainsaws to remove heavier fuels, and therefore people and equipment work in proximity to cultural resources. However, with proper planning and coordination, maintenance of fuel thinning zones is unlikely to affect historic properties. Furthermore, fuel thinning could reveal archaeological sites that had previously been obscured.

The Effects of Fire on Cultural Resources

The effects of fire on cultural resources depend on several factors, including: the material composition of the constituent artifacts (i.e., organic or inorganic); whether the artifacts are on the surface or buried (and if so, at what depth); the fuels present at the site (grasses to dead trees and stumps); the intensity and duration of the fire; and the moisture of the fuel soil and duff (Timmons et al. 2012:176). Heavy fuel loads, thick duff, and tree stumps pose the greatest threat to buried cultural resources from fire (Timmons et al. 2012:183). Conversely, lighter fuels like grasses and thin duff produce lower temperatures and burn quickly, resulting in minimal impacts to surface artifacts (Timmons et al. 2012:183).

The majority of the previously recorded archaeological sites within the WPP APE, and presumably within the impact areas, consist of chipped and ground stone artifacts, bedrock milling features, and shell scatters (Leidos 2017:3–99). The most common effects of high-intensity wildland fires to these types of cultural resources include spalling of bedrock milling features and shattering of surface artifacts (Leidos 2017:3–99). However, research has demonstrated that the shorter durations and lower severity of prescribed burns result in fewer adverse effects to cultural resources than wild fires (Ryan and Koerner 2012; Smith 2002; Timmons et al. 2012). Ryan and Koerner (2012:46–47) summarize the effects of heat on stone and ceramic artifacts in a laboratory test using a furnace to simulate a range of wildland fire intensities. The results indicated that the diagnostic qualities of the artifacts are relatively unchanged at temperatures under 800 °F (Ryan and Koerner 2012:46–47). Prescribed fires that are burned when air temperatures are under 80 °F and relative humidity is greater than 20% typically result in surface temperatures below 800 °F and soil temperatures below 100 °F (Smith 2002:4). Furthermore, if prescribed burns are excluded from burning within archaeological sites, the sites are at a higher risk of being burned over during a wildland fire, in which temperatures are much higher, and artifacts, both on the surface and below, are more likely to be damaged or destroyed (Smith 2002; Timmons et al. 2012). In fact, prescribed burning can be used to reduce fuel loads that could burn at high temperatures during a wildland fire and ultimately adversely affect buried cultural resources (Timmons et al. 2012:182).
There is a long history and high frequency of wildland fires on MCB Camp Pendleton, especially in the military training areas. Prescribed burns are designed to manage fuel loads and ultimately reduce the intensity and occurrence of wildfires. As stated above, without prescribed burning, archaeological sites are actually at a higher risk of being damaged by wildfires. Additionally, no new fire breaks are proposed in the impact areas, so there is no risk of unidentified sites being impacted by dozer or hand lines used for managing prescribed fires. Prescribed burns in the impact areas will be managed through careful consideration of fuel, topography, and weather.

The majority of the prescribed burn areas proposed for the WPP are grasslands with relatively low fuel loads (Leidos 2017:3.99–3.100). Therefore, the authors argue that, where prescribed burning is proposed, the majority of the locations within the impact areas that are suitable for the presence of prehistoric archaeological sites in accordance with the model presented here are within grasslands that burn at relatively low temperatures.

**Identification of Historic Properties**

Under 36 CFR 800.4(b), federal agencies are required to identify historic properties within the APE through background research, consultation with tribes, sample field investigation, and ultimately field survey. MCB Camp Pendleton is divided into cantonment areas, training areas, ranges, and impact areas. The impact areas are subdivided into what are referred to as “dudded” and “non-dudded” areas. Non-dudded impact areas are locations where the types of weapons fired do not produce unexploded ordnance, such as rifles and side arms. Dudded impact areas are locations where the kinds of weapons fired do produce unexploded ordnance (UXO), including artillery, mortars, aerial gunnery and bombing, and UXO demolition. In accordance with the Marine Corps Installations West-Marine Corps Base Camp Pendleton Range and Training Area Standard Operating Procedures (MCIWEST-MCB CAMPENO 3500.1), the dudded impact areas are off-limits to all ground activities and personnel, unless authorized by the Assistant Chief of Staff for Operations and Training and preceded by a safety sweep conducted by an Emergency Ordnance Disposal (EOD) team to locate, detonate, and/or remove any UXO. Typically, there are no undertakings, other than training, that occur in the dudded impact areas. The WPP APE is 24,378 acres, of which 18,982 acres are intensively surveyed. The remaining 5,396 acres are prescribed burn areas and firebreaks within the dudded impact areas and cannot be surveyed by traditional methods.

The inability to survey the dudded impact areas for cultural resources has resulted in a unique challenge for MCB Camp Pendleton to consult on the WPP undertaking with the California State Historic Preservation Officer (SHPO) and tribes. While it is not possible to survey the dudded impact areas for cultural resources due to safety reasons, it is imperative to conduct prescribed burns within the dudded impact areas since they are the locations where wildfires are most likely to ignite due to the high volume of explosive ordnance being delivered into them and the proximity to the Cleveland National Forest. There are no exemptions in 36 CFR Part 800 that relax requirements for surveying areas containing unexploded ordnance in an active and live-fire training areas; therefore, its necessary to seek another alternative to meeting the regulatory requirements.

**Application of the Base-wide Streamlined Section 106 Programmatic Agreement**

In August 2014, MCB Camp Pendleton entered into the Programmatic Agreement among the United States Marine Corps, the Advisory Council on Historic Preservation, and the California State Historic Preservation Officer Regarding the Process for Compliance with Section 106 of the National Historic Preservation Act for Undertakings on Marine Corps Base Joseph H. Pendleton (PA). The PA streamlines the Section 106 process of the NHPA and its implementing regulations, 36 CFR 800. It eliminates case-by-case consultation with the SHPO and Invited Signatories for undertakings whenever there will be no adverse effects to historic properties, due to either the lack of historic properties within the area of potential effect (APE) or implementation of standard protection measures to avoid those resources, or undertakings that are unlikely to affect historic properties. This PA requires MCB Camp Pendleton to inventory, identify, evaluate, treat, protect, preserve, and consult about historic properties and comply with
the Archaeological Resource Protection Act (ARPA), the Native American Graves and Repatriation Act (NAGPRA), Section 110 of the NHPA, and the goals and guidelines of the Integrated Cultural Resource Management Plan (ICRMP) for MCB Camp Pendleton (Brasket 2017).

The PA considers certain classes of undertakings that do not have the potential to affect historic properties, such as land/easement acquisitions, broadcast seeding, and sign replacement, as automatically exempt from further review. Other undertakings may fall under one of the 13 screened exemptions in which the Cultural Resource Manager will determine if the undertaking may be considered exempt from further review.

The PA outlines a streamlined process for traditional identification methods but includes a stipulation for reconnaissance survey which requires SHPO approval. As defined in the PA, a reconnaissance survey: is a non-intensive inventory strategy employed when gathering data to refine a historic context; checks on presence or absence of expected property types; estimates distribution of historic properties in a given area; provides general understanding of properties in an area; and may require more detailed survey to meet specific needs.

As an alternative to a standard intensive cultural resources survey, the MCB Camp Pendleton Cultural Resources Section (CRS) used GIS to estimate the potential distribution of historic properties in the duded impact areas. Generally following methods demonstrated by Reddy and Brewster (1999), the authors created an archaeological site location suitability model for the impact areas. The model is correlative, in that it identifies and quantifies relationships between environmental variables and archaeological site locations (Sebastian and Judge 1988:4). Specifically, this model examines the relationships of the locations of previously recorded archaeological sites and two environmental variables: slope and distance to streams.

**ARCHAEOLOGICAL CONTEXT**

The prehistoric hunter gatherers that occupied the area that is now MCB Camp Pendleton most likely practiced a combination of the forager and collector strategies (Reddy and Byrd 1997:62), as originally defined by Binford (1980). As described by Binford (1980), foragers move residential bases seasonally to exploit locally available resources. Resources are gathered daily during trips from a residential base to locations from which the resources are extracted (Binford 1980:9). Collectors organize task groups that travel to an area to establish a field camp for exploiting an array of available nearby resources and store them temporarily before returning to the residential base. The fundamental difference between the two types of procurement systems that Binford (1980) describes is that groups either relocate to areas where resources are available (foragers) or logistically bring the resources to the consumers (collectors). Environmental factors and storage-related technology are key variables in understanding the conditions that result in the selection of one strategy over another (Binford 1980). Over time, as technologies developed that improved storage of surplus (ceramic pottery, in particular), hunter gatherers may have transitioned from forager to collector strategies because they were capable of sustaining dietary needs for longer periods while away from the residential base. The archaeological record left by the prehistoric people that once occupied MCB Camp Pendleton may reflect a continuum of this transition. As described by Reddy and Byrd (1997:62):

The early periods of occupation in the southern California coastal area are generally characterized as a foraging settlement strategy (Erlandson and Colton 1991; Moratto 1984; Warren 1964). The onset of the Archaic period may well represent the beginning of a collector’s strategy, particularly focused on resources associated with coastal lagoons. Archaic sites during the early-middle Holocene are often large and intensively occupied sites, and may have been semi-sedentary.

During the Late Prehistoric period, residential bases may have been sedentary villages or extensively occupied seasonal settlements (Byrd and Serr 1993; Jones 1991, 1992). Other sites were related to these larger residential bases, including field camps, locations, stations and caches. With adequate storable resources, such as acorns, the Late Prehistoric period
may have witnessed a logistic-collector strategy utilizing oak groves during the fall and winter months, and focusing on coastal resources during other periods of the year (Bean and Shipek 1978, Craib 1982; Rice and Cottrell 1976) [Reddy and Byrd 1997:62].

Ethnographically, the Luiseño and Juaneño settlement pattern reflects subsistence systems involving annual movements from the coast and valleys up into the highlands and mountains in order to maximize exploitation of seasonally available resources. The availability of plant and animal resources within ecological zones at varying elevations heavily influenced the location and duration of settlements. In the late spring and summer, seedbearing grasses were available near the coast, in broad inland valleys, and in the uplands. Later in the year, settlements may have moved to higher elevations to harvest acorns. Throughout the year, depending on the location of the seasonal settlement, hunting, fishing, and gathering shellfish may have provided supplements to staple plant resources (Reddy and Brewster 1999:8).

Whether the prehistoric peoples of MCB Camp Pendleton employed a foraging or collecting subsistence strategy, or some combination thereof, they were relatively mobile and would have had to make regular decisions regarding the locations to collect and/or process resources, and how long to stay at those locations. Attempting to account for the full range of human decision-making processes is well beyond the scope and purpose of this study. Regardless, prehistoric archaeological sites are not randomly distributed at MCB Camp Pendleton; they are most often located in specific topographic and environmental settings. Specifically, prehistoric archaeological sites are most often located on relatively level ground near reliable sources of freshwater (Byrd 2012:25). The assertion that prehistoric archaeological sites are most likely to be located on relatively flat terrain near streams was tested during the development of this model. The results of those analyses are presented below.

The authors recognize that this model does not account for different types of archeological sites, or for the chronology of these sites. Clearly a more robust model would consider and classify a broad range of site functions, the age(s) of sites, and how the functions of sites may have changed over time. Additionally, the authors understand that more environmental variables could be considered, including, but not limited to: availability of freshwater in the past, the reliability of sources of freshwater during different seasons, possible locations of springs that are no longer present, proximity to vegetation communities that supported an array of resources, proximity to productive hunting areas, distance to the coast and to lagoons, prevailing winds, and aspect, to name only a few. However, the purpose of this study was to attempt to satisfy a regulatory requirement: to account for the affects that a federal undertaking may have on historic properties, assuming they are present, in a large area that cannot be intensively surveyed. With that goal in mind, we deliberately contemplated which environmental variables would be most suitable for locating the majority of prehistoric archaeological sites, regardless of function or age: level landforms near easily accessible streams.

GIS METHODOLOGY

The following section presents a detailed description of the methodology employed to create the suitability model using Esri’s ArcGIS 10.4.1.

Study Area

In order to determine if slope and distance to streams are strong predictors for identifying suitable areas for prehistoric archaeological site locations, a study area that has been completely surveyed for cultural resources was defined (Figure 2). Portions of training areas and non-duded impact areas that have a similar range of topography and hydrography, as well as similar total acreage as the duded impact areas (23,941 acres), and are adjacent to the impact areas, were defined as the study area. A shapefile representing the study area was created by roughly tracing elevation contours at a scale of 1:15,000. The authors specifically excluded the Santa Margarita River floodplain and the coastal terrace since neither of these kinds of major geographic features are within the duded impact areas. The study area is 23,769 acres.
Figure 2. Study Area.
Vector data analyzed included a National Hydrologic Data streams shapefile that was clipped to the study area. All previously recorded cultural resources within study area were then selected and exported to a new shapefile. Any cultural resources that were entirely historic (i.e., no prehistoric components) were subsequently removed. Sites that were partially outside of the study area were removed from the analysis in order to avoid errant measurements of slope and distance to streams from the sites. All data analyzed within the study area was projected to State Plane Zone 6 US Feet. A total of 143 prehistoric archaeological sites within the study area were included in this analysis.

**Digital Elevation Model**

A digital elevation model (DEM) was the foundation for the suitability model. A DEM is a type of raster data, which is an array of cells that form a continuous grid (Longley et al. 2001:187). Specifically, a DEM is a representation of terrain “in which each grid cell records the elevation of the Earth’s surface and reflects a view of terrain as a field of elevation values” (Longley et al. 2001:288). The DEM used for this predictive model was developed as an ArcInfo Grid by the San Diego State University (SDSU) Department of Geography by referencing United States Geological Survey (USGS) 7.5-minute quadrangle elevation contour lines at 20-foot and 40-foot intervals (San Diego Association of Governments 2017). Each cell in the grid measures 10 meters and was assigned a value representing the elevation in feet above mean sea level. The DEM created by SDSU represents the elevations of all of San Diego County, so for this project portions of the DEM were extracted for the base, the study area, and ultimately the impact areas.

The Spatial Analyst extension of ESRI’s ArcGIS 10.4.1 was used to derive two sets of raster data from the DEM: a degree slope raster and a cost weighted distance to streams raster. The creation of these two rasters is described in detail below.

**Raster Analysis**

Before creating the degree slope and cost weighted distance to water raster data, the raster analysis environment was defined so that the output data would automatically: reference the same coordinate system as the DEM (State Plane Zone 6 US Feet); produce rasters with the same cell size as the DEM (10 meters); and scale the rasters to the same extent as the study area. The DEM for the study area was then extracted from the county-wide data.

Using the Spatial Analyst extension, a degree slope raster for the study area was derived from the DEM (Figure 3). The slope function calculates the maximum rate of change in elevation between each cell of the DEM and its eight neighboring cells (McCoy et al. 2004:153). In this model, slope was used both as an independent variable and as a cost surface for the cost-distance to streams analysis. The cost surface is used to define the cost of traveling through each cell in the raster to a source (McCoy et al. 2004:218). In this case, slope is used to define the cost required to travel to source of fresh water, with the cost being the relative energy expended by prehistoric hunter-gathers traveling on foot across the landscape.

The slope raster data was then used to derive a cost weighted distance to streams raster. The cost weighted distance function computes the cumulative cost of traveling from each cell in a raster to the nearest source, “based on the cell’s distance from each source and the cost to travel to it” (McCoy et al. 2004:126). The values assigned to the cells in the output raster are represented in abstract cost units relative to the source, not in geographic units (ESRI 2017). Applying this type of distance measurement “provides a more relevant and accurate reflection of the effort which prehistoric peoples had to expend to obtain a given resource” (Duncan and Beckman 2000:42). For the current analysis, the degree of slope of a cell is considered to affect the cost to travel from one cell in the raster to the next to reach a stream; cells with steeper slopes are more difficult to pass through. The cost weighted distance to streams raster for the study area is displayed in Figure 4.
Figure 3. Degree of Slope Raster for the Study Area.
Figure 4. Cost Weighted Distance to Streams Raster for the Study Area.
In order to determine if prehistoric archaeological sites are not randomly distributed across the landscape and that they are more frequently located on fairly level terrain with relatively easy access to water, the authors compared the distributions of previously recorded archaeological site locations to the distribution of random points. Two shapefiles of 143 random points (which is the same number of archaeological sites recorded in the study area) were created to independently test the distribution of archaeological sites across the slope and cost weighted distance to streams rasters. One set of random points was created for comparison with site distribution within the slope raster (Figure 5), and one set random points was created for comparison against site distribution within the cost weighted distance to streams raster (Figure 6).

Slope values in the study area range from zero to 81 degrees. The random points are located on terrain that is no greater than 40 degrees with a median of 11 degrees slope. Sites are located on slopes that are no greater than 16 degrees, with a median of 5 degrees (Figure 7). The distribution of site locations clusters around 5 degrees, while the random points have a much wider spread and variance. This suggests that prehistoric people were choosing relatively flat ground for site locations. Both of these data sets have a normal distribution, lending them to analysis with chi-square. The analysis resulted in an 80 percent confidence level that sites are not randomly located across the landscape and are more frequently located in areas with lower slope values.

The second set of random points was used to compare cost weighted distance to stream values at random points to cost weighted distance to stream values at archaeological sites. Cost weighted distance to stream values ranged from zero to 76,865. Figure 8 depicts the cell value for cost weighted distance to streams for all 143 points and all 143 sites. The random points have a cost weighted distance to stream value no greater than 75,267 and a median of 10,237. Archaeological sites are located in cells with a cost weighted distance to stream value of no greater than 17,442 and a median of 4,225. These data sets were not normally distributed and therefore did not lend themselves to analysis with chi-square; however, the median cost weighted values are clearly clustered around the lower values in this analysis.

This provides evidence, although not as statistically robust as the slope variable, that sites tend to be located in areas with a lower cost weighted distance to stream value.

Based on the analysis presented above, the authors considered the variables of slope and cost weighted distance to streams to be relatively equal factors for identifying suitable areas where archaeological sites may be located, and therefore should be treated as equal variables in the model. In order to arrive at a common scale for the slope and cost weighted distance to streams rasters, each raster was reclassified. The degree slope raster was reclassified into 20 equal intervals, where cells with a score of one are on the most level ground, while cells assigned a value of 20 are on the steepest slopes. The cost weighted distance to streams raster was also reclassified into 20 equal intervals, in which cells assigned a value of one are in areas where streams are readily accessible. Cells with a reclassified value of 20 are in locations where steep slopes inhibit access to streams.

The cell statistics tool was used to create a raster that averages the values of all of the cells in the reclassified slope and cost weighted distance to streams rasters. The resulting raster is the site location suitability model in which the value assigned to each 10-meter cell was the average value of the cells that occupy the same space from the degree slope and the cost weighted distance to streams rasters. In the site location suitability model raster, 10-meter cell values closer to one represent the flattest ground, near water that is relatively easy to access, while cells with values closer to 20 are on steep slopes in areas where streams are difficult to access. After averaging the two rasters together, the range of intervals was 1–15; there were no cells with average values between 16 and 20, which is a reflection of the general topography of the study area. This resultant model does not measure the probability that a site will be located within particular areas but reflects the suitability of particular cells for locating a prehistoric archeological site (Duncan and Beckman 2000:42) based on the cells’ slope and access to streams. The site location suitability model is presented in Figure 9.
Figure 5. Distribution of Random Points and Archaeological Sites over Slope Raster.
Figure 6. Distribution of Random Points and Archaeological Sites over Cost Weighted Distance to Streams Raster.
Figure 7. Comparative Distributions of Slope Values at Random Points and Archaeological Site Locations.

Figure 8. Comparative Distributions of Cost Weighted Distance to Stream Values at Random Points and Archaeological Site Locations.
Figure 9. The Site Location Suitability Model for the Study Area.
Internal Model Test

To test the efficacy of the suitability model in the study area, the locations of the 143 prehistoric archaeological sites in the study area were compared to the cell values of the site location suitability model. Figure 10 displays the frequency distribution of the 143 previously recorded archaeological sites and their average suitability model cell values. All 143 archaeological sites in the study area are located within suitability model cells with values averaging between one and four, with a mean cell value of 1.78, indicating that sites are typically located in areas that the model suggests are more suitable. No archaeological sites were located in areas with a mean value higher than 4, indicating that archaeological sites are not typically located in areas that the model suggests are less suitable. Therefore, the authors argue that the site location suitability model presented here is effective for determining locations where archaeological sites are likely to be located.

Application of the Suitability Model to the Impact Areas

Following the same methodologies, and using the same environmental variables described above for the study area, a site location suitability model was created for the impact areas (Figure 11). For the impact areas, the suitability model reclassified cell value scale ranges from 1 to 16. Based on the test results from the study area, the authors argue that archaeological sites in the impact areas are likely to be located in areas with cell values of four or less.

In 2013, the MCB Camp Pendleton Range Operations Division slightly expanded several portions of the duded impact areas as a safety precaution. There are 47 prehistoric archaeological sites that were previously recorded near the edges of the duded impact areas before they were expanded to their current configuration. These 47 sites are no longer accessible because they are now within the defined boundaries of the duded impact areas. In order to test the efficacy of the site location suitability model, the authors compared the locations of the 47 previously recorded archaeological sites to the suitability model scores. Previously recorded sites in the impact areas are located with an average suitability score of 3.84. This figure is somewhat higher than the average suitability value for sites in the study area, but this appears to be a reflection of access to streams in the duded impact areas as compared to the study area. There are two clusters of 10 archaeological sites (total) in the impact areas that have high average suitability scores (between 5 and 12): one cluster in the far western portion of the impact areas, and one cluster in the northwestern portion of the impact areas. Within the duded impact areas, streams are relatively distant from these two site clusters (between approximately 750 and 1000 meters). However, just outside of the impact areas, San Mateo Creek and one of it’s a perennial tributaries flow within approximately 500 meters of these site clusters. Therefore, if the duded impact areas where slightly larger and partially encompassed these nearby streams, the suitability model values at these two groupings of archaeological sites would have been somewhat lower.

The results of an aerial survey within the Zulu Impact Area also demonstrate the efficacy of the site location suitability model. In November 2015, the lead author assisted the MCB Camp Pendleton Game Wardens with a helicopter survey to count deer and bison on base. The helicopter was flown in transects over large portions of the base with the goal of counting, photographing, and recording GPS coordinates of the locations of deer and bison when visible from the aircraft. During that survey, the lead author inspected a few relatively flat areas near streams, where bedrock was visible to see if any bedrock mortars were visible. Bedrock mortars were specifically targeted simply because the helicopter could fly no lower than approximately 20 feet above the ground, and bedrock mortars would presumably be the only cultural features that could be visually confirmed from that height. Two sites, with a total of three bedrock mortars were identified within the Zulu impact area from the helicopter. The author recorded the coordinates of each feature. The bedrock mortar sites are located in suitability model cells with values of 2.0 and 2.3.

Figure 12 displays the locations within the impact areas that have a suitability model score of four or less in orange and are therefore the locations where archaeological sites are likely be located. The yellow polygons in Figure 12 are the portions of the proposed prescribed burn areas within the impact areas where archaeological sites are likely be located, according to the site location suitability model.
Figure 10. Distribution of Archaeological Sites over Site Location Suitability Model.
Figure 11. Site Location Suitability Model for the Dudded Impact Areas.
Figure 12. Prescribed Burn Areas in the Dudded Impact Areas Suitable for Archaeological Sites
SUMMARY

MCB Camp Pendleton is in a unique situation, in which intensive pedestrian survey for a federal undertaking is not possible for safety reasons. As an open space area where ordnance is exploded and UXO is present, new federal undertakings in the impact area are not usually planned. In an attempt to comply with identification responsibilities under the regulations, the site location suitability model presented here is effective for determining where prehistoric archaeological sites areas are more likely to occur. As the model demonstrates, archaeological sites should be present in the impact area however, the effects associated with prescribed burning in the impact areas are less deleterious than no action, which would likely result in a higher frequency of wild fires, and ultimately cause more damage to archaeological sites.

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