

A Geographic Information System (GIS) Based Model for the Prediction of Archaeological Sites: Manu'a Islands American Samoa

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Abstract:

Predictive modelling in archaeology requires the assessment of two critical variables. First, landscapes containing the necessary settlement requirements must be identified. Second, natural environmental processes affecting the present location of archaeological materials must be taken into consideration. In this paper a GIS based model for archaeological site prediction on the Manu'a Islands, American Samoa is presented. Important model variables include, slope, coastal access, and elevation. Integrating archaeological data with GIS modelling allows for a statistical evaluation of the predictive success of the model. GIS models for predicting site locations should be an integral part of cultural resource management proposals and applied research designs.

Key Words: Geographical Information Science, predictive modelling, landscape change, raster, geomorphology

Introduction

The ability to predict the location of archaeological sites is an important goal for land management practitioners because it allows for cost effective planning which facilitates the preservation of cultural resources. Predictive modelling in archaeology is based on a number of processes that affect the present day location of prehistoric materials. The first process comprises human decisions regarding settlement location, resource use, and resource acquisition within a particular environmental context (Jochim 1976:48-49). Consequently, spatial organization reflects the outcome of a number of decisions concerning habitat use. Some of these variables include proximity to important resources, topography, and seasonal environmental variability.

Land use is not the only set of variables responsible for the present day location of archaeological materials. Changes in the natural environment can significantly transport remnants of prehistoric activity away from a primary location, confounding the success of a predictive model based solely on decisions regarding optimal habitat use. Post depositional transportation factors have been discussed at length by Schiffer (1987), and Dancey (1983), and will not be addressed in detail here. In island settings, landscape evolution due to changes in coastal geomorphology, natural and human induced sedimentation, and local tectonic activity, can also drastically affect the location of archaeological material (see Kirch and Hunt 1993; Hunt and Kirch 1997; Clark and Michlovic 1993). As a result, predictive models must take into consideration both cultural and post depositional factors when considering model development.

In this article, I test a number of hypotheses regarding the prediction of archaeological material from the Manu'a islands American Samoa using archaeological data in concert with a computer based geographical information science. Although the current quality of information concerning archaeological site locations in some areas of the Manu'a islands is limited, the model confirms the usefulness of GIS for archaeological prediction.

GIS Technology: Digital Representations of Geographical Phenomena

GIS is a computer-based technology that has gained widespread use in a number of fields including ecology, urban planning, geography, and archaeology. One of the hallmarks of GIS is the ability to overlay numerous digital geographical surfaces, creating more realistic representations than conventional paper maps alone. Moreover, because GIS has built-in database functionality, searching through large amounts of archaeological and geographical information is greatly facilitated.

Two types of GIS data are used in this analysis. Vector data models are developed by digitizing environmental and archaeological features as a series of points, polylines, or polygons. Vector representations of archaeological features consist of points, representing artefacts or clusters of artefacts with corresponding geographical coordinates recorded in a database table. Other examples of vector models include polylines representing streams and polygons used to represent different types of coastal areas. Raster models deal with continuous geographical surfaces, such as topography, which are far less discrete than self contained archaeological features. Raster models consist of a grid of cells numerically representing different geographical characteristics. For example, a raster representation of elevation shows an increase in the numeric cell values as elevation increases. Through the use of raster mathematics, several grid based layers can be combined to create surfaces based on combinations of distance, slope, and elevation among other variables. Consequently, with GIS, environments can be more realistically model according to criteria for solving research problems, such as predicting the location of archaeological materials.

The Environment of the Manu'a Islands, American Samoa

American Samoa is made of the large island of Tutuila and the smaller islands of Manu'a. Located approximately 100 km to the east of Tutuila, the Manu'a Islands (Figure 1) consisting of `Ofu, Olosega and Ta'u, are characterized by steep topography, high basalt rock coastlines, and narrow fringing reefs (Atlas of American Samoa 1981).

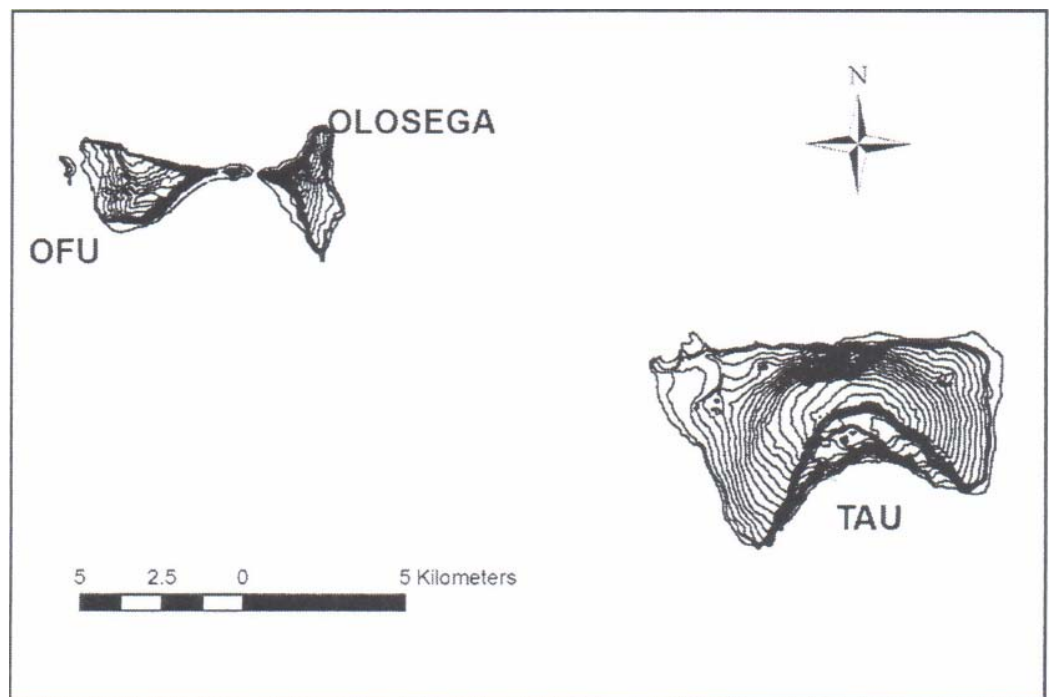


Figure 1: The Manu'a Islands, American Samoa

The steep slopes and restricted coastal access severely limit adequate areas for settlement and agriculture (Coulter 1941). As a result of these environmental constraints, low coastal plains were likely the main locales of settlement activity and are major area of interest for archaeologists (Hunt and Kirch 1988:157).

Soils

Manu'a soils are poorly developed and shallow in most places. However, many coastal areas are made up of 'Aua very silty clay foams which are used to grow taro, bananas, breadfruit and coconut. Additionally, Ngedebus mucky sand occurs along the southern coast of 'Ofu and is also commonly used for subsistence farming (Atlas of American Samoa 1981: Plate 6). Hunt and Kirch (1988:156) note that " ... on 'Ofu and Olosega, most of the terrain, including that used for subsistence gardening, consist of deep well drained 'Ofu silty clays.' Inland areas on 'Ofu and Olosega consist predominately of 'Ofu silty clays with high potential for gardening, and Fagasa family-lithic Hapuldols-Rock outcrop associations with poor soil productivity.

The island of Ta'u consists largely of Olotania family and Sogi variant-Pava'ia'i association soils in the inland areas and rock outcrop-Hydrandepts-Dystrandeps associations along very steep mountainsides (Atlas of American Samoa 1981). The Atlas of American Samoa (1981) suggests that soils of the Olotania family form from volcanic ash under high amounts of rainfall. The risks of severe soil erosion are high and the relative degree of difficulty in access makes their use inefficient. Soils of Sogi-Pava'ia'i association occur in moderate to steep mountainsides. Some areas can be used for subsistence farming (Atlas of American Samoa: Plate 6) but appear to be limited by steep slopes. Coastal areas near Ta'u and Faleasao villages have better developed soils for subsistence farming (Hunt and Kirch 1988:157), with the majority classified as Pava'ia'i stony clay loam. These soils are moderately deep and well drained supporting the growth of taro, bananas, breadfruit and coconuts (Atlas of American Samoa: Plate 6).

The Marine Environment

The Manu'a islands are surrounded in most places by a healthy and diverse fringing reef providing a significant amount of protein to island inhabitants past and present (see Figures 2 and 3). The reef ecosystem supports a variety of fish, shellfish, and many other important marine resources exploited for subsistence. Shellfish species include an array of bivalves and gastropods such as *Turbo setosus*, *Tridacna maxima*, *Periglypta reticulata*, and numerous species of *Nerita* and *Cypraea* that inhabit rocky shorelines, intertidal areas, and reef crests (Kirch and Hunt 1993).

Topography and Elevation

The Manu'a Islands are relatively young geologically, and as a result are topographically steep in most inland areas. At over 500 m, Tumutum Mountain, near the southwestern coast, is 'Ofu's highest point. 'Ofu's south coast is also characterized by the steep cliffs of Le'olo ridge which quickly rise to approximately 400 m. On Olosega, Piunafua Mountain stands at near 500 m. On Ta'u, Lata Mountain, a collapsed summit forming an exposed caldera, is approximately 1,000 feet in height (Hunt and Kirch 1987). Hunt and Kirch (1987) report that 59 per cent of land on Ta'u is located on slopes greater than thirty per cent, while 'Ofu and Olosega are both closer to ninety per cent of land located on slopes greater than thirty per cent.

Archaeology

Problems with the concept of "Site"

The basic ground upon which most archaeological research stands is the concept of the "site" (Ebert 1992:6; Dunnell and Dancey 1986:271). However, the actual explicit characteristics of a "site" are at times arbitrary, misleading, and often useless. For example, it is not uncommon for a large distribution of artefacts, such as an arrangement of house mounds and a series of walls, to be recorded within the boundaries of one site (for example, a village). The actual house mounds, walls and so forth, within the site are often referred to as features. However, in the same report, one may find that smaller groupings of walls, wells, portable artefacts, or house mounds away from the village, are all also recorded as "sites". If analysed in such a way, comparison of "site" patterning is actually a comparison of human activity at relatively different scales without an explicit recognition of this scalar variability (see Ebert 1992:173-185).

Robert Dunnell has criticized the "site" concept on several grounds. Dunnell suggests that "the concentration of artefacts that are taken to constitute sites are the products of numerous discrete

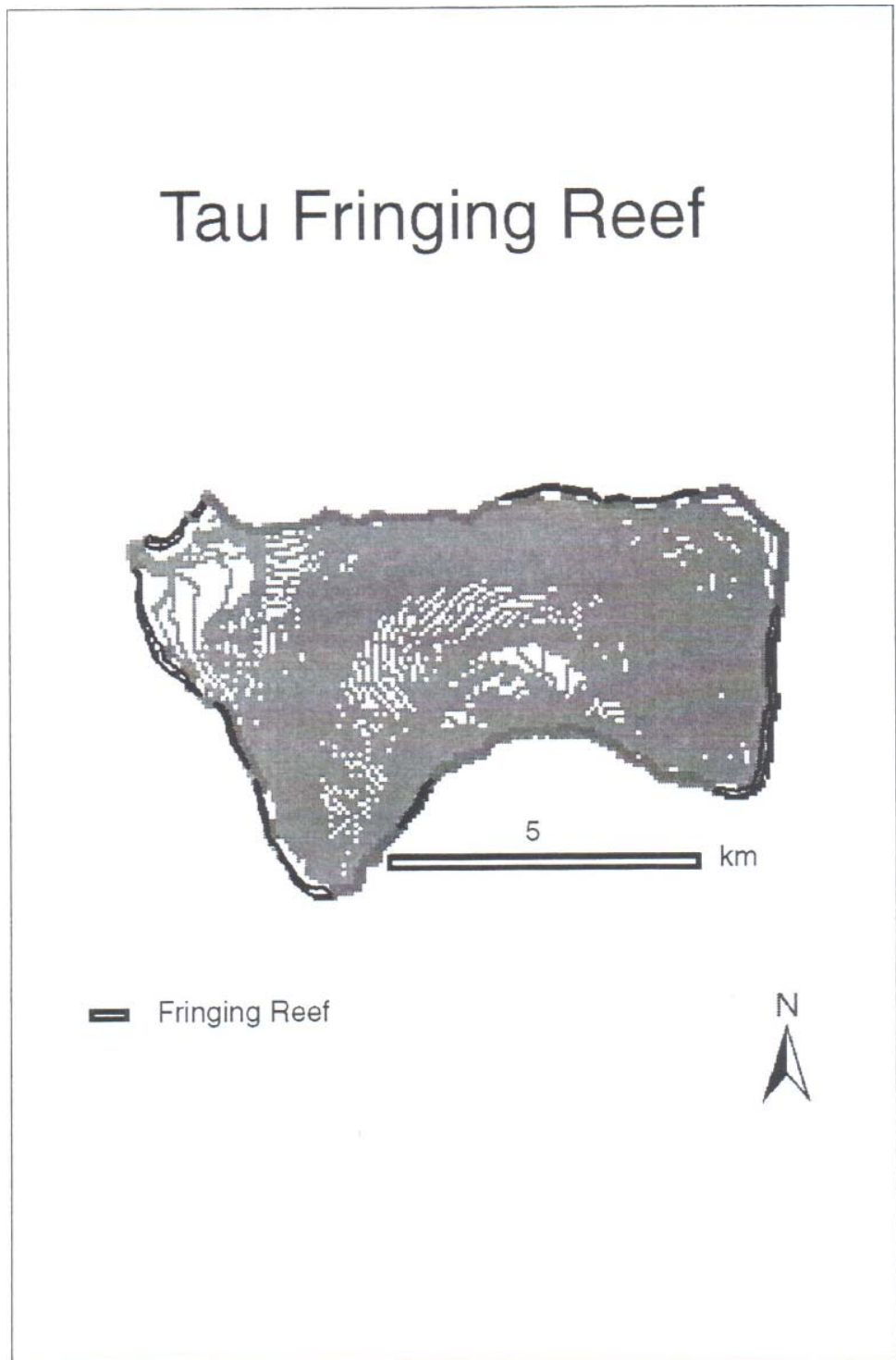


Figure 2: Ta'u's fringing reef

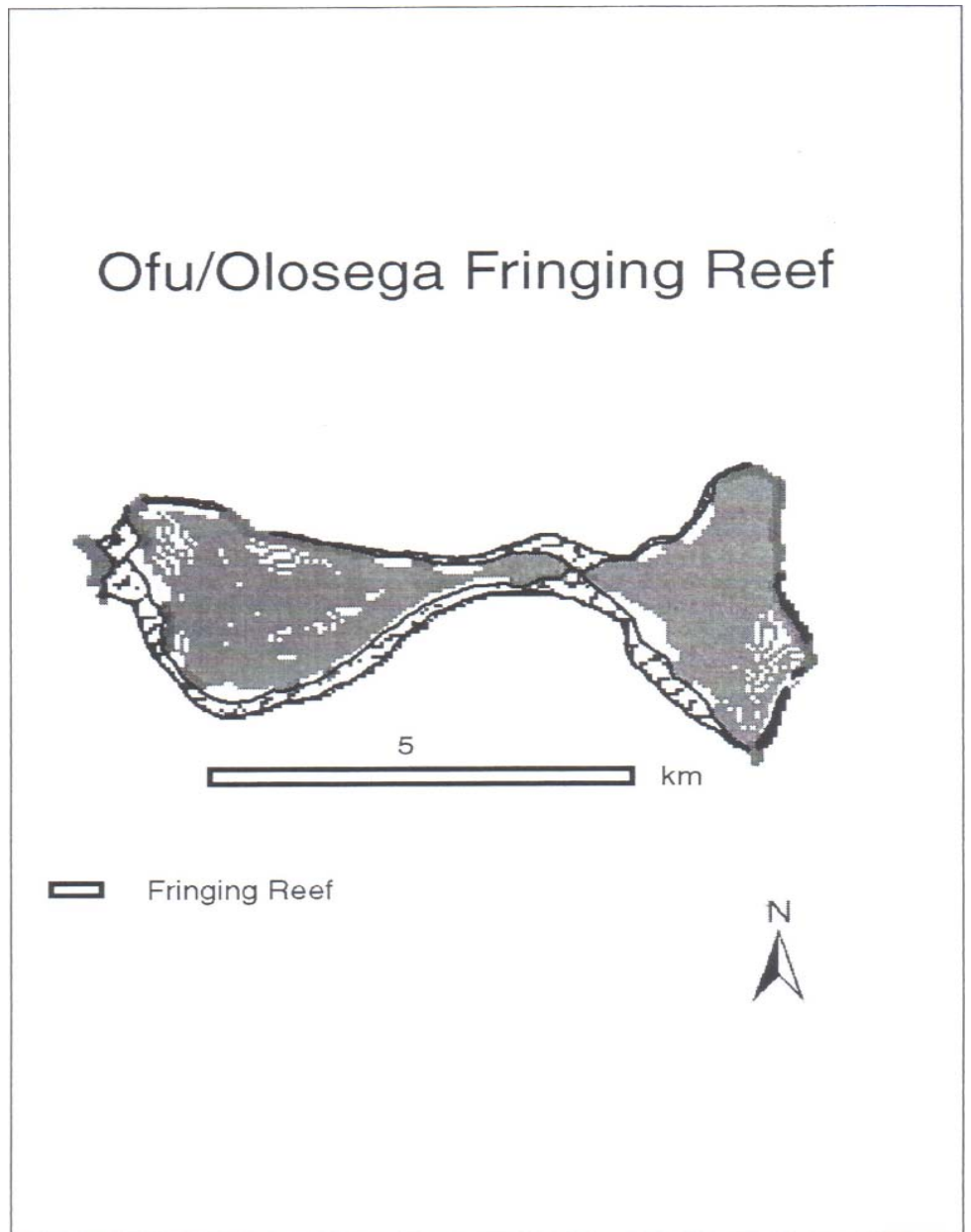


Figure 3: 'Ofu and Olosega's fringing reef

events of deposition, the independence or relatedness of which must be empirically determined in order to obtain archaeologically meaningful units of association" (Dunnell 1992:36). Moreover, the assumption that high densities of artefacts produce the most significant amount of cultural information severely limits data collection to a small fraction of the total area occupied by any past cultural system and systematically excludes nearly all direct evidence of the actual articulation between people and their environment" (Dunnell and Dancey 1986:272).

As an alternative to the concept "site", Dunnell and others (Dunnell and Dancey: 1986; Dunnell 1992; Ebert 1992) call for a new emphasis on data collection looking at the distribution of artefacts regionally rather than comparisons of indiscriminate aggregates of artefacts (sites). Analysing artefact distributions allows for areas with less artefact densities to still be considered relevant on a regional scale. For example, Dunnell and Dancey (1986:272) describe the archaeological record as consisting of "a more or less continuous distribution of artefacts over the land surface with highly variable density characteristics". Density measurements allow archaeologists to create more informed hypotheses about human activity in relationship to environmental contexts and post depositional factors that may have led to differential present day locations.

In the present analyses, I examine what earlier archaeologists working in Samoa commonly assigned as a 'site'. In most cases, it appears that an archaeological 'site' refers to structures located above the ground (such as house mounds, walls, terraces, graves, and star mounds). In much rarer cases, a 'site' may refer to the horizontal extent of a subsurface deposit, although buried deposits are likely to be much more difficult to locate than surface remains and therefore underrepresented in any site inventory.

A few problems associated with distinguishing 'sites' concerns the arbitrariness associated with a demarcated boundary. For example, Hunt and Kirch (1988) refer to To'aga as one subsurface deposit (likely encompassing an aggregation of structures, and portable artefacts referred to as features). In close vicinity to To'aga, Best (1992) records portable artefacts and burials as individual 'sites'. Therefore, a 'site' may potentially be as large as an entire village or as small as an agricultural terrace or grave depending on the archaeologist who conducted the survey. Moreover, surface surveys will result in higher frequencies of late period sites because early deposits are almost certainly deeply buried today.

The locations of "legendary" sites are also included in this analysis because they share an important role in the lives of modern Samoans and deserve recognition as a cultural resource under US legislation. In this analysis, site distributions should be considered the remains of a combination of prehistoric human activity, post depositional process, and decisions regarding site recording made by archaeologists. Future research will undoubtedly be aimed at "siteless" survey and distributional approaches, documenting the continuous location of archaeological material across the landscape.

Previous Archaeological Research in the Manu'a Islands

Early archaeological research in Manu'a was directed by William Kikuchi and Yoshi Sinoto. In 1962, they conducted survey and small scale excavations on Ta'o; the results ultimately reported in Kikuchi's master's thesis (Kikuchi 1963, 1964). In 1980, Jeffrey T. Clark completed a site inventory for the Historic Preservation Office in which descriptions and locations of all recorded archaeological "sites" in American Samoa were reported (Clark 1980).

In 1986, Terry Hunt and Patrick Kirch carried out the Manu'a project (Hunt and Kirch 1987, 1988, 1997; Kirch and Hunt 1993). The primary goals of the project were "(1) through intensive survey, to compile a catalogue of prehistoric and proto-historic surface archaeological remains; (2) through the use of systematic test excavations, to locate and delineate major areas of subsurface deposits; (3) to determine the relationship between subsurface archaeological resources and local geomorphological features and processes; (4) to generate a predictive model of the number and extent of undiscovered subsurface deposits, on the basis of results from objectives 2 and 3; and (5) to enhance the local appreciation of archaeology and historic preservation through the training of local personnel and through a range of public activities" (Hunt and Kirch 1988:154-155).

In order to achieve these goals, Hunt conducted surveys in numerous areas of 'Ofu, Olosega, and Ta'o, recording archaeological sites/features in a series of "classes" that form the basis for the current "classification" (see Table 1).

Table 1: Site/Feature classes (adapted from Hunt and Kirch 1988)

Site/Feature Class	Tau	Olosega	Ofu
Buried Ceramic Midden	1		1
Domestic site complex	6	2	2
Rockshelter	7		1
Specialized site	3		1
Constructed Pathway / Trail	4	2	
Agricultural / Water Trail	1	1	
Legendary Only	10	1	1
Well	5	3	1
Spring / Pool	8		1
Petroglyph	1		
Miscellaneous	11	1	2
Historic	5		1
Total	62	10	11

The 1986 Manu'a survey extended knowledge regarding the nature of late prehistoric settlement and land use into the first century AD. During two subsequent field seasons (1987 and 1989), Kirch and Hunt focused work at the To'aga Site on 'Ofu Island. The subsurface deposits at To'aga date to the earliest periods of Samoan prehistory, with Lapita age plainware pottery dating to AD 500. The excavation also yielded an extensive invertebrate and vertebrate assemblage including marine fauna and evidence for prehistoric bird over predation (Kirch and Hunt 1993; Nagaoka 1993; Hunt and Kirch 1997).

Kirch and Hunt's research is significant because it focused on the impact of geomorphological change and prehistoric settlement and subsistence. The To'aga site has been affected by a combination of sedimentation, sea level fall, and island subsidence that ultimately created a highly productive coastal plain (Kirch and Hunt 1993; Hunt and Kirch 1997). Landscape transformation has implications for the location and prediction of subsurface deposits because talus from nearby slopes has buried many older sites located inland in areas that were once sandy beaches. Consequently, it is important to take geomorphological changes into consideration when discussing the current location of Samoan coastal archaeology.

In 1992 Simon Best added close to 40 new archaeological 'sites' to the Manu'a inventory during survey and excavations for the 'Ofu/Olosega highway link and work for Pacific International Engineering on Ta'u. However the majority of 'sites' located and recorded by Best were found within the area previously defined by Kirch and Hunt as To'aga, attesting to problems associated with the 'site' concept. Best also conducted small scale subsurface testing at AS-11-11, 12, and 13, near Va'oto Lodge.

Ninety nine archaeological 'sites' are used in the present analysis. The majority of these sites are surface archaeology, with only a few locations associated with legends and/or subsurface deposits. Undoubtedly, a vast amount of subsurface materials remains unexplored, deeply buried under several metres of talus.

The Model

One goal of predictive modelling in archaeology is locating environmental characteristics that meet specific requirements for human survival. Jochim (1976:11) views settlement prediction as a solution to three main problems: 1) resource use schedule, 2) site placement, and 3) demographic arrangement. The natural parameters of a particular environment place constraints on these solutions. For example, the spatial distribution of flat topography, easily accessible coastlines, proximity to fresh

water, and elevation all define limitation and opportunities in the Manu'a environment. As a result, any model aimed at locating suitable areas for human activity must find areas that maximize opportunities for resource acquisition while minimizing other variables.

In the Manu'a environment, access to relatively flat land is crucial to agricultural success and human settlement. Reliance on available marine resources would have also favoured settlement near areas with easy coastal access and productive coral reefs. Elevation can place an important constraint on human settlement because in areas similar to Manu'a, high elevations lead to greater difficulty reaching coastal areas. However archaeological evidence on both Tutuila and Upolu suggest an expansion of inland settlement after AD 1400, (Pearl 2004; Green and Davidson 1969, 1974; Nunn 2000), possibly indicating the increased importance of agriculture and trade to buffer travel costs. Proximity to fresh water and location of productive soils were also likely important variables in human settlement and activity.

Description of Geographical Layers

Coastal Access

The Coastal Access layer (see Figures 4 and 5) consists of four zones: 1) sand beaches, 2) high basalt coasts, 3) low basalt coasts, and 4) rubble foreshores. Generally, sand beaches have the best coastal access because the amount of effort and danger entering and exiting the water during foraging and fishing expeditions is minimal when compared to other areas such as high basalt coastlines. Quick inspection of the location of archaeological sites indeed suggests that areas around sandy beaches were loci of human activity.

Slope

Slope degree is a limiting factor in Manu'a settlement as it is generally assumed that steep slopes are inhospitable for settlement and agriculture. On Ta'u (see Figure 6) the northeastern portion is relatively flat with gently increasing slopes moving inland.

In contrast, most of the southern coastline quickly inclines to greater than 15 degrees. On 'Ofu and Olosega (see Figure 7) most coastal areas are relatively flat and gently sloping, excluding 'Ofu's southern coast which inclines dramatically near Le'olo Ridge.

Elevation

Elevation is a relevant environmental variable because the costs of living at higher elevations translate into travel time and energy expenditure if other social mechanisms such as trade networks, do not evolve as solutions. Furthermore, in Manu'a, higher elevations are heavily forested and the time and effort needed to clear these areas would have been extremely costly. In this analysis it was important to add elevation as a layer because high elevation areas inland on Ta'u are relatively flat in many places (Figures 8 and 9). Therefore, slope alone can not be considered a reliable indicator of settlement without taking elevation into consideration.

Methodology

The goals of this GIS analysis are to locate areas in the Manu'a environment that played a role in structuring the location of archaeological sites and then highlight overlapping regions of highly suitable environmental zones. These intersecting areas are used to create ranked optimal environmental zones. Earlier research (Hunt and Kirch 1987, 1988; Best 1992) on archaeology in the Manu'a group is used to compare site locations with the intersecting optimality zones. In order to do this, I acquired geographical data on coastal access areas, slope, elevation, and streams. I then created digital representations of these themes and performed several in depth analyses using ESRI Arc 9.1 software.

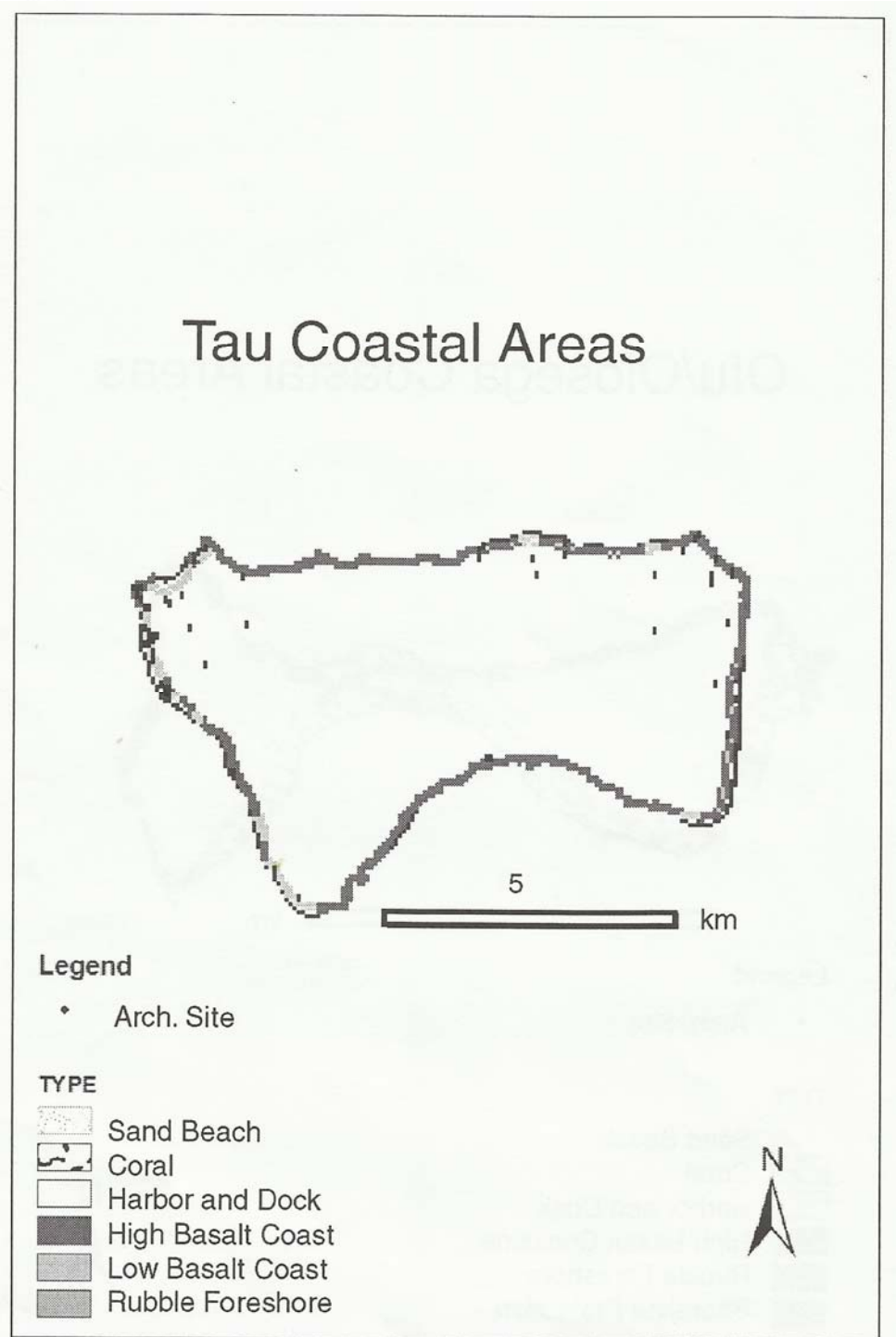


Figure 4: Ta'u coastal access zones

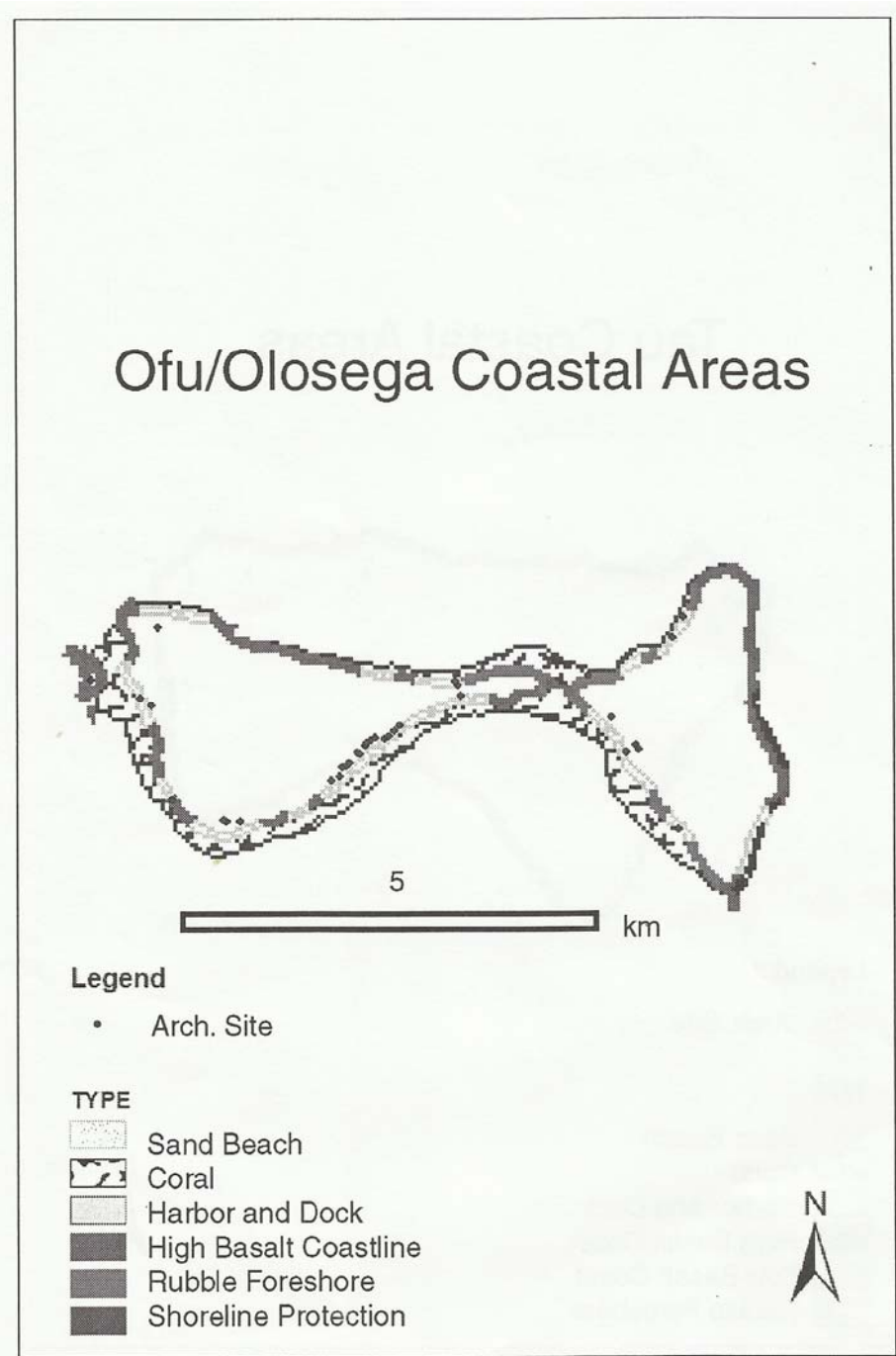


Figure 5: 'Ofu/Olosega coastal access zones

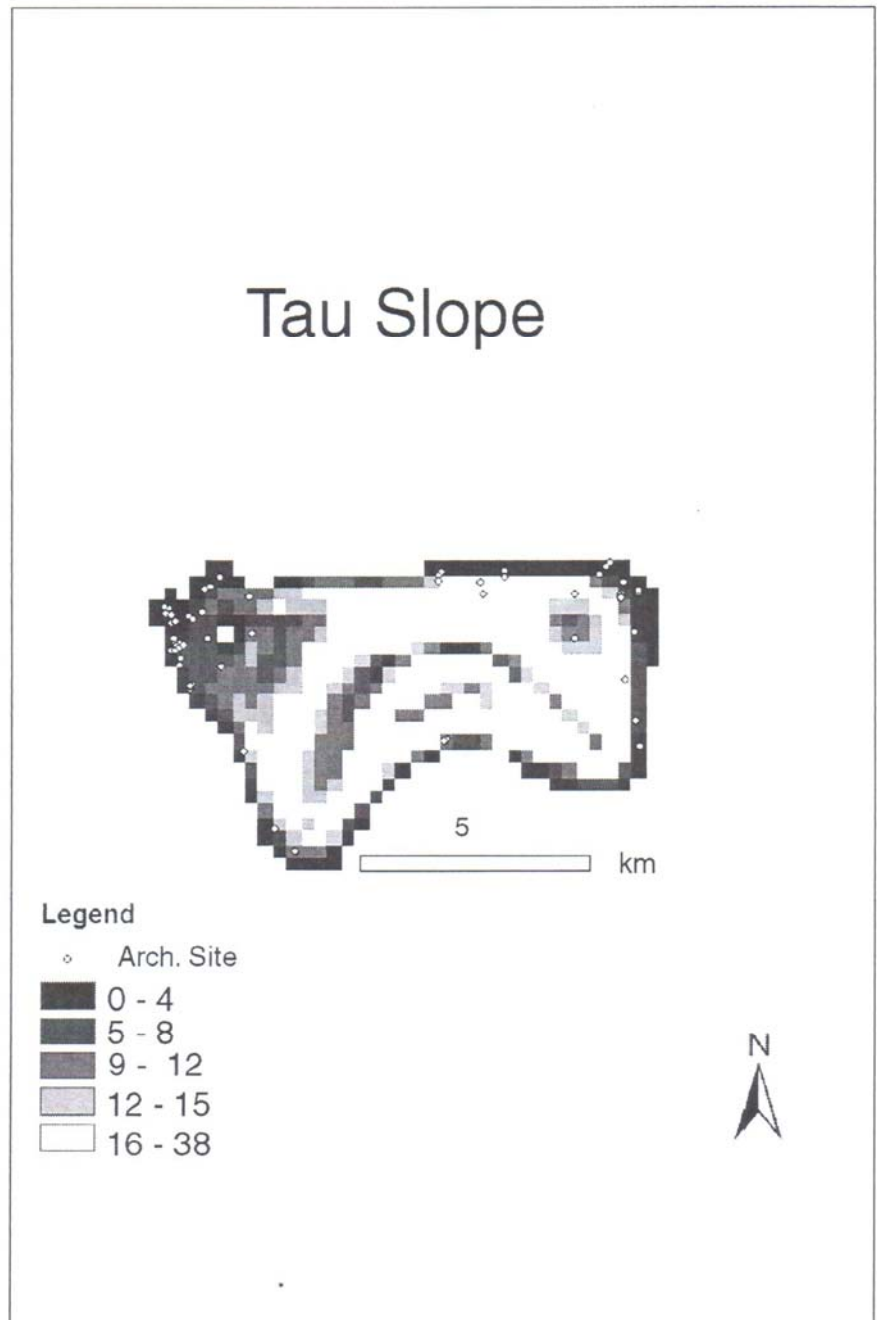


Figure 6: Ta'ū slope zones

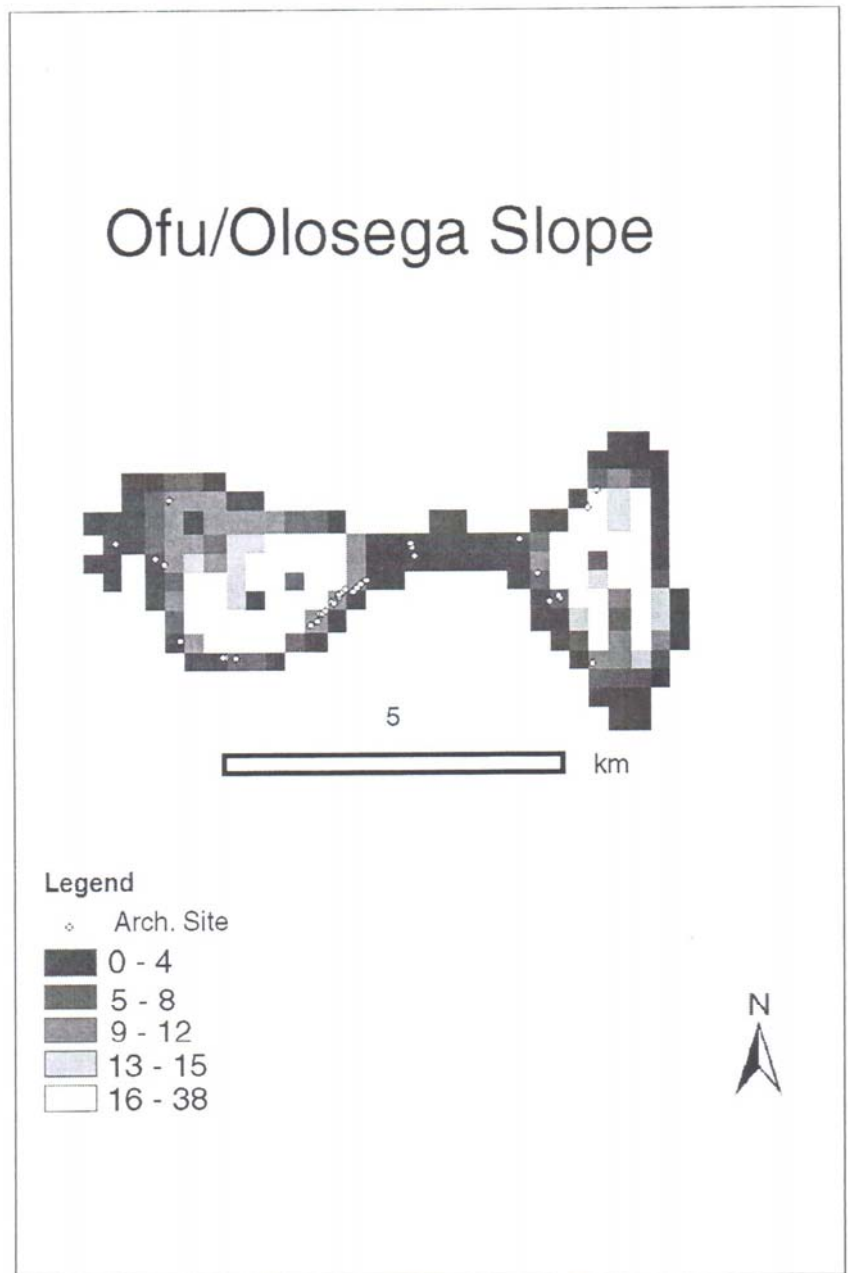


Figure 7: 'Ofu/Olosega slope zones

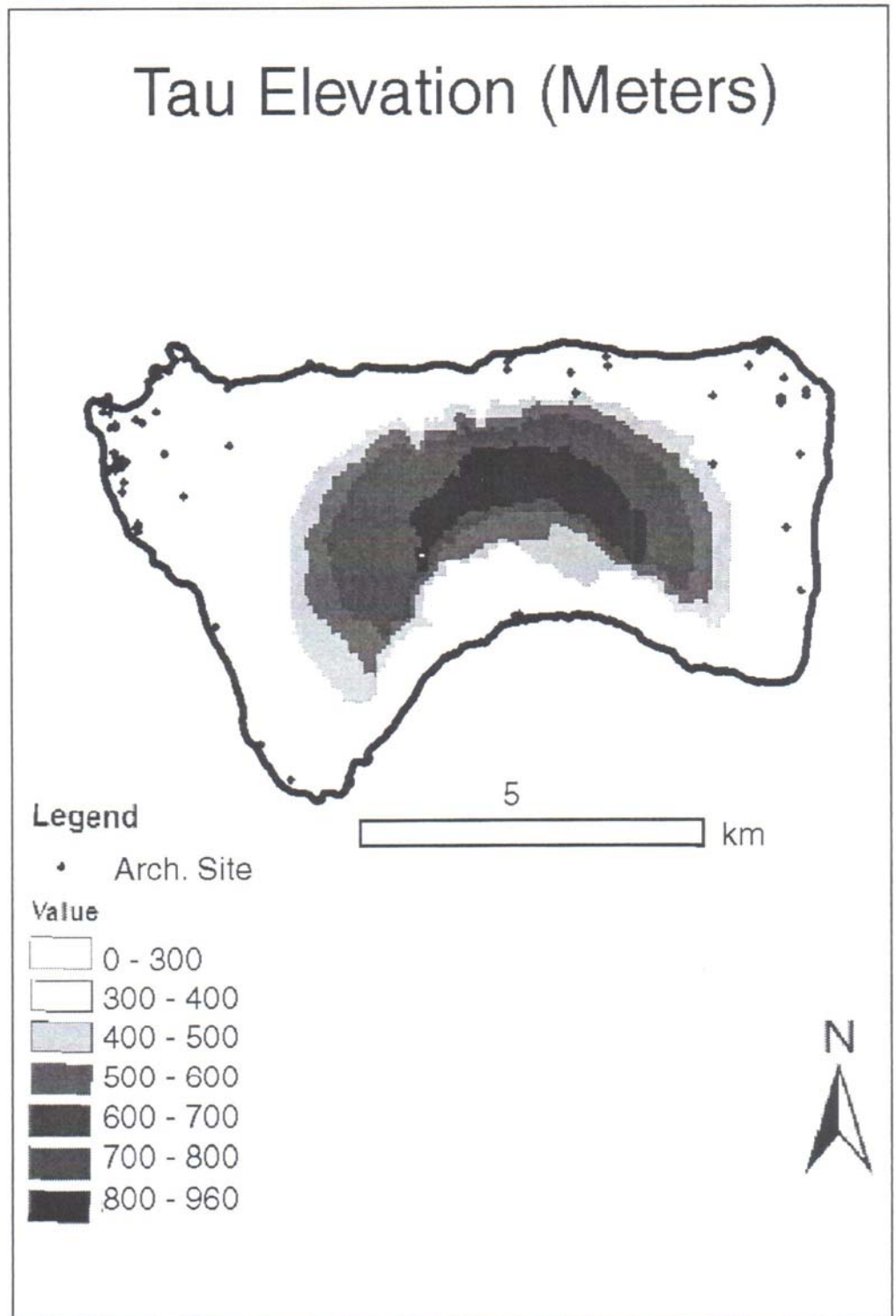


Figure 8: Ta'ū elevation zones

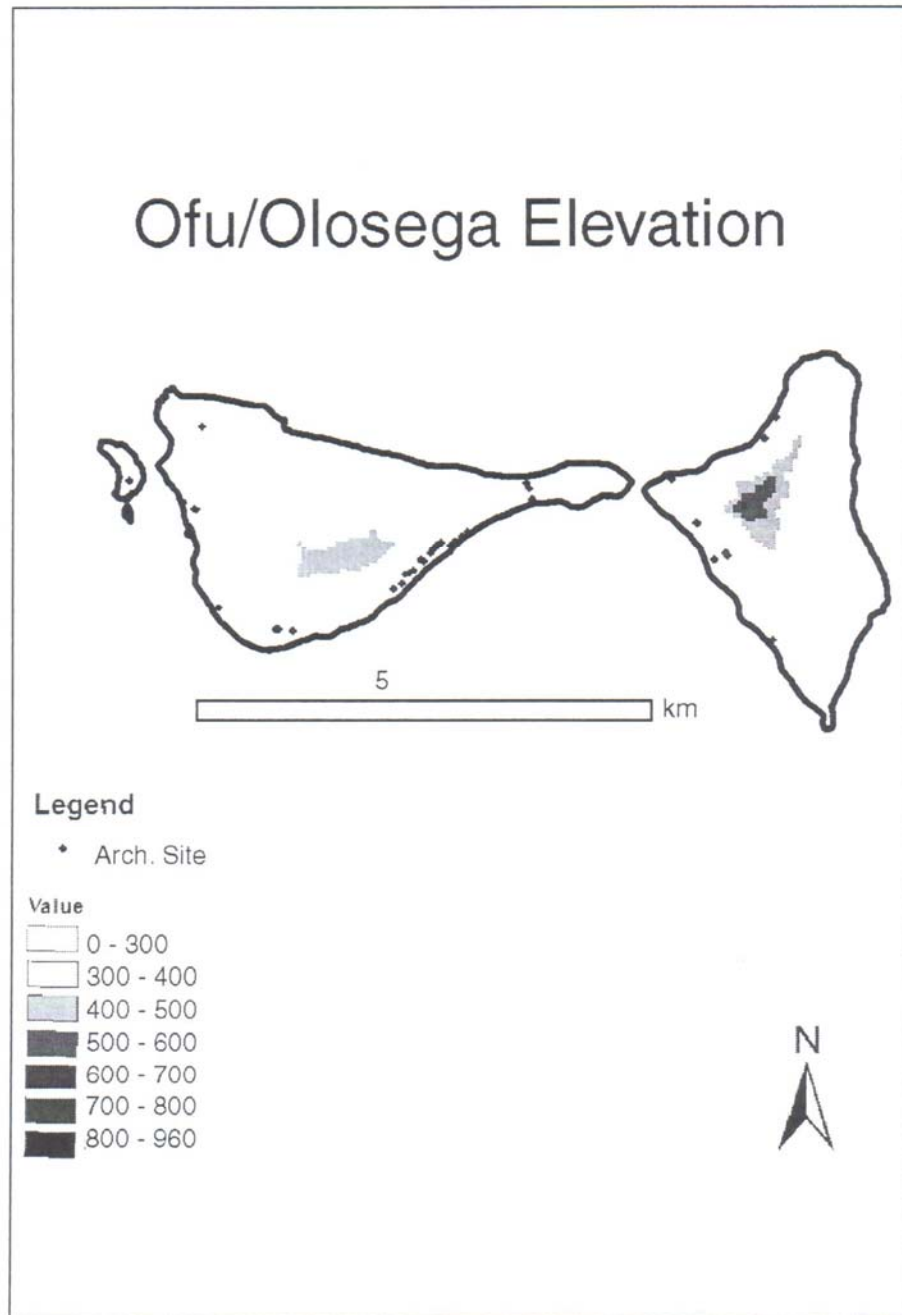


Figure 9: 'Ofu/Olosega elevation zones

Raster Cost/Distance Surface Analysis: Elevation/Slope/Coastal Access

In order to locate areas that ranked highest in elevation, slope zone, and coastal access, it was necessary to rank the slope and elevation zones according to suitability (Tables 2 and 3). Performing a reclassification calculates raster cells according to rankings rather than absolute values. For example (Table 2), a reclassification of slope zones returns raster values of one to ten rather than zones based on absolute slope degrees.

Table 2: Reclassification-slope ranks

Slope (degrees)	Rank
0-4	1
4-9	2
9-12.5	3
12.5-16	4
16-19	5
19-22	6
22-26.5	7
26.5-31	8
31-37	9
>37	10

Table 3: Reclassification-elevation ranks

Elevation (meters)	Rank
0-100	1
100-200	2
200-300	3
300-400	4
400-500	5
500-600	6
600-700	7
700-800	8
800-960	9

In order to create ranked zones for coastal access, it was necessary to develop a raster surface of distance from the high ranked coastal access areas. The raster distance tool allocates increasing values based on cell distances from the sand beaches. These various zones were then reclassified to produce ranked zones of distance from coastal access (Figures 10 and 11).

Next, the three ranked raster layers (slope, elevation, and distance from coastal access), were combined and reclassified to create one cost distance surface based on slope, elevation, and coastal access, approximating suitable zones for archaeology (see Figures 12 and 13).

Tau Distance Cost Surface

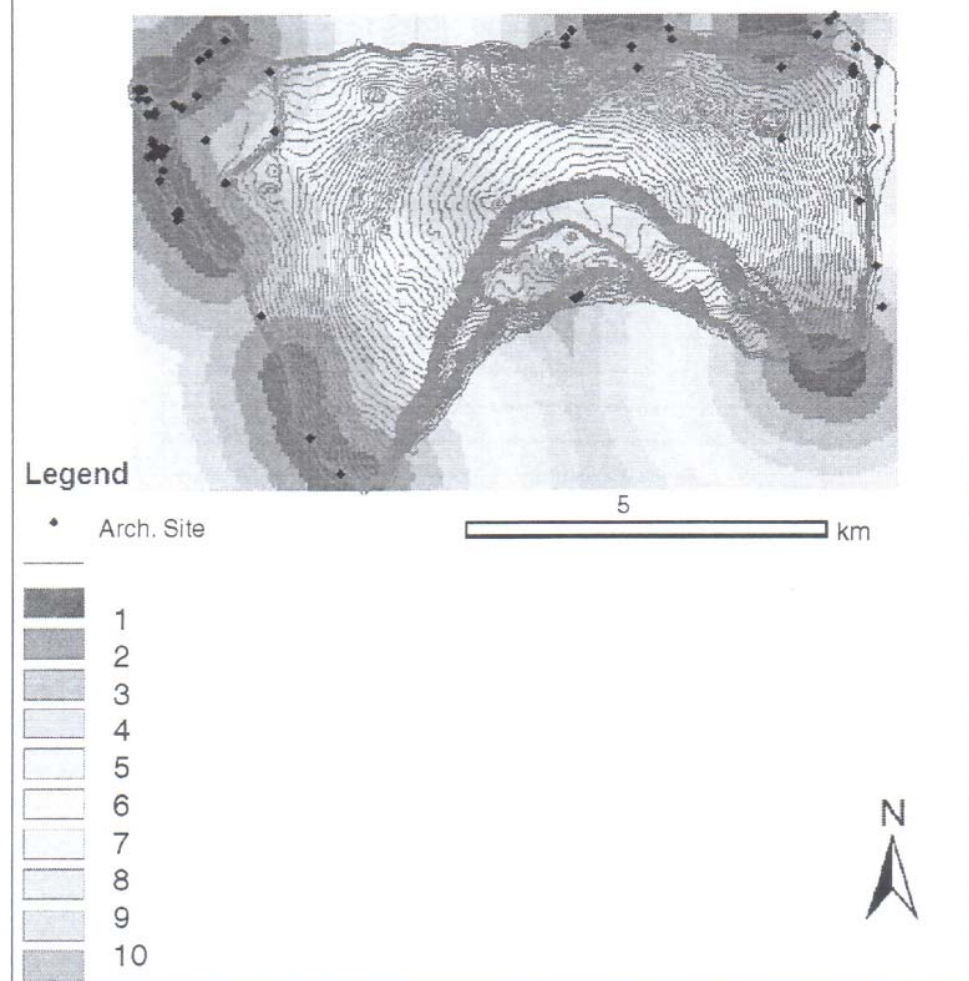


Figure 10: Ta'u distance from coastal access (Ranked Zones)

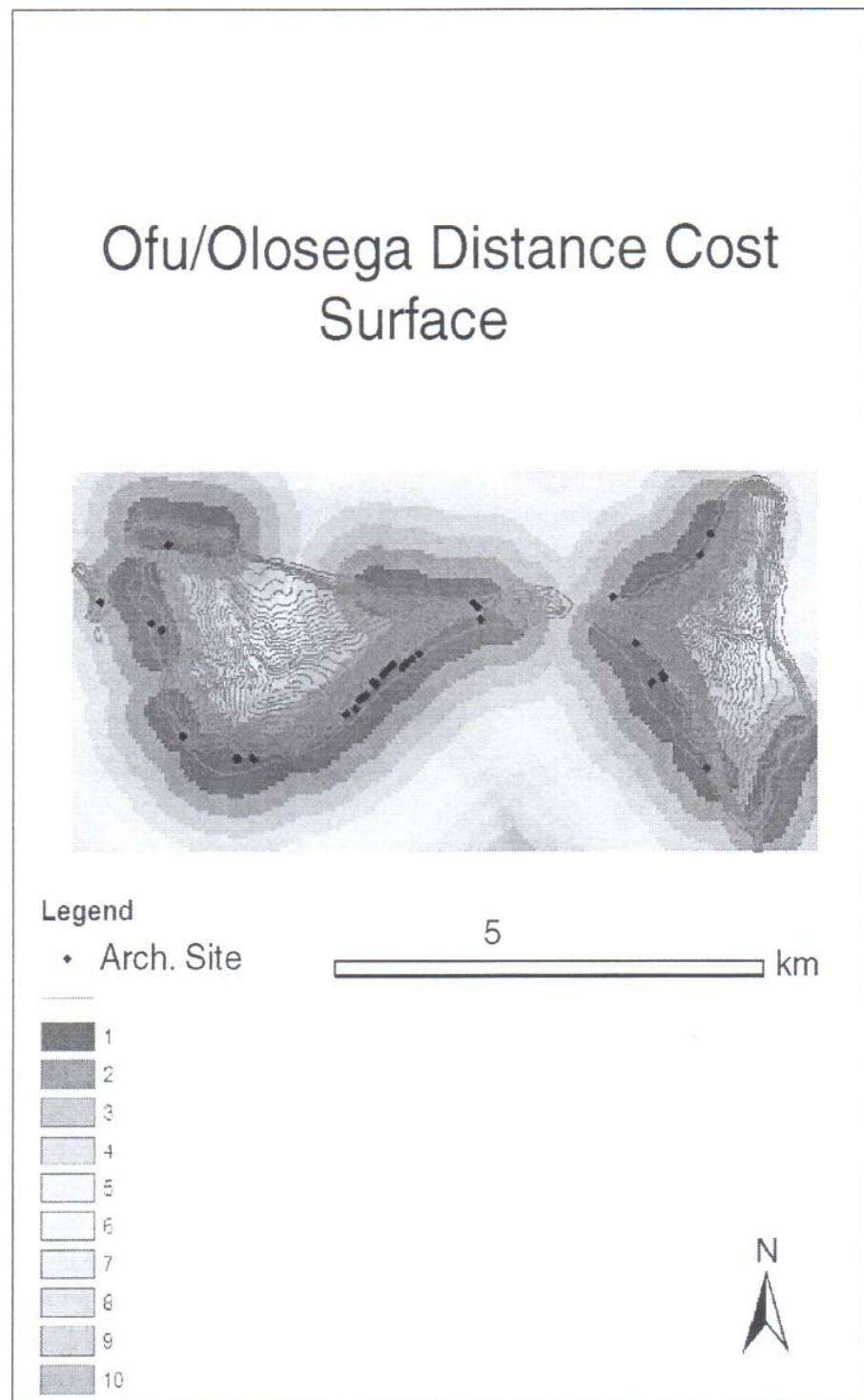


Figure 11: 'Ofu/Olosega distance from coastal access (Ranked Zones)

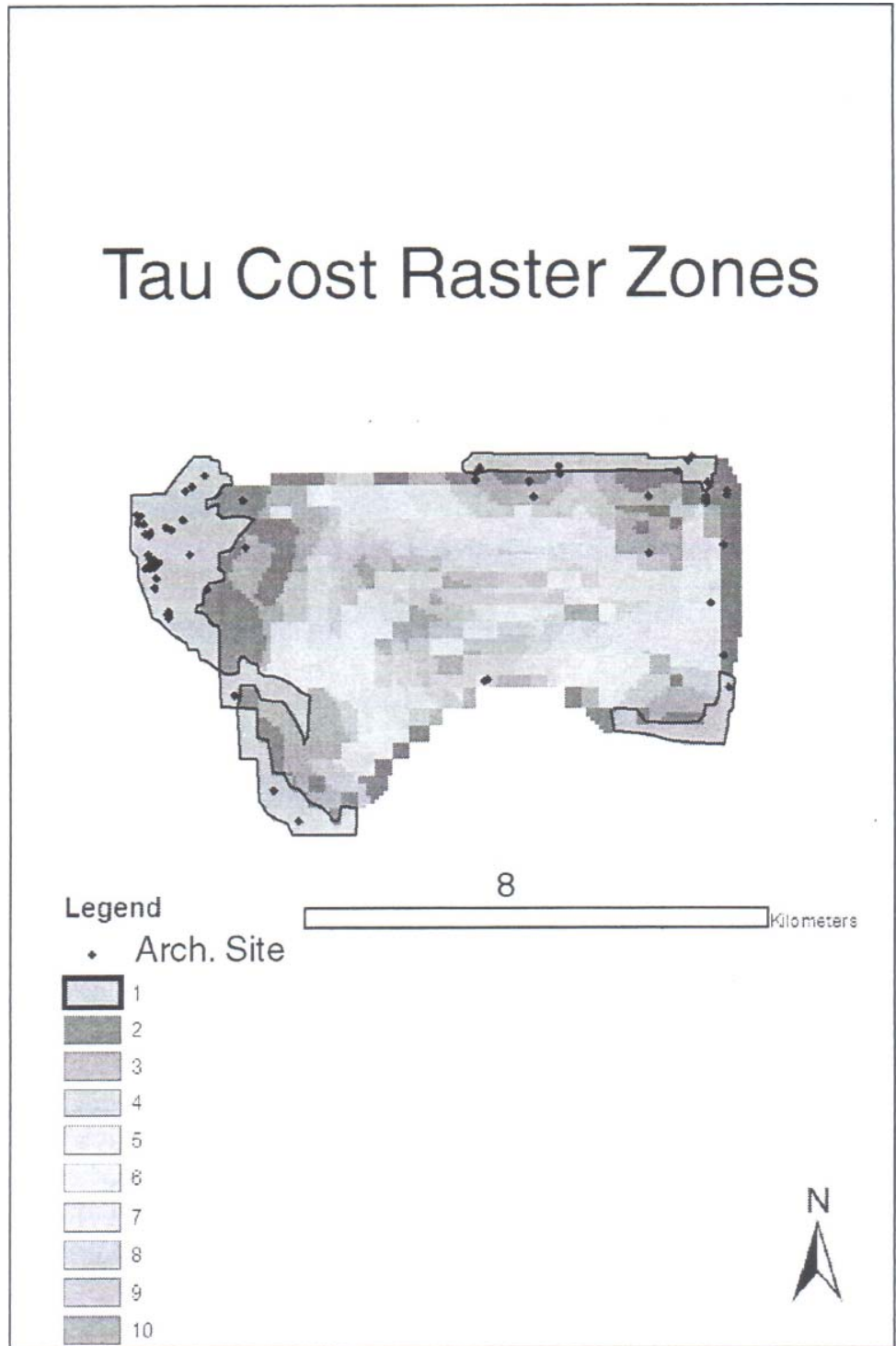
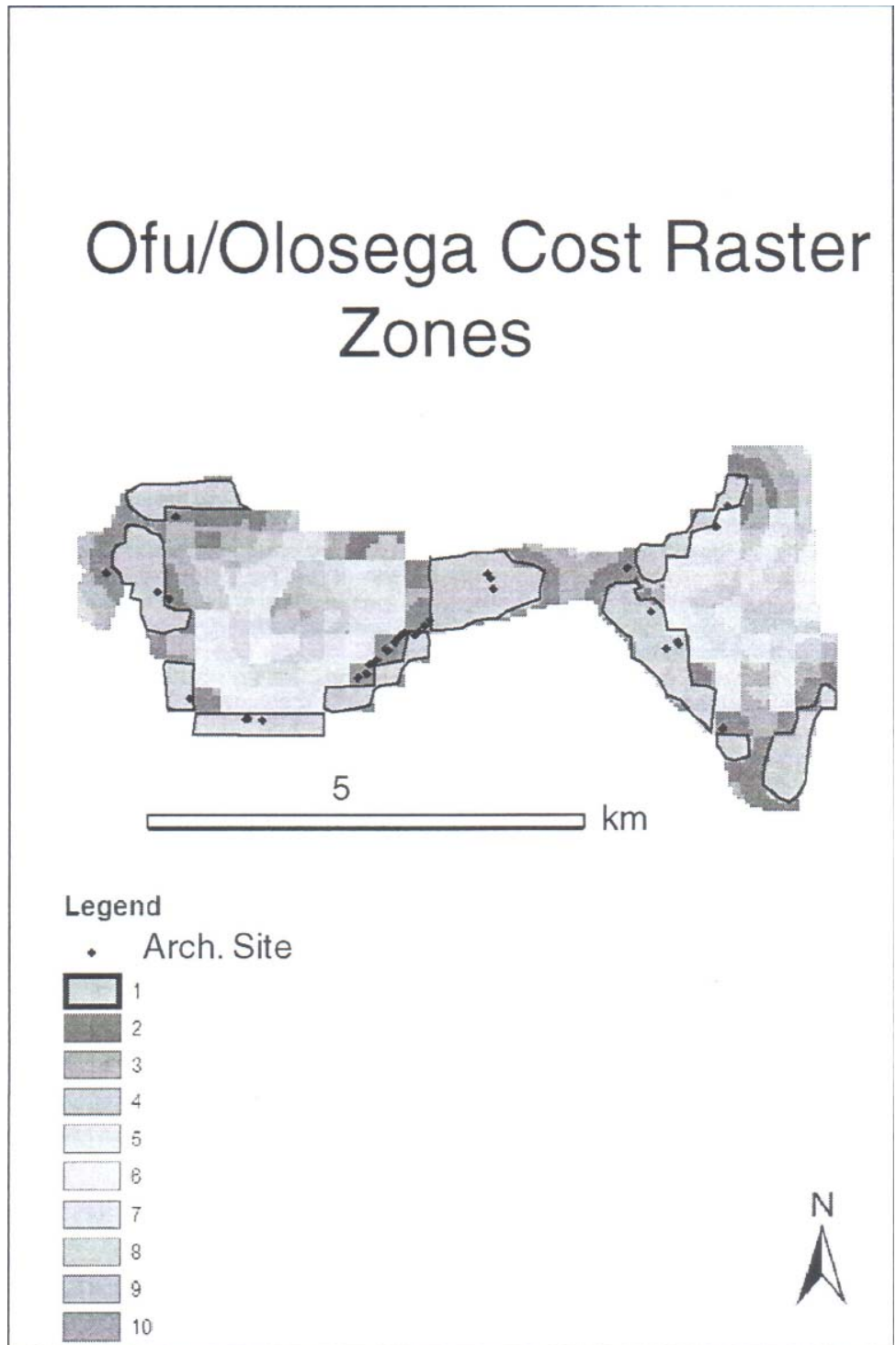


Figure 12: Ta'u slope/elevation/distance from coastal access ranked zones



0

Figure 13: Ofu/Olosega slope/elevation/distance from coastal access

Results

On Ta'u Island, the cost/distance surface using elevation, slope, and distance from coastal access successfully predicted the location of 44 out of 65 archaeological sites (68 per cent success rate). When a 50 metre distance zone was placed around Zone 1, 51 of 65 (78 per cent success rate) archaeological sites were successfully located. Finally, using a 100 metre distance zone identified 53 of 65 (82 per cent).

On 'Ofu and Olosega the cost/distance surface successfully predicted 14 out of 34 sites (41 per cent). Another 10 sites were located 50 metres from the boundary of Zone 1 increasing the success rate to 71 per cent. Further distance analysis revealed that on 'Ofu and Olosega, 91 per cent (31 of 34) of all archaeological sites were either located within or at most 100 metres away from the boundary of Zone 1.

Streams and the Location of Archaeological Sites

In order to check if variables other than slope, elevation, and coastal access affect the location of archaeological sites, I performed an analysis using the location of streams as a relevant factor (see Figures 14 and 15).

On Ta'u, only one archaeological site was located within 100 metres of a stream. If proximity to streams was an important variable in the placement of archaeological sites, one would expect a high number of sites to be located less than 100 metres from a stream. These results suggest that on Ta'u proximity to streams is not an important factor for predicting archaeology.

On the islands of 'Ofu and Olosega, only four of 34 archaeological sites are located within 100 metres of the 20 streams distributed across the two islands (see Figure 15). Olosega's east coast has several relatively significant streams flowing from high elevations to the sea but there does not appear to be archaeological sites in this region of the island. The eastern area of Olosega has very steep topology that when mixed with an alluvial environment, likely has high potential for flooding and mudslides. Consequently, settlement along the eastern coast of Olosega would have been quite risky. Moreover, coastal access is poor in this region with the majority of coastline consisting of high steep basalt cliffs.

Methodological Issues Associated with Arbitrary Environmental Zones

The results of the distance analysis lead to a few relevant issues. First, it is important to mention that the distance zones chosen (50 and 100 metres) are arbitrary and suggest that although environmental Zone 1 failed to predict the location of every archaeological site in Manu'a, in general the majority of archaeology is indeed located in close proximity to Zone 1. The use of arbitrary zones is also important when discussing the location of low ranked zones such as Zones 6-10. For example, based on the archaeological evidence, there is no reason to suggest Zone 8 may potentially contain more sites than Zone 10. It is quite likely that areas may reach a point of diminishing returns where the land will no longer satisfy the necessary requirements for human activity. In such a case, an actual zone ranking is meaningless beyond use as a heuristic device.

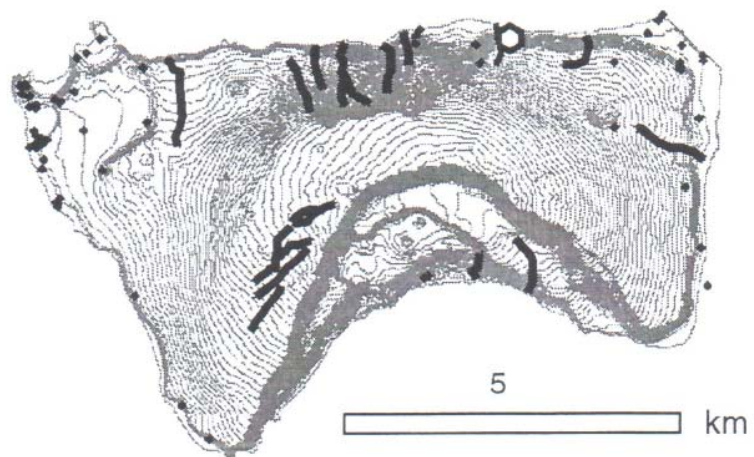
In the current model, zone rankings were simply developed as methodological tools useful for classifying various areas of land into more manageable analytic units of analysis. Beyond the model, these analytical units should not be used as reconstructions or actual measurements of settlement optimality. As heuristic tools, the development of environmental zones suggests that higher ranked environmental zones (Zones 1-3) contain more archaeological sites than lower ranked ones. Statistical analysis also supports this point.

Statistical Relationships between Number of Sites and Zone Rankings

The original environmental zones were based on criteria thought to be relevant to settlement and resource acquisition. Consequently, one would expect that as environmental zones decrease in rank, so will the number of archaeological sites found. In order to test this hypothesis, I use Spearman's rank order coefficient and Kendall's tau to test for a correlation between environmental zone rank and number of sites.

On Ta'u there is a strong positive correlation between high ranked environmental zones and

Tau-Sites Within 100 Meters of Streams



Legend

- Arch. Site
- ⬡ Arch. Site within 100 meters of streams
- Streams



Figure 14: Ta'u sites located within 100 metres of streams (n =1)

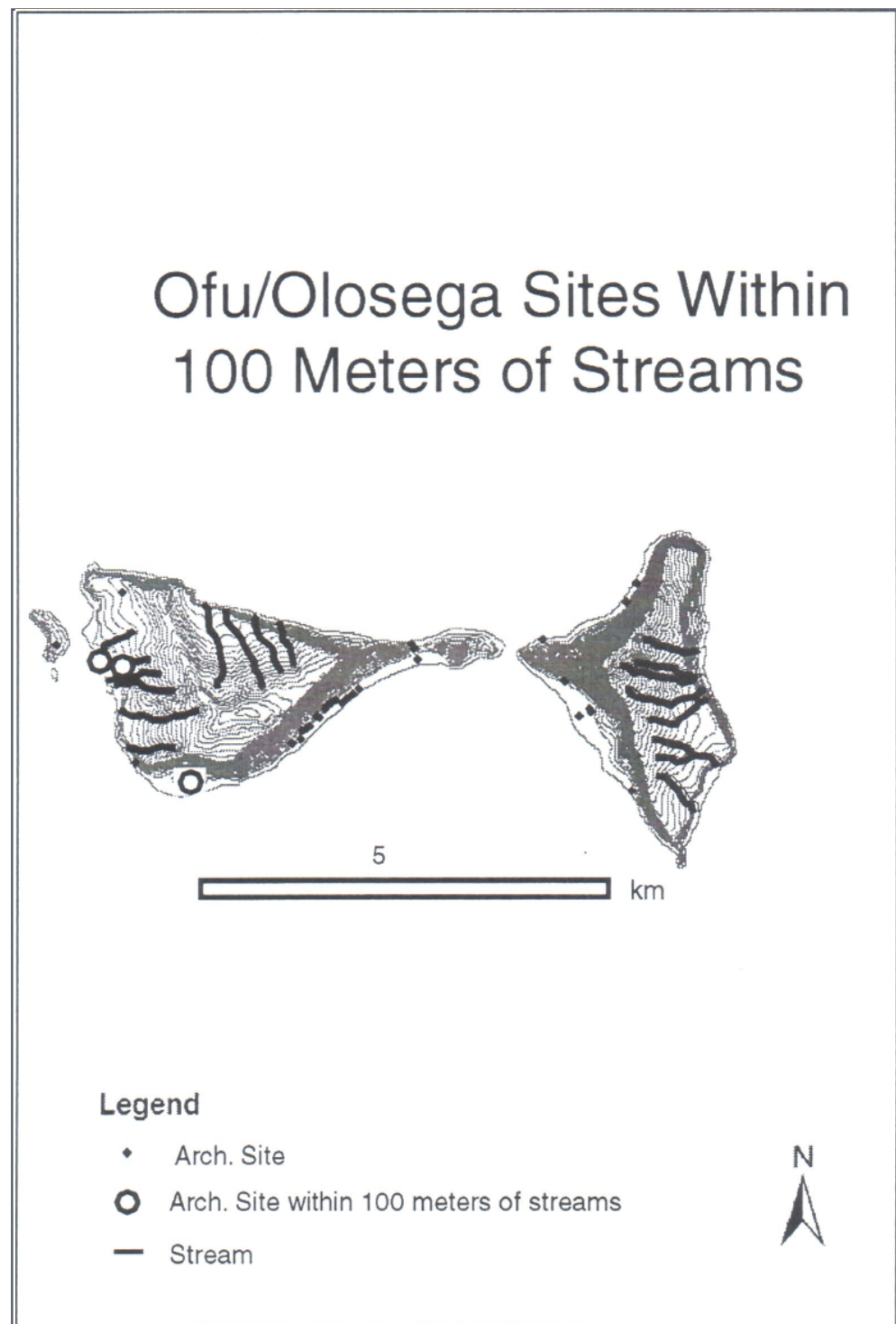


Figure 15: Ofu/Olosega sites located within 100 metres of streams (n = 1)

number of sites ($n = 10$, $r_s = .912$, sig. $< .000$ (1 tailed); Kendall's tau = .845, sig $< .001$ (1 tailed). Relative comparisons of the number of archaeological sites found supports the conclusion of the statistical test with 69 per cent of all archaeological sites on Ta'u found within Zone 1, 17 per cent found in Zone 2, 10 per cent found in Zone 3, and only 4 per cent found within the remaining seven zones.

Results on 'Ofu and Olosega also suggest a strong positive correlation between environmental zone ranking and number of archaeological sites found ($n = 10$, Spearman's $r_s = .619$, sig $< .028$; Kendall's tau .487, sig $< .037$). Comparisons of relative abundance support the statistical test but demonstrate that Zone 1 and Zone 2 have the majority of archaeological sites with Zone 2 actually containing 53 per cent of archaeological sites and Zone 1 containing 44 per cent. The remaining 3 per cent of archaeological sites consists of one water well found in Zone 6.

Geomorphological Changes and Site Locations

It is noteworthy to mention that on 'Ofu and Olosega, archaeological sites are predominantly located in both environmental Zones 1 and 2, in contrast to Ta'u where the majority of sites were located within Zone 1. A few explanations are worth speculation. Analysis of the different environmental characteristics of each island may prove insightful. For example, 'Ofu and Olosega have much narrower coastal plains than Ta'u resulting in less land availability. Consequently, settlement in environmental Zone 2 may have been the result of necessity rather than optimality. As more suitable areas filled up, settlements moved slightly inland.

however, a more likely scenario concerns the progradation of the coastal plain on 'Ofu's southern coast. Geoarchaeological research by Kirch and Hunt (1993) suggests that the region near the To'aga site was transformed from a marine environment into a coastal plain through a combination of sea level regression and sedimentation. Much of the current beachfront was under water during the mid-Holocene high sea level stand. In fact, 2,000 years ago, the coastline at To'aga appears to have been located close to 100 metres inland (see. Hunt and Kirch 1997:111). During early prehistory, what is now environmental Zone 2 was likely very similar to modern day environmental Zone 1.

At To'aga, a narrow coastal bench formed approximately 3,000 years ago over 100 metres from the present day shoreline. Sediment analysis reveals the presence of coral fingers and cobbles indicative of a high energy marine environment at the time considerably inland of the modern high tide line. A cultural layer containing thin orange/red slipped pottery was found on top of the ancient coastal bench suggesting initial human settlement of the terrace. This occupational zone is now located 5-15 m beneath boulder talus and colluvium. A thin paleosol marks the stabilization of the coastal terrace between 2,000-1,600 years ago. Settlement moved closer to the modern shoreline during the late-Prehistoric period with house mounds and gravel floors (*'ili'ili*) located approximately 50 m from the current beach. This area in area would have most likely been under water 2,000 years ago. By 1000 BP, a layer of clay-silt colluvium had been deposited over the coastal terrace reflecting increased use as an agricultural zone (Kirch and Hunt 1993:67-68; Hunt and Kirch 1997:112-114).

In environments experiencing coastal progradation, stratigraphy is deposited horizontally across the prograding coastal terrace. Consequently, older deposits will be found deeply buried inland of the present day shoreline with younger deposits located closer to the coast. The actual modern day surface is the result of contemporary depositional events. Therefore, surface remains are likely to be biased towards more recent materials.

Evidence from 'Aoa Bay on Tutuila's northeastern coast suggests that the ancient shoreline is also significantly inland of the modern bay (Clark and Michlovic 1993). Green (2002) sums up the relationship between settlement and geomorphology in 'Aoa valley: "While the relative mid-Holocene sea level high stand at 6-3 ka apparently inundated the valley mouth, its late Holocene decline fostered the positioning of its earliest human settlement on the protected shores of what was then an embayment valley, with the result that the early pottery site now lies inland in a position behind the present coastal village ... " (Green 2002:133). Future research on local landscape evolution in Manu'a will undoubtedly aid archaeological prediction by elucidating the chronology of environmental transformations and settlement history.

Recommendations for Management of Archaeological Resources

This GIS model demonstrates a number of important factors for heritage resource management and archaeological prediction in the Manu'a Islands. First, in light of the relative paucity of data from inland areas, it is difficult to say with complete confidence how the distribution of archaeological sites inland will differ from coastal areas once more survey and site recording is completed.

The results of the raster cost surface using elevation, slope, and coastal access suggest that on *Ta'u*, Zone 1 contains the most archaeological sites. Environmental Zone 1 is made up of coastal areas in close proximity to sand beaches, with elevations below 100 metres, and slopes less than 10 degrees. Therefore, any development projects planned in Zone 1 are more likely to encounter archaeology than in the other nine zones. The Spearman's rank order coefficient and Kendall's tau both suggest a strong positive correlation between zone ranking and number of archaeological sites recorded.

Similarly, on 'Ofu and Olosega, the Spearman's rank order coefficient and Kendall's tau test show a strong positive correlation between zone ranking and archaeology. In contrast to *Ta'u* where the majority of archaeology was found in Zone 1, on 'Ofu and Olosega, environmental Zones 1 and 2 are both equally likely to contain archaeological sites, while most other zones contain virtually no sites.

Finally, the history of island geomorphology must be critically examined when addressing suitable environments for archaeological sites. Research at To'aga on 'Ofu Island (Kirch and Hunt 1993), and 'Aoa Valley, Tutuila (Clark and Michlovic 1993) indicate that coastal environments in American Samoa have undergone dramatic changes since human settlement. Future research should attempt spatial and temporal modelling of these environments while chronologically ordering archaeological sites accordingly. Adding a temporal component to a spatial GIS analysis will aid site prediction by creating spatio-statistical relationships between chronological periods and landscape changes. These relationships can then be used to predict where archaeology of different time periods are likely located today. Although, the data requirements for a spatial-temporal GIS model are large, the future potential of this important technology is quite exciting.

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