A GIS ANALYSIS OF ENVIRONMENTAL AND ANTHROPOGENIC THREATS TO COASTAL ARCHAEOLOGICAL SITES IN SOUTHERN MONTEREY COUNTY, CALIFORNIA

MAXIMILIAN VAN RENSSELAER

This article provides an overview of the impact of selected environmental and anthropogenic disturbances to 18 archaeological sites on the coast of southern Monterey Country. A Coastal Vulnerability Index (CVI) was modeled in ArcGIS 10.2, a Geographic Information Systems (GIS) environment, and averaged seven potential threats to the cultural landscape. These variables ranked distance to the coastline, streams, roads, and trails, as well as percent slope, soil, and land cover types within the archaeological study area. A hydrologic analysis was conducted, producing additional datasets identifying hazardous areas. A separate index model was created, employing slope and stream data derived from the hydrologic analysis, and compared to the raster incorporating USGS stream and slope data. Both indices produced roughly similar results, and identified at least 12 archaeological sites within areas of moderate to severe vulnerability. Ground truth of the indices should be affirmed by monitoring sites, both remotely and on the ground, in order to establish the accuracy of the GIS model. GIS models are practical tools for guiding research and mitigation strategies negating impacts to archaeological sites. Efforts must be made to identify and mitigate damage to archaeological resources in order to preserve knowledge of human and environmental history.

The modern world faces an expanding population, sea level rise, and environmental instability, and the archaeological record holds information about these same past events. Human societies and environmental ecosystems will potentially undergo massive changes as the process of climate change advances. GIS provides an assessment tool for modelling the impacts of environmental and anthropogenic variables upon archaeological resources and landscapes. In California, "management agencies are at the early stages of understanding how to facilitate adaptation" to climate change (Hanak and Moreno 2012:45).

This study applies Coastal Vulnerability Indices (CVIs) to the coastal cliffs south of Big Sur in southern Monterey County, California, and compares digital elevation models (DEMs) and hydrologic datasets obtained from the U.S. Geological Survey (USGS) to those derived from operations performed in the ArcGIS environment. GIS also can promote dialogue between scientific researchers, indigenous groups, and federal, state, and local agencies, as well as the public, for visualizing the effects of climate change and taking steps to address them. Without a centralized database integrating many different types of information over the course of time, protection and preservation of archaeological sites and landscapes will not be as easily assessed. The identification and quantification of destructive processes aid mitigation strategies for conserving archaeological resources (Reeder et al. 2010). Efforts must be made to identify and mitigate damage to archaeological resources in order to preserve knowledge of human and environmental history.

Expanding populations, rising sea levels, increasing storm intensities, and associated coastal erosion threaten to prevent research concerning "ancient coastal societies, fisheries, and ecosystems" (Erlandson 2010:137). Archaeological sites are nonrenewable resources, and coastal sites are vulnerable to rapidly expanding urban development and natural hazards, including sea level rise and erosion (Reeder et al. 2010:187). Coastal archaeological sites are valuable because they detail cultural identities, local histories, and human adaptations, as well as providing a means to collecting ecological samples for environmental reconstruction (Reeder et al. 2010:187). GIS, including digital photography and Global Positioning System (GPS) technology, is "an effective tool for managing the protection of archaeological, faunal, and geologic remains" (Constantinidis 2009:112). "GIS comprise[s] a range of computer database programs for the storage, analysis, and manipulation of spatially referenced data," and is useful for predictive modelling in archaeology (Rennell 2012:513). As erosion and other destructive processes affect the integrity of archaeological sites, a GIS database is useful for accurately identifying and quantifying the condition of sites and potential negative human and environmental impacts upon them. In addition to monitoring sites on the ground with pedestrian survey and excavation, threat index values and digital databases attributed to specific sites provide another instrument for analyzing resources of historic and cultural significance.

GIS aids in the protection and preservation of exposed archaeological resources, and can even be used to monitor the effectiveness of protective measures, such as the control of soil erosion or tourist visitation (Constantinidis 2009:115). GIS is an effective tool for classifying coastline geomorphology and hazard vulnerability as a function of erosion rates and cliff retreat. Establishing a predictive model using variables processed in the GIS environment is useful for monitoring change over time. Identifying the factors most detrimental to an area is critical to mitigating damage, because agents can attempt to minimize the most negative impacts (Constantinidis 2009:114). Visual models such as threat indices allow for multidisciplinary integration of spatial data, promoting interdisciplinary dialogue and cooperation. Threat indices rank potential damage to remains by assigning a number in a range corresponding to likely threat level. These rankings can be weighted and then combined together in order to produce a cumulative threat index for ease of understanding dynamic and complex human and environmental processes. Once threatened sites have been identified, they should be monitored through both survey and remote sensing technology in order to "make recommendations for the effective preservation of sites" (Constantinidis 2009:116). On-the-ground site monitoring will contribute to understanding the predictive accuracy of site safety models, and will establish meaningful observations comparing differentially ranked archaeological sites.

Sea levels are estimated to rise between roughly 50 and 200 cm within the next century, affecting coastal sediment and morphology as stronger waves, tides, and storms lead to greater rates of erosion (Reeder et al. 2010:190). Sea level rise, increasing sea surface temperatures, and an increase in the frequency and strength of El Niño events will contribute to "catastrophic erosion" (Reeder et al. 2010:190). More intense storms will dramatically erode vulnerable coastal areas over brief periods of time, but "the long-term effects of constant erosion may be equally or more destructive" (Reeder et al. 2010:190). CVIs have been applied to local areas, as well as expansive stretches of coastline, as in a USGS survey of the west coast of the United States, and provide a scientifically derived analysis that is useful to planning policy (Reeder et al. 2010). CVIs provide a dynamic tool for planners, allowing for informed decisions in developing plans for erosion, sea level rise, and other coastal hazards (Stanchev et al. 2013:725). GIS analyses incorporating a weighted summation of factors including slope steepness, soil erodibility, and land use have been effectively used to predict soil erosion risk (Wahyunto and Abdurachman 2010). "Erosion models can be used as predictive tools for assessing soil loss and soil erosion risk for conservation planning" (Kumar and Kushwaha 2013:390). While an analysis such as a CVI model is useful for determining potential damages to an area, action must be taken to mitigate or prevent archaeological data loss. It is not realistic to attempt full excavation and study of all threatened sites. However, the most threatened sites as determined by GIS models and ground survey should have baseline data recorded before site constituents are lost or greatly altered. Reeder and colleagues (2010:195) propose that "smaller column or bulk samples of eroding sites" be excavated, especially those sites facing immediate erosion.

Archaeology can make relevant contributions to contextualizing the effects of climate change upon the environment and how past communities have acted in response (Van de Noort 2011). Modern climate change discussions do not place importance on understanding the correlation between environmental events and human adaptations (Van de Noort 2011). While studies of communities' response to climate change would not directly apply as methods for reacting to modern climate change, past examples of human behavior detail the "adaptive capacities" for dealing with rapid climate change (Van de Noort 2011:1041). For example, the interrelationships of "environmental, socio-economical, and cognitive aspects of living with climate change" could be explored by archaeological research and GIS methodology, and contribute to the debate on dealing with modern climate change (Van de Noort 2011:1041). However, archaeologists should act in coordination with Native American descendants, local, state, and federal agencies, and private landholders in order to maintain balanced land management practices.

ARCHAEOLOGICAL BACKGROUND

Big Sur archaeological sites date back to almost 5000 B.C. and detail technical, environmental, and social developments in the history of central California's coast (Jones 1996). During the Early period, beginning around 3500 B.C., an intensive industry based on acorn harvesting and processing emerged, as mortar-and-pestle technology replaced milling slabs. Mobility shifted from occupation of interior and coastal settings to "more constrained systems of transhumance," as evidenced by changing correlations of faunal data and bone-isotope results between the Millingstone and Early period (Jones 1996:257).

Mortar-and-pestle technology is correlated with storage of food, high population densities, and greater sociopolitical complexity (Jones 1996:244). Additionally, "hunting-related flaked-stone tools increased relative to ground stone," representing a change from highly mobile and selective gathering strategies to more sedentary, intensive subsistence patterns based on hunting and acorn processing (Jones 1996:243). Hunting appears to have become more important as shellfish collection became less productive during the Early period (Jones 1996:243). Obsidian hydration profiles provide evidence of increased interregional trade coinciding with these developments in technology and subsistence patterns (Jones 1996:243).

A possible explanation for the rise of sedentary lifeways and mortar-and-pestle technology is a "decreased expanse of seed-bearing plant communities as a consequence of early-Holocene sea level rise" (Jones 1996:244). Coastal sites such as those in southern Monterey County provide a "wealth of information concerning economy and subsistence, environment, and technological information," and are necessary to preserve if we are to continue to gain information from these invaluable sites (Milner 2012:223). Coastal erosion, agriculture, development, and bioturbation threaten these coastal sites (Milner 2012).

DATA AND METHODS

I obtained site records created by the 2012 Cabrillo College Field School during one week of pedestrian survey of the coastal landscape. These records included hand-drawn site maps and primary records detailing boundaries and coordinates of site locations. Also included in the site records packet were USGS 7.5-minute Cape San Martin topographic maps at a scale of 1:24,000 with approximate site locations filled in with a marker. Combining a digital version of the same topographic map downloaded from the USGS National Map Viewer platform with GPS coordinates and site maps, I was able to digitize these site boundaries using ArcGIS 10.2 into Geographic Coordinate System WGS 1984, resulting in an accurate representation of georeferenced site locations.

The USGS National Map Viewer platform also serves as a database for spatial information, allowing me to download hydrography, elevation, and transportation datasets in the same projection and scale as the digitized topographic map. The hydrography dataset contained land and sea boundaries as well as an incomplete network of streams. The streams dataset covered most of the study area, but did not include the three most northern sites in this research. Employing the capabilities of Google Earth, I zoomed into the study area and recorded GPS points in an Excel document of pedestrian trail vertices within the study area. This spreadsheet was added to the ArcMap document, and the latitude and longitude coordinates were displayed on the map. I then created a feature representing trails, connecting vertices of the GPS coordinates together. Stream, road, and trails datasets were buffered to represent relative threats, based on proximity to these features. Areas closer to the features received higher numeric threat levels. The DEM downloaded from the USGS allowed for slope percent calculation.

Land cover datasets are available from the Multi-Resolution Land Characteristics Consortium (MRLC) within their National Land Cover Database (NLCD), and the most recent land cover data from 2006 were used for this research. The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service portal offers the Web Soil Survey (WSS) database, from which the soil shapefiles were downloaded. Land cover classifications and descriptions are provided by the MRLC, and rankings between 1 and 10 were assigned, designating susceptibility to erosion, for inclusion in the threat index. Soil types were similarly ranked using descriptions of erodibility offered by a soil survey of Monterey County conducted by the USDA. Soil types classified for erosion risk were assigned ranks of low, moderate, and high erodibility (Wahyunto and Abdurachman 2010:29). Slope gradients were classified in five categories: > 8 percent, 8-15 percent, 15-25 percent, 25-40 percent, and > 40 percent, and received ranks of 1 to 5, from least to greatest slope (Wahyunto and Abdurachman 2010:29). High-risk land cover rankings were generally assigned based on the presence of little to no vegetation coverage.

After adding a field ranking the respective threat levels to each of the six variables, an unweighted threat index was calculated, producing a raster dataset visually translating the comprehensive index. Because the stream dataset did not include the three northernmost sites, a separate unweighted index not including the stream dataset was calculated. In order to double-check against errors within the USGS hydrography and elevation datasets, a separate hydrologic analysis was carried out. After processing the dataset for errors using ArcGIS functions such as the Fill and Sink tools, which help to rid the DEM of false depressions, the Flow Direction and Flow Accumulation tools were utilized. Essentially, these processes recreate the stream network, but are inherently limited by the accuracy of the DEM. Flow direction and flow accumulation were used to delineate flow area and derive a stream network. Flow area of the streams was calculated by multiplying flow accumulation by cell area, providing the drainage of each cell in the raster, and consequentially, a stream network was derived. After converting the derived streams to a feature using the Stream to Feature tool, the stream network was buffered with the Euclidean Distance tool, providing a datum for a threat ranking of proximity to streams. Additionally, this derived stream network allows for the manipulation of the DEM dataset. Stream burning or DEM reconditioning is a useful tool when the DEM and the given stream network do not provide the most accurate information, as was the case in this study. To burn the stream network into the elevation dataset, the AGREE methodology developed by Hellweger (1997) was employed, using the formula:

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Con ("str_dist" ≤ 10, "elev" – 200, Con ( ("str_dist" > 10) & ("str_dist" ≤ 150), "elev" –
(1/"str_dist") * 100, "elev") )
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A new slope dataset could be calculated after burning the stream network into the DEM, perhaps reflecting a more accurate assessment of percent slope. With six variables individually ranked to model environmental and anthropogenic disturbances, including slope percent, land cover type, soil type, distance to road, distance to trail, and distance to stream, final index models were created. One index model used the USGS network of streams, another used the stream network derived in ArcMap, and the last index model used no stream proximity dataset. Reeder and colleagues (2010) developed an index to rank coastal hazard variables, including distance to coast, slope, geomorphology, historical erosion rates, wave height, and human development. A CVI is a generalized equation for factoring variables into an output that serves as an index for coastal hazards. The equation developed by the USGS for identifying vulnerability of the west coast of the United States (Reeder et al. 2010:191) is:

$$\mathrm{CVI} = \left((a * b * c * d * e * f) / 6 \right)^{0.5}$$

A raster index model detailed the results of this equation. The suggested variables include geomorphology (a), historical rates of shoreline change (b), coastal slope (c), relative sea level rise (d), wave action (e), and tidal range (f). This same equation was calculated, but with variables including proximity to streams, coastline, roads, and trails, slope, land cover and soil rankings.

Vulnerability indices calculated using the USGS and derived stream and slope data were produced using the expression:

float (a + b + c + d + e + f + g) / 7

Four additional visual aids were created to identify erosion potential and capture the workings of the hydrologic network. The stream power law of erosion index identified likely locations of erosion, and provides an index with which to visualize erosion potential. The expression to derive stream power is:

“flowarea” * “percent_slope”

Next, the Erosion Index (EI), which more specifically measures erosion by upslope drainage and basal shear-stress, was calculated with the expression:

Power ("flowarea", 0.33) * Power ("percent_slope", 0.67)

The sediment transport index (STI) measures the capacity of sediment transport as a function of drainage area and slope gradient. Similar to the Universal Soil Loss Equation (USLE), the STI measures potential erosion risk but is applicable to 3D surfaces. Low values represent an area where sediment is deposited, while high rankings indicate greater erosion potential.

$$\mathrm{STI} = (A_s / 22.13)^{0.6} * (\sin(\rho) / 0.0896)^{1.3}$$

In the STI equation, A_s is the drainage area (a surrogate for discharge) and ρ is the slope gradient (rise/run). The equation delivered in Raster Calculator is

Power ("flowarea" / 22.13, 0.6) * Power (sin ("percent_slope") / 0.0896, 1.3)

Finally, the Compound Topographic Index (CTI) is a measure of soil’s water content per cell as a function of slope, flow accumulation, and flow direction, given the formula:

$$\mathrm{CTI} = \ln (A_s / \tan(\rho))$$

and the equation in Raster Calculator is:

Ln (("flowarea" + 1) / Con (tan ("slope_grad") = 0, 0.001), tan ("slope_grad"))

RESULTS

The vulnerability index created with USGS stream and slope data details a vulnerability range between 0.2 and 0.8, and a mean of 0.405. It shows eight sites that fall within an area of low to moderate vulnerability, and 10 sites are placed in areas of moderate to severe vulnerability. The CVI index model created factoring the derived network of streams produced threat rankings between 0.314 and 0.843, and a mean of 0.509. It shows that only four sites are located in areas of low to moderate vulnerability, while 14 sites fall within areas of moderate to severe vulnerability. The vulnerability index taking into account USGS stream and slope data, calculated with the USGS suggested formula, indicated 13 sites in areas of low vulnerability and five sites of moderate vulnerability. The derived index categorized more cells as subject to moderate to severe threats, especially near the coast and streams, and the USGS CVI showed the least hazard across the study area.

The derived stream network using ArcMap tools produced significantly more streams than the USGS stream network. Of particular note is the northern study area, in which the USGS shapefile displayed no streams, while the derived network produced a raster dataset detailing stream networks consistent throughout the map. Slope calculated from the DEM with derived streams burned in was significantly steeper than the USGS DEM, especially farther inland from the study area. The CTI was populated with low to moderate cell values, which covered about 50 percent of the map, leaving the rest without cell values. The STI projected mostly low value cells, with some moderate cells sparsely populated in two major streams, Prewitt Creek and Plaskett Creek, outside of the archaeological site boundaries. However, the Stream Power Laws of Erosion Index showed a high occurrence of moderate to severe index cells along both Prewitt and Plaskett creeks. The Erosion Index detailed the most severe conditions of all the indices, showing moderate to severe erosion potential not only at Plaskett and Prewitt creeks but also along many of the derived streams.

DISCUSSION

The higher vulnerability rankings of Index 3 compared to Index 2 are a function of greater values of derived slope and stream data compared to those datasets downloaded from the USGS National Map Viewer. Drastic differences between Index 1 and Indices 2 and 3 are a function of the different equations used to calculate vulnerability. The inability of Index 1 to produce similar and perhaps accurate results compared to other models may be a result of incorrect modification of the USGS CVI equation in terms of the variables applied to the model calculation. Because Index 2 and Index 3 are somewhat similar, they should be regarded as the most accurate, and serve as predictive guides for future area research and management. Field data collection, ground monitoring, and remote sensing observations should be periodically conducted, providing qualitative and quantitative evidence of anthropogenic and environmental impacts with which to judge model precision. It is clear from both Index 2 and Index 3 that the archaeological sites of this area are threatened by a variety of factors.

Land cover correlated well with vulnerability in Index 2 and Index 3, suggesting denser vegetation provided better erosion and disturbance control. The derived network of streams provided better coverage and predictability than the USGS network that failed to display about half of the streams, especially in the northern portion of the map, compared to the derived stream calculation. If the slope and stream datasets generated in ArcMap are indeed more accurate that the USGS datasets, Index 3 is the most reliable and truthful index. The STI was not a good indicator of erosion potential, grouping together cells in both steep and flat slopes as having low vulnerability. Additionally, the CTI mixed low to moderate cells without much variation in the dataset. Both the STI and CTI did not calculate the value of a significant number of cells on the map, which contributes to both indices’ unreliability in this instance. Because neither index discriminated between different areas of the map, they will probably not be useful for advancing planning or mitigation strategies. Percentage calculations of slope based on the derived stream network and USGS shapefile varied greatly in steeper areas, but remained generally similar in the coastal flats where archaeological sites are located.

Due to the inconsistent nature of the USGS stream shapefile and the ability of the derived stream network to model a consistent dendritic pattern, it is likely that the derived stream network and slope data are more representative portrayals of reality. Two indices produced somewhat similar results, suggesting that the models accurately portray local vulnerability to the included environmental and anthropogenic variables. Moderate to severe index values typically were located in areas of barren land, more prevalent in the southern map area, as well as areas immediately proximate to the coastline, and less significantly, those areas surrounding Highway 1. Those areas that fall within or near archaeology site boundaries should be prioritized for damage mitigation and restoration, as well as further monitoring. This study finds that vegetation cover, primarily in flat to moderately sloped areas, provides effective soil erosion control, reiterating findings of previous studies, such as that undertaken by Dengiz and Akgül (2005:444). In terms of land management and planning, vegetation control can be an effective strategy for mitigating erosion. The presence of trails did have a moderate effect on vulnerability, and in order to ground truth the variable, sites within these locations should be monitored for the presence or loss of surface artifacts. Periodic monitoring should remain a research goal of archaeologists and geologists in order to establish changes in rates of erosion, artifact distribution and frequency, and the effectiveness of land management practices. These on-the-ground facts should be correlated with GIS analyses to determine the value of particular models. Future studies could apply a weighted average to variables, useful principally when reliable data exist. Alternative applications of GIS in the region include more subject-centered types of studies such as determination of least-cost paths for migration from the coast to the interior.

CONCLUSION

As human interferences and destructive environmental processes continue to affect archaeological sites, responsible land management and conservation practices require identification and evaluation of these threats. Knowledge of the sites that are most threatened by environmental processes and human activity will ensure that conservation resources are appropriately directed. Ultimately, "efficient recording and documentation of sites" will enable wide-scale and detailed monitoring of negative effects to archaeological sites and aid the protection of cultural landscapes (Constantinidis 2009:118). Archaeological sites are non-renewable resources serving as tools for reconstructing cultural behavior in dynamic environments, but they are threatened by anthropogenic influences and climatic events (Constantinidis 2009:112).

"Under high emission scenarios, recent models predict 1.4 m or more of sea level rise by 2100, accompanied by increasing storm surges" (Hanak and Moreno 2012:45). According to Harley and colleagues (2006) "higher temperatures and higher water levels may alter ocean circulation and lead to more frequent and more powerful storms and waves, exacerbating erosion and shoreline retreat" (Hanak and Moreno 2012:47). "Sea level rise as a result of climate changes will increase the risks associated with coastal hazards of flooding and erosion" (Revell et al. 2011:S273). Sea level rise will alter wave action and rates of erosion, especially affecting loosely consolidated or unconsolidated soils (Revell et al. 2011). Steep cliff morphologies consisting of this type of loose sediment will continue to experience erosion, which will increase as water levels and action change (Revell et al. 2011). Soils' physical, chemical, and biological properties are altered "by the interaction of soil, rainfall, slope, vegetation, and management," which ultimately cause soil erosion (Dengiz and Akgül 2005:439).

Regarded as the "battlefront" of landscape archaeology (Rowland 2008), coastal sites, especially those located in low-lying areas, will be affected most severely by rising sea levels and increased storm and wave intensity (Daly 2011:299). Archaeological data reveal the nature of these changes over thousands of years of coastal occupation, and are therefore relevant to contextualizing developing landscapes. In understanding the interaction between human decisions and environmental changes, archaeologists may illuminate "the impact and ramifications of those decisions on local ecosystems" (Reeder et al. 2010:188). A well-managed GIS applied to archaeology may streamline communication between scientific researchers, indigenous people, and state, federal, and local agencies, as well as the public, supporting better management of landscapes and cultural resources. While GIS is neither neutral nor passive, GIS applications serve as an intermediary stage and are not the end from which objective data are derived (Rennell 2012:513). Interpretations of the GIS process are made by external means, and are not inherently exposed by a simulated model (Rennell 2012:513). However, GIS is useful because it provides an alternative lens through which to view the interconnectedness of environmental and human phenomena.

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