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THE SĀMOA ARCHAEOLOGICAL GEOSPATIAL DATABASE: INITIAL DESCRIPTION AND APPLICATION TO SETTLEMENT PATTERN STUDIES IN THE SĀMOAN ISLANDS

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Jeff Clark's contributions to the archaeology of Sāmoa and Hawai'i are numerous and variously highlighted throughout this Special Issue. In this paper we describe our efforts to assemble an archaeological geospatial database incorporating the locations of more than 900 archaeological sites and features distributed across the archipelago with an associated suite of 420 radiocarbon and 10 thorium-series dates. The Sāmoa Archaeological Geospatial Database builds on the pioneering settlement pattern research by Jeff Clark and Roger Green and the current corpus of radiometric dates from the archipelago. While the database offers an important first step for examining regional patterns in demography and land use, much additional work is required to convert previously recorded "site"-based data into meaningful comparable analytical units for settlement pattern studies (see Morrison 2012; Morrison and O'Connor 2015). We highlight this process with an example drawn from Clark's archaeological surveys in 'Aoa Valley on Tutuila Island.

SĀMOAN SETTLEMENT PATTERN STUDIES

For archaeologists interested in settlement pattern research in Polynesia (see Morrison and O'Connor 2015 for a recent review), the Sāmoan Archipelago is significant largely as a result of Roger Green, Janet Davidson and colleagues' initial research during the 1960s in the western part of the archipelago (formerly Western Samoa) (Green and Davidson 1969, 1974). The resulting two volumes of *Archaeology in Western Samoa* were the first to describe the spatial and temporal distribution of Sāmoan site types and archaeological deposits on the islands of 'Upolu and Savai'i and set the agenda for later archaeological research conducted within the remaining Sāmoan Islands. Although by the

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close of the 1970s only limited archaeological research had been conducted on the eastern islands of Tutuila, Ofu, Olosega and Ta‘ū (see Frost 1978; Kikuchi 1963), the mid-1980s witnessed the growth of more intensive research projects covering large landscapes. Explicitly noting the lack of research similar to Green and Davidson's in the eastern islands, Jeff Clark and colleagues (e.g., Clark 1993; Clark and Herdrich 1988, 1993; Clark and Michlovic 1996; Clark *et al*. 1997) conducted settlement pattern research in the eastern district of Tutuila Island, which they termed the Eastern Tutuila Archaeological Project. They sought to improve "our understanding of how prehistoric populations were distributed over the landscape, how that pattern of distribution changed over time, and the systemic relationships between … those populations and their environmental surroundings" (Clark and Herdrich 1993: 147).

The results of the Eastern Tutuila Archaeological Project, along with contemporaneous investigations conducted in the Manu‘a group (Hunt and Kirch 1988; Kirch 1993), produced new information about the prehistory of the archipelago's eastern islands that could be compared with the earlier projects on ‘Upolu and Savai‘i. Consequently, by the early 1990s it was possible to summarise broad archipelago-scale patterns in Sāmoan settlement and chronology and begin to discuss research problems for the island group as a whole. This task was taken up in synthetic publications by Clark (1996) and later Green (2002). The foundational work by Green and Davidson, Clark (see above), and Kirch and Hunt (Hunt and Kirch 1988; Kirch 1993) outlined the major themes in Sāmoan archaeology and set the stage for academic and cultural resource management (CRM) projects that would be carried out in subsequent decades (e.g., Addison *et al*. 2008; Burley and Addison 2014; Carson 2006; Cochrane *et al*. 2004; Cochrane *et al*. 2013; Cochrane *et al*. 2016; Martinsson-Wallin 2016; Pearl 2004; Quintus 2012; Quintus *et al*. 2015, 2016; Rieth and Cochrane 2012; Rieth *et al*. 2008; Wallin *et al*. 2007).

Major research themes outlined by Clark (1996) and later Green (2002) include the relationship between landscape evolution and settlement pattern, the chronology of inland and upland expansion, the development of the Sāmoan village layout, and the development of monumental architecture. All of these research themes have been variously taken up by archaeologists working in the archipelago over the last several decades, attesting to the influence of Clark and Green on Sāmoan archaeology and regional settlement pattern studies more generally. The following section describes our efforts to compile settlement pattern and chronological information generated over nearly 60 years into a comprehensive spatial and temporal database. After describing the database development and preliminary analytical results, we discuss the remaining steps necessary to conduct analyses with this database in the context of "siteless" survey techniques (e.g., Dunnell 1992; Dunnell and Dancey 1983) and settlement pattern studies.

THE SĀMOA ARCHAEOLOGICAL GEOSPATIAL DATABASE DEVELOPMENT METHODS

The Sāmoa Archaeological Geospatial Database combines spatial and temporal data into a single searchable database format. Available publications and CRM documents were reviewed to compile the following: i) a database of radiocarbon and thorium-series dates and ii) a geographic information systems (GIS) database representing the spatial locations of known archaeological sites. Data were compiled in a single relational database in ArcGIS v10.5 (ESRI 2017). The methods for developing the final database are described in greater detail below.

Radiometric Dating Database Development

The last 30 years have seen a substantial increase in archaeological research in the Sāmoan Archipelago, particularly in American Samoa. Academic research programmes and, importantly, CRM projects have resulted in an assemblage of over 400 radiocarbon determinations. The majority of this corpus has been generated by CRM projects and remains in little-known and poorly circulated "grey literature". Rieth and Hunt (2008; see also Rieth 2007; Wallin *et al*. 2007) initially compiled data, tabulating 236 radiocarbon ages as of 2007. An additional 194 radiocarbon dates and 10 thorium-series dates were added to the database between 2007 and 2018, making the current total 420 radiocarbon dates and 10 thorium-series dates. Each age determination entry in the database includes fields corresponding to laboratory number, island, site number, provenience information, GIS number, sample material type, isotopic fractionation ratios, conventional radiocarbon age, calibrated age ranges at 1 and 2 standard deviations and bibliographic reference.

GIS Database Development

The locations of the majority of the known sites across the archipelago with published spatial information were compiled in the geodatabase and included brief text descriptions and contextual information provided in the original publications. Additional fields incorporated in the database include site number, feature type, artefacts found in association, site function (if known) and bibliographic reference.

To incorporate site spatial data from older research and hard-copy publications into the geodatabase, paper maps were georeferenced to orthorectified IKONOS base satellite imagery (in WGS 1984, UTM Zone 2S) by scanning the maps and manually rotating and scaling the images in ArcGIS v10.5 until the coastlines on the maps matched the location of the shoreline on the IKONOS imagery. The estimated accuracy of the georeferenced maps is approximately 10 metres or less. In addition to the georeferencing error, there is likely some additional unknown error as a result of the geopositioning techniques used during the original field projects. Nevertheless, our spatial estimates still provide useful information about the general locations of the sites and in some cases associated features and areas within sites. Upon completion of the georeferencing procedures, the site locations indicated on the maps were digitised as a set of point geometries. Identical methods were used to plot site locations generated by more recent archaeological research (e.g., Cochrane *et al*. 2016; Ishimura and Inoue 2006; Martinsson-Wallin *et al*. 2003, 2005; Petchey 2001; Sand *et al*. 2016); however, in the majority of these cases the locations of archaeological sites are more accurate as a result of modern field methods for geopositioning. In some cases, the locations of sites were not clearly depicted, but the corresponding villages were noted, which were used for coarse locational information.

The final step in the development of the database was to integrate the radiometric and spatial databases into a single relational database platform using ArcGIS v10.5, to allow queries based on the characteristics of any data entered in the age estimate or the GIS table, and display GIS point geometries based on spatial attributes or chronometric qualities. The following section briefly describes the data in the Sāmoa Archaeological Geospatial Database.

General Patterns in the Spatial and Chronological Data

Table 1 shows the number of archaeological point geometries in the geodatabase distributed by island. Variation in the distribution of points is largely related to the geographic focus of research programmes and cultural resource management projects (e.g., Clark and Herdrich 1993; Cochrane *et al*. 2004; Green and Davidson 1969, 1974; Jennings and Holmer 1980; Jennings *et al*. 1976; Rieth and Cochrane 2012). A cursory investigation of the GIS points (Figs 1–3) reveals a number of important patterns. For example, the majority of the western portion of Tutuila has seen limited archaeological work, with almost no large-scale surface surveys conducted. Consequently, our understanding of Tutuila's prehistory may only correspond to the eastern and central parts of the island. A similar situation exists on Ta‘ū, where fairly limited fieldwork has been completed in upland and interior locales. Comparatively speaking, the large island of Savai‘i has seen minor amounts of archaeological work since Green and Davidson's research and Jackmond and Holmer's (1980) reconnaissance survey of Sāpapali‘i, the exceptions being projects conducted at Pulemelei Mound and the surrounding area (e.g., Martinsson-Wallin *et al*. 2003, 2007), and limited work conducted by Ishimura and Inoue (2006). Undoubtedly, the island contains an abundance of archaeological remains with important ramifications for our understanding of Sāmoan prehistory. An additional relevant factor leading to island-scale discrepancies in site distributions is variation in the way that archaeological spatial units (that is, "sites") are defined. Problems related to the site concept are discussed further below.

Table 1. GIS and radiocarbon entries in the geodatabase by island.

Island	Sites	Radiocarbon Dates
‘Upolu	378	70
Apolima	1	0
Tutuila	269	248
Savai‘i	113	20
Ofu and Olosega	72	45[a]
Ta‘ū	66	20
Manono	3	17
Total	902	420

[a] Ten thorium dates also are available for Ofu Island (see Clark *et al*. 2016).

Table 1 also shows the number of radiocarbon dates for each island. As is the case with the distribution of spatial entries, Tutuila and ‘Upolu have the largest number of age determinations. Again, this reflects the early history of projects conducted on ‘Upolu and the growth of CRM archaeology as it relates to development projects on Tutuila. Fifty-five age determinations have been acquired for the small islands of Ofu and Olosega, a result of several substantial research projects (e.g., Clark *et al*. 2016; Kirch 1993; Quintus *et al*. 2015). Savai‘i has provided a limited number of radiocarbon determinations, with those present primarily related to archaeological investigations within the Pulemelei area (Martinsson-Wallin *et al*. 2003, 2007) and limited earlier archaeological projects during the 1960s (Green and Davidson 1969).

The geodatabase provides the current best compilation of settlement pattern and chronological data for the Sāmoan Archipelago. Although these datasets offer important information regarding land use, demography and spatial organisation across the islands, it must be noted that the distribution of entries for age estimates and archaeological sites is strongly influenced by contemporary factors, such as the history of infrastructural development, the rise of CRM archaeology in American Samoa, and methodological issues related to how we define archaeological units for the purposes of management and analysis.

While the Sāmoa Archaeological Geospatial Database is useful for quickly assessing the spatial and temporal distribution of archaeological site data across the archipelago, as well as generating new theoretical models and hypotheses regarding land use and spatial organisation (e.g., Morrison and

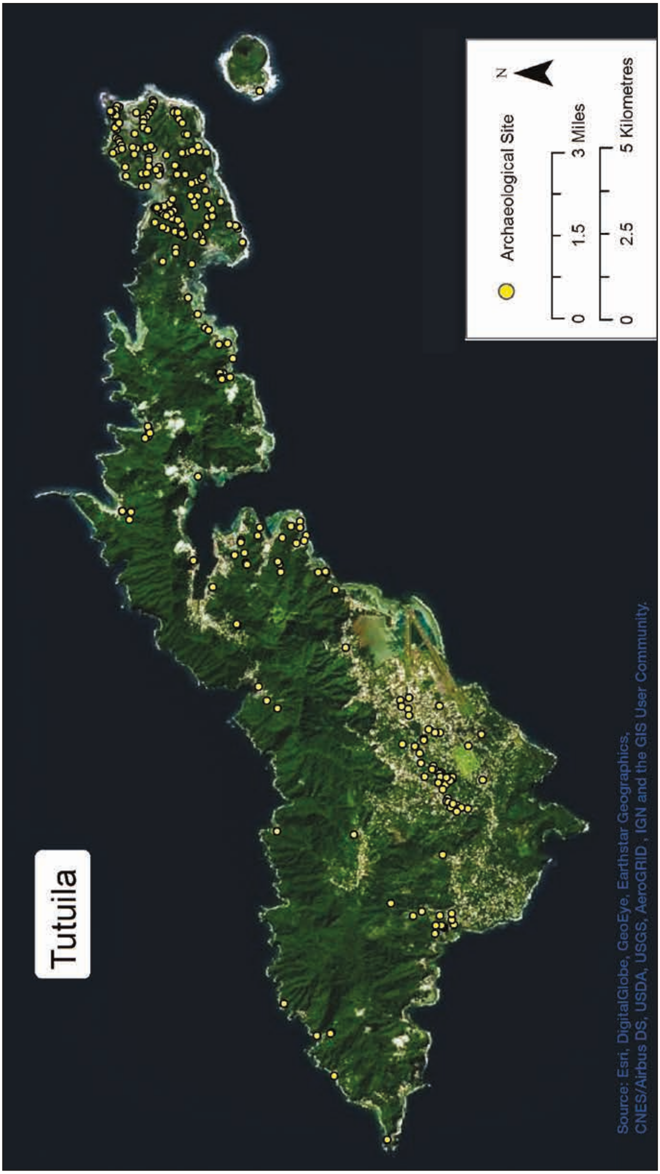

Figure 1. Distribution of archaeological sites on Tutuila in the Sāmoa Archaeological Geospatial Database.

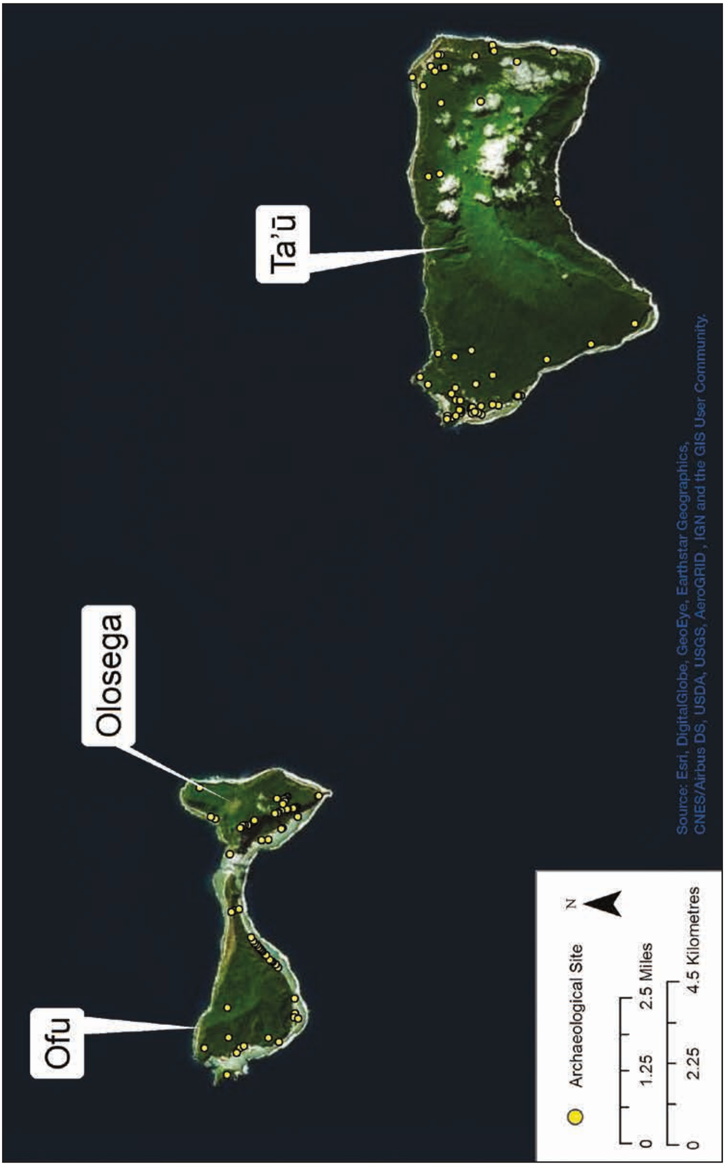

Figure 2. Distribution of archaeological sites in the Manu'a Islands in the Sāmoa Archaeological Geospatial Database.

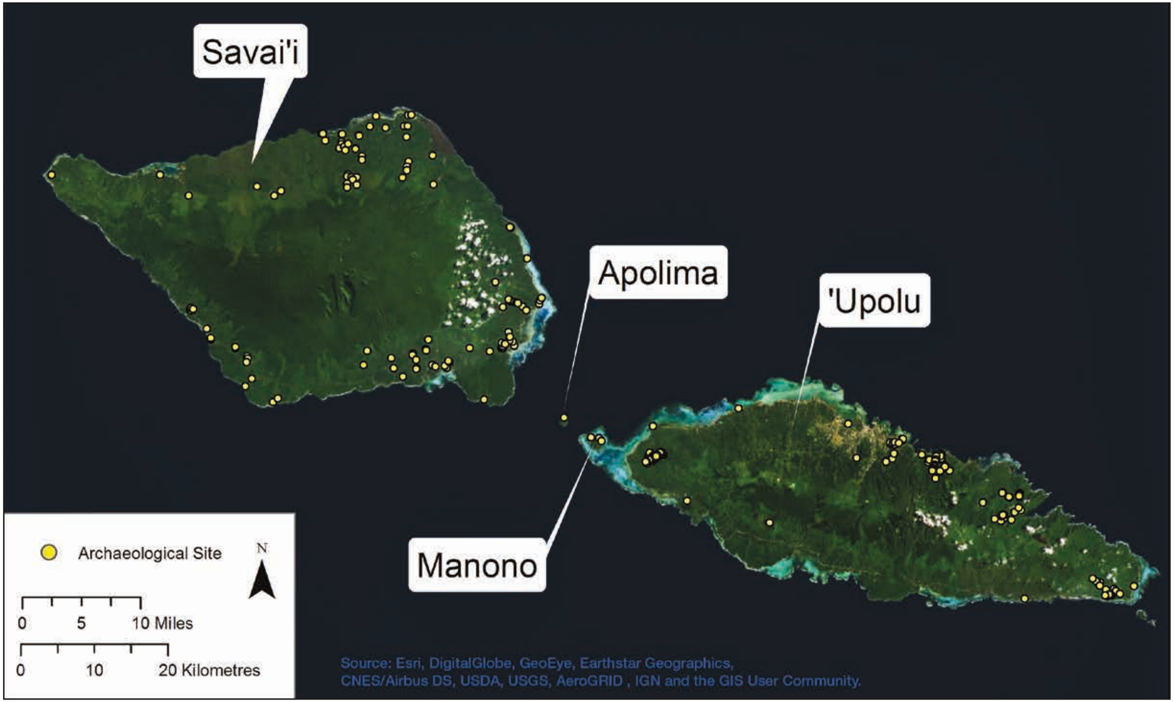

Figure 3. Distribution of archaeological sites on ‘Upolu, Savai‘i and Manono Islands in the Sāmoa Archaeological Geospatial Database.

Allen 2017), there are a number of data limitations that presently constrain its utility. These limitations are not unique to this specific context but highlight the greater challenges of assembling previously generated data (where the data were not originally generated for use in a GIS) and chronometric data collected using different methods. Below we focus on two primary limitations: (i) the definition of archaeological units and ii) the generation of reliable chronological estimates.

Analytical Units Versus Managerial Units in Settlement Pattern Studies

The assembly of large amounts of previously recorded archaeological spatial and chronometric data presents a unique set of problems for ensuring comparability among analytical units that are ultimately defined as GIS geometries in the database. The problem is readily apparent when dealing with the most commonly assigned archaeological unit, "the site". The concept of "site" in CRM archaeology is for the most part a managerial unit: that is, for a variety of reasons, cultural heritage managers require inventories of significant properties or "sites" for particular areas. The archaeological objects that are brought together within these managerial units are often inconsistently defined such that it becomes extremely difficult, if not impossible, to use "the site" as a unit in any analytical capacity. Simple inconsistency in site definition could be ameliorated, but more troublesome is the typical lack of problem orientation guiding the choice of features to be aggregated into a site, which results in comparability issues between researchers (see Dunnell 1992; Dunnell and Dancey 1983; Morrison 2012; Morrison and O'Connor 2015). Unfortunately the site has been, and continues to be, the primary archaeological unit used in Sāmoa, Hawai'i, and much of the United States. Consequently, in the Sāmoa Archaeological Geospatial Database, the data compiled for American Samoa rely on the site as the primary unit, largely as a result of a heavy reliance on CRM documents, which are primarily descriptive and managerial in aspect.

The problem with the site concept is not unique to American Samoa; however, this situation highlights larger problems with the concept of "site" when used for analytical purposes. With these thoughts in mind, the site designations currently in place within the database are managerial rather than analytical in most instances and therefore require further efforts to disaggregate spatial geometries into lower-level units before many analytical tasks, such as comparing the spatial distribution of functional activities and assessing settlement boundaries, can be tackled.

One resolution to this problem for Polynesian settlement pattern research is the "siteless" survey (Dunnell and Dancey 1983), whereby the minimal unit of recording equates with the unit of discard, preferably the artefact or bounded architectural component (i.e., feature) (Morrison and O'Connor

2015). In many instances, it is possible to create comparable analytical units by "deconstructing" previously defined sites into individual features. While this remains a daunting task for the over 900 recorded sites currently in the database, in the following section we demonstrate the necessary steps for this type of analysis with an example from ʻAoa Valley and the surrounding area on Tutuila.

THE ʻAOA VALLEY CASE STUDY

ʻAoa Valley is located along the northeastern coast of Tutuila Island. The valley is characterised by a large and pronounced bay that fronts a well-developed central coastal plain. Six primary streams and an estuary can be found in the valley. Clark and Herdrich (1988) subdivided the main portion of the valley into three zones with varying ecological and archaeological characteristics: the lower valley, the middle valley and the upper valley.

In 1986 Clark conducted an exhaustive survey of the valley floor and a diversity of archaeological features was identified. ʻAoa Village and the majority of the valley (AS-21-5), as well as Faʻalefu Village (AS-21-6), were each given site numbers with designated archaeological localities within each of these sites. Nearly 60 archaeological sites ranging from isolated terraces to large clusters of surface features have been recorded in the valley and on surrounding ridges. These sites and descriptions, originally documented by Clark, are included in the Sāmoa Archaeological Geospatial Database and provide the data for this analysis. A more detailed discussion of the valley's chronology and archaeology can be found in Clark and Michlovic (1996) and Clark and Herdrich (1988). It is noteworthy that ʻAoa Valley has played an important role in the generation of many research questions that still remain important in Sāmoan archaeology, including the relationship between geomorphological evolution and landscape use (e.g., Clark and Michlovic 1996) and the timing of the cessation of pottery production across the archipelago (Clark 1996).

Generating Comparable Analytical Units

As discussed in the previous section, "sites" have not generally been defined according to analytical needs but instead often serve a managerial or administrative purpose. In the case of American Samoa settlement pattern analysis, it is often not analytically meaningful (aside from gross, and previously recognised, patterns) to analyse the spatial distributions of recorded "sites" given their difficult-to-compare, arbitrarily defined and non-problem-oriented nature. Importantly, Clark explicitly defined his criteria for aggregating features into sites. Regarding "site definitions" in the Eastern Tutuila Archaeological Survey, Clark and Herdrich (1988) note:

> Clusters of associated features—such as house foundations and other domestic features, or related defensive features—were regarded as single settlement units and therefore assigned one site number. Discrete and comparatively isolated structural remains (e.g., terraces, *tia ʻave* [star mounds], paths, and walls) were given individual site numbers. Furthermore, to single out members of different site categories, specialized sites were assigned individual site numbers even if found in close spatial association with other features. These site categories are *tia ʻave* and basalt quarries. In some cases, ditches and other features that are in proximity to and were probably functionally related to *tia ʻave* have been grouped with the *tia ʻave* [typo in original corrected] (p.10)

Clark's careful recording and clear explicit description of these variably defined sites has allowed us to revisit his work in ʻAoa Valley and the surrounding area (Fig. 4) and identify the features he recorded. Single locations were then given to each discrete feature described in the associated technical reports (e.g., Clark and Herdrich 1988), such that all spatial geometries now represent individual discrete artefacts (i.e., adzes or formal lithic tools) or individual structures (i.e., terraces, star mounds, house foundations) and are therefore analytically comparable for documenting patterns in landscape use and activity areas.

To explore spatial patterns in surface features within Clark and Herdrich's (1988) ʻAoa survey area, we use a geostatistical technique called *kernel density estimation* (KDE) to visualise spatial patterns in the data. KDE is useful for documenting geographic variability in point patterns (e.g., artefacts or features) by mapping their density as a spatial probability function or as expected counts derived from this probability estimate. KDE works by placing a curved surface over each point, called a *kernel function*, with a user-defined standard deviation, called a *smoothing bandwidth*, resulting in a map of probability density that smoothly decreases with distance from each point. The result can be thought of as an undulating surface with height equal to density (Baddeley *et al*. 2015: 168). For any given location within the study area, the kernel density estimate is given by:

$$\lambda(u) = \sum_{i=1}^{n} \kappa(u - x_i)$$

Where λ is the density of the feature class at location u and κ is an isotropic Gaussian kernel with smoothing bandwidth computed using a spatial variant of Silverman's Rule of Thumb that is robust to spatial outliers (Baddeley *et al*. 2015: 168; see also Silverman 1986). KDEs are computed for house foundations, terraces, lithic tools and star mounds (*tia ʻave* or *tia seu lupe*),

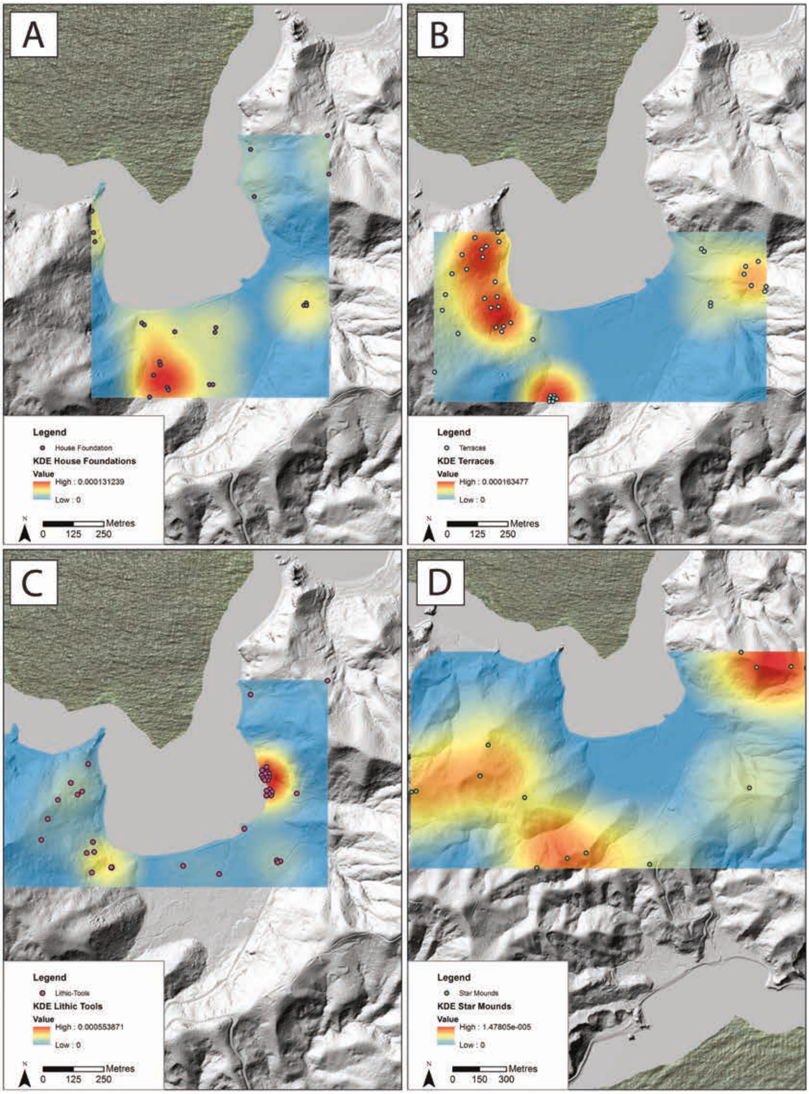

Figure 4. Kernel density estimation plots depicting expected counts per km^2 for A) house foundations, B) terraces, C) lithic tools and D) star mounds.

which are visualised as expected counts per km^2. Figure 4 displays the results of the KDE plots for the four feature classes used in the analysis, and general spatial patterns for each feature class are discussed further below. Other feature classes are present in the data but are not presented here.

House Foundations

House foundations are defined by Clark and Herdrich (1988: 11) as "represented by foundations with curbing or the surface scatters of *'ili'ili* (pebbles and/or coral rubble) of old floors". The distribution of house foundations at 'Aoa suggests that they were primarily concentrated within the central valley floor (Fig. 4, Panel A). However, there are a few located at higher elevations on top of Afimuao Ridge to the east. Distinct clusters of house foundations are found within Site 21-05, which corresponds to much of the valley floor. The distribution of archaeological house foundations suggests continuity between the location of the current village houses and those of the past, which is likely influenced by the benefits of living on relatively flat land with nearby coastal access (Morrison *et al*. 2010; Rieth *et al*. 2008).

Terraces

Terraces are well represented in the valley and on the surrounding ridges. The KDE displayed in Figure 4 Panel B demonstrates that terraces are concentrated along the slopes of the valley and generally at higher elevations than the house foundations. High concentrations of terraces are found along the base of the western slopes of the valley near Fa'alefu Village (22-06) and Lemafa Ridge. However, another cluster is located near the southwestern portion of the valley floor against the ridge slope. These terraces retain the slope of the surrounding ridges and likely functioned as places for agricultural activities.

Lithic Tools

Lithic tools are defined here as formal basalt artefacts, including complete and incomplete adzes, chisels and miscellaneous basalt tools (Fig. 4, Panel C). These artefacts are often in association with terraces or in clusters within Site 21-05 and especially along the base of the western slopes of the valley near Fa'alefu Village (22-06) and Lemafa Ridge. A dense cluster of lithic tools is also present in the northeast section of the valley floor within Site 21-05, Locality 03 near Laoulu Stream. The high abundance of formal tools in proximity to the stream mouth raises the possibility that many of these artefacts are in secondary contexts, having been transported by fluvial action to their current locations.

Star Mounds

The distribution of star mounds (*tia 'ave* or *tia seu lupe*) demonstrates that they are at high elevations on ridge tops, away from primary residences in the lower areas of the valley (Fig. 4, Panel D). The spatial segregation of star mounds away from other features indicates that these were special-use areas. This spatial pattern seems logical considering that star mounds are interpreted as places for the chiefly sport of pigeon-snaring and may have been important meeting places (Herdrich 1991).

'Aoa Valley Settlement Pattern Summary

Although the 'Aoa Valley settlement pattern study is primarily illustrative of the potential uses of the Sāmoa Archaeological Geospatial Database to understand broader issues in Sāmoan prehistory, certain conclusions regarding land use and spatial organisation can be discussed. House foundations are located primarily on the valley floor in flat locations that would have provided easy access to ocean resources and alluvial soils for cultivation. Clusters of terraces can be found along valley slopes and at higher elevations. These terraces retain slopes and produce flat locations for agriculture, thus increasing the total acreage of potential arable land. Formal lithic tools are associated with terraces and to a more limited extent with house foundation locations. The co-occurrence of lithic tools and terraces suggests that basalt tools were used during agricultural activities (e.g., for clearing land and processing crops). Finally, star mounds are located away from residential areas at high elevations on ridge tops, attesting to a specialised function and segregation away from other feature classes.

* * *

This article provides a description of the Sāmoa Archaeological Geospatial Database and a case study from 'Aoa Valley. While purposely limited in scope and primarily illustrative, the techniques applied in the 'Aoa Valley example can be expanded to other locations in the archipelago and eventually the entire archipelago. Forthcoming analytical efforts will focus on updating site inventories as archaeological projects in the Sāmoan Islands continue.

Avenues for Future Research

Future archaeological survey projects should describe the surface archaeological record at the discrete object/feature scale, which is necessary for both examining spatial correlations between functional activity areas and highlighting divergent patterns in land use, important goals of settlement pattern research. Consequently, deconstructing currently recorded archaeological sites already in the database into lower-scale feature entities will be an important preliminary task.

Rather than focusing on settlement organisation at the scale of individual valleys like ʻAoa, future research will delineate multiple scales of organisation using multi-scalar statistical approaches (e.g., Peterson and Drennan 2005), which offer the potential to document regional organisational patterns with archaeological data. Eventually, the database will be made accessible to researchers via an online platform as we continue to increase the data entries and refine the spatial resolution of the database.

Finally, note is made of the need to generate reliable chronologies for the archaeological features depicted in the database. Radiometric dating technology has significantly improved in its capabilities and level of precision during the last 60 years. Sāmoa's relatively deep history of archaeological research has resulted in a large corpus of radiocarbon dates, many of which are problematic by current standards (Rieth and Hunt 2008). Ultimately, redating efforts for key deposits or structures should occur, either using curated charcoal samples or through renewed excavations. Looking forward, there are relatively simple practices that archaeologists working in the archipelago (or elsewhere) must implement to ensure the creation of reliable chronologies. These include paying close attention to archaeological and depositional contexts to identify what specific events of interest are being dated (see Dean 1978). Charcoal dating samples should be identified to taxon, and short-lived plants or young plant parts should be submitted for dating (Allen and Huebert 2014; Rieth and Athens 2013). Results should be published in full, including provenience information, sample material (and analyst who made the identifications), the target event (with a defensible justification), laboratory data, calibration details, including calibration curve, Delta R values if used, and calibration program and version. Lastly, Bayesian model-based calibration has gained recognition in the Pacific as a powerful method for building chronologies (Allen and Morrison 2013; Burley *et al*. 2015; Dye 2015; Rieth and Athens 2017). The application of Bayesian statistical methods to Sāmoan archaeology has begun as well (Clark *et al*. 2016; Rieth and Morrison 2017). These data can be incorporated into future iterations of the Sāmoa Archaeological Geospatial Database and promise to greatly improve our understanding of the Sāmoan past.

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ABSTRACT

Jeff Clark's archaeological research on Eastern Tutuila Island provided the first regional scale settlement pattern data in American Samoa that could be meaningfully compared to earlier data drawn from projects on the archipelago's western islands, Savai'i and 'Upolu. Building on Clark's work, in this paper we generate a spatial and temporal geodatabase incorporating 900 archaeological sites and 520 age estimates spanning the entirety of the Sāmoan Islands. The Sāmoa Archaeological Geospatial Database is useful for addressing a number of regional research questions using spatial and temporal data at multiple geographic scales; however, preliminary work must first be conducted to covert "site" data into comparable lower-scale analytical units. To highlight this process, we provide an example drawn from Clark's archaeological surveys in 'Aoa Valley, Tutuila Island. Finally, we suggest that a "siteless" survey approach is necessary to generate comparable data for settlement pattern and landscape analyses.

Keywords: Sāmoa, geographic information systems (GIS), settlement pattern archaeology, Polynesian archaeology, geodatabase, landscape archaeology

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