

JPS

The Journal
of the
Polynesian Society

Special Issue

**SĀMOAN LANDSCAPES THROUGH
TIME: A SPECIAL ISSUE IN
HONOUR OF JEFFREY T. CLARK**

VOLUME 127 No.1 MARCH 2018

**THE POLYNESIAN SOCIETY
THE UNIVERSITY OF AUCKLAND
NEW ZEALAND**



EXPLORING THE INTERSECTION OF SETTLEMENT, SUBSISTENCE AND POPULATION IN MANU‘A

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The study of settlement systems is a hallmark of the archaeological enterprise in Sāmoa (e.g., Clark and Herdrich 1993; Green and Davidson 1969, 1974; Jennings and Holmer 1980; Kirch and Hunt 1993). Broadly, settlement systems encapsulate the behavioural dimensions that contribute to the distribution of features, subsistence patterns and other elements of the socioecological landscape. As such, these analyses require an examination of several interacting variables, including population size, site distribution and cultivation practices. Largely missing from settlement system studies in the archipelago has been population estimates. Those that have been completed have been limited in scope, relying on historic descriptions (Green 2007: 212), estimations of total arable land (Green 2007: 215) or the distribution of archaeological remains within small areas (Davidson 1974: 235–36; Jackmond and Holmer 1980: 151–52).

Investigations of population size and density are essential for understanding settlement systems, in that population size often interfaces with subsistence and settlement pattern decisions. The inclusion of demographic variables into a consideration of variable protohistoric (17th–18th century) settlement systems is accomplished here for the islands of Ofu and Olosega. These are small islands, 7.3 km² and 5 km² respectively (Fig. 1). Estimations of population are more easily accomplished for smaller islands, especially when those islands have been subject to intensive archaeological survey work, as is the case in Manu‘a.

Both feature high topographic relief, with the highest point of Ofu at 494 m and of Olosega at 639 m. Each island receives in excess of 3,000 mm of rain each year, but no permanent streams flow. Several intermittent waterways run after heavy rainfall and some retain water well after these rainfall events. The interior uplands of both are covered in dense vegetation distributed along an elevation gradient (Liu and Fischer 2007). Generally, more economic species (e.g., *Cocos nucifera*, *Artocarpus altilis*, *Aleurites moluccanus*, *Inocarpus fagifer*) are situated seaward of secondary-growth forest (e.g., *Rhus taitensis*, *Hibiscus tiliaceus*), which is itself seaward of what remains of native rainforests.

Ofu was settled some 2,650–2,700 years ago (Clark *et al.* 2016), and sites from this period are distributed along the leeward coastlines (Kirch and Hunt 1993; Quintus 2015). Archaeological remains from the first millennium BC

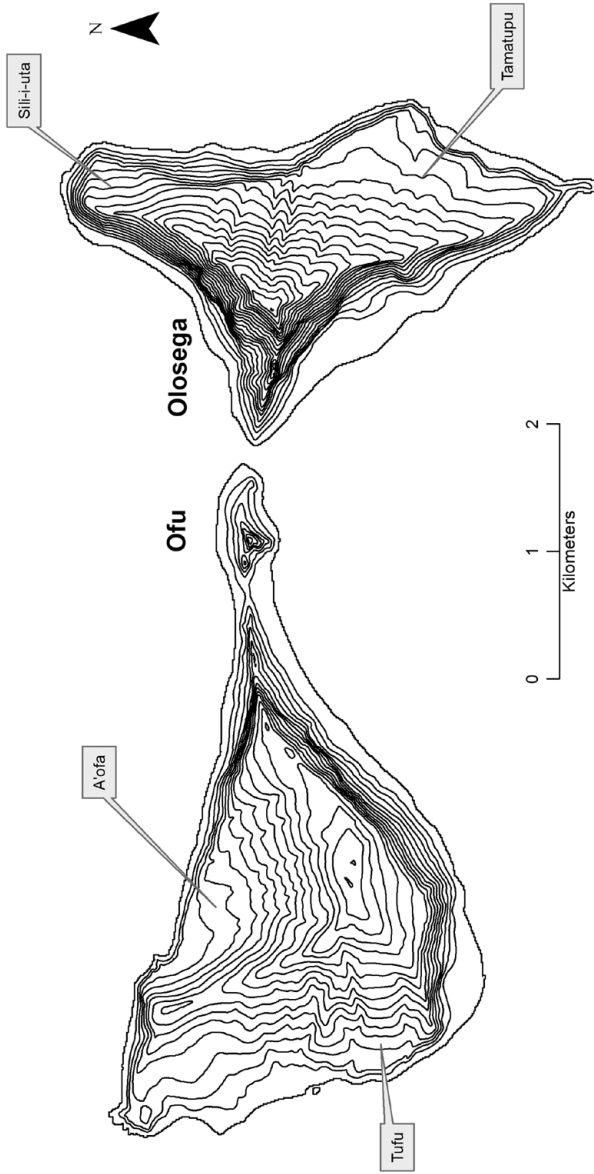


Figure 1. Ofu and Olosega with investigated, either by pedestrian survey or by LiDAR survey, high-feature density zones labelled. Contour lines are 20 m from a DEM derived from a LiDAR dataset.

have also been identified and dated on Olosega, but these have not yet been reported in detail (American Samoa Power Authority files; Clark pers. comm.). Habitation on the coast persisted through the first millennium AD with the initial permanent settlement of the interior uplands of Ofu at the beginning of the second millennium AD (Quintus *et al.* 2015a). Activities continued to be undertaken on the coast, but areas of the interior uplands became the major loci of human activities on Ofu and Olosega until European contact.

The results of several years of field research in the interior uplands focusing on the individual settlement zones of Tamatupu and Sili-i-uta on Olosega and A'ofa and Tufu on Ofu (Fig. 1) have recently been published (Quintus 2012, 2015; Quintus and Clark 2012, 2016; Quintus *et al.* 2015b, 2016). What has not been considered is variation between these islands. The aim of this article is the evaluation of the interiors of Ofu and Olosega collectively to isolate and explain points of variation relating to settlement, subsistence and population. The intersection between population density and subsistence systems provides important information from which to understand population vulnerability (susceptibility to damage caused by perturbations) and resiliency (ability to persist through perturbation) in these small-island societies. At a general scale, such case studies provide important models for contemporary island societies adapting to socioecological change.

METHODS

The distribution of terraces and forest types, two proxies for productive strategies, are used to calculate two population estimates: hypothetical carrying capacity and settlement patterns. The calculation of carrying capacity (K), defined as the population that could potentially be sustained based on a modelled food-production system, is not an ideal way to estimate past population sizes (see Brush 1975). Not all subsistence-related activities can be included in most calculations given incomplete knowledge, and there may be a lack of correlation between K and actual population (Kirch and Rallu 2007: 8–9). Still, the calculation of a heuristic K provides some useful information regarding a maximum population (see Addison 2006; Burley 2007; Spriggs and Kirch 1992). The examination of the archaeological manifestations of residential activity through the assessment of the distribution and density of architectural features (i.e., terraces) should provide a more realistic population estimation, providing a check of the estimation of K, and has been used successfully in the region (Conte and Maric 2007; Hamilton and Kahn 2007; Molle and Conte 2015).

Vegetative patterning, and the spatial distribution of different vegetation formations as a proxy of past productive strategies, is used here to calculate carrying capacity (Liu and Fischer 2007). General vegetation classes,

specifically those corresponding to remnants of past agroforestry (e.g., *Cocos nucifera*, *Artocarpus altilis*, *Cordyline fruticosa*) and secondary forest (e.g., *Hibiscus tiliaceus*, *Rhus taitensis*), have been shown to co-vary with archaeological remains (Quintus 2012, 2015). The extent of these vegetation classes are used as a proxy of the spatial extent of tree cropping (modified agroforestry) and shifting cultivation (secondary forest) in the past.¹ The lack of arboreal food plants in secondary forests suggest a different land-use history relative to modified agroforestry sections. That shifting cultivation plots revert to secondary forest is supported by ethnographic research (Kirch 1994) and contemporary botanical research in the region (Liu *et al.* 2011: 13; Webb and Fa‘aumu 1999). Yield and caloric data is derived from adjacent areas of the region (e.g., Hamilton and Kahn 2007; Kirch 1994).

Population size and density are estimated from the number of total households, as calculated from a combination of total area of settlement, terrace number and the percentage of terraces interpreted as having residential functions. The distribution of terraces within particular zones of Ofu and Olosega has been discussed elsewhere (Quintus and Clark 2012, 2016), but what has not been considered is the distribution of archaeological remains across the entirety of the islands. This was not feasible until the acquisition of LiDAR datasets from which high-resolution digital terrain models (DTM) could be derived. These DTMs enabled a more efficient and effective evaluation of the total distribution of archaeological features, and terraces are especially visible on these images. Such images are used here to identify areas of high feature density (HFD), defined by the density of terraces (see Quintus 2015; Quintus *et al.* 2015b). Absolute terrace density was calculated based on intensive pedestrian survey data from A‘ofa, Tufu, and Tamatupu and extrapolated for additional HFD areas that have not been surveyed on the ground. Residential terraces were defined based on the presence of coral and terrace area, as supported by ethnographic accounts (see below). These two characteristics also correlate with elevation (Quintus and Clark 2016), a critical test of their function since Sāmoan spatial logic, at least in late pre-European times, included a graded relationship (Shore 1996: 256) wherein residential features are located seaward of non-residential features and activities (i.e., shifting cultivation). While some might question the contemporaneity of terraces, and sufficient radiocarbon dates are not available to evaluate this, it is assumed that a new terrace would not be built unless no others were available for use. Still, the number of residential features was reduced by 10% to consider residential terraces that were not actively inhabited at a given time (based on assumed use in Jackmond and Holmer 1980: 151). Various historic-era household sizes have been proposed for Sāmoa, ranging from three to seven people per structure (Davidson 1974:

235–36; Jackmond and Holmer 1980: 151). For this analysis, two estimates were calculated based on a household occupancy of three and six. Given these assumptions, these estimates are at best a reflection of a maximum population during a slice of time shortly before or just after European contact in 1722.

POPULATION DISTRIBUTION AND DENSITY

Terraces are the most common feature type encountered in the interiors of Ofu and Olosega. As such, they provide an important point of comparison between the islands. Artificially flat surfaces with as many as three free-standing sides, these terraces likely functioned as foundations for various activities (i.e., sleeping, cooking, eating, working and, perhaps, cultivation). The discrimination of function has been difficult, though the presence of waterworn coral or basalt paving (*'ili'ili*) and large size have been used to define those of residential function,² as these pavings are documented for residential structures in the ethnohistoric and ethnographic literature (e.g., Buck 1930: 19; Stair 1897: 108–9; Turner 1861: 256).

Four zones of high feature density have been identified on Ofu and three have been recorded on Olosega (Fig. 2a). More dispersed features are located outside of these HFD zones, but I suggest that these relatively well-defined HFD zones form distinct settlement units (residential areas). Contrast is apparent in considering the sheer area of each island's interior covered by the HFD zones. The three HFD zones on Olosega encompass ~61% (~1.53 km²) of the entire land area of the interior (~2.34 km²), which does not take into account the question of whether the remaining land area could be feasibly used. In comparison, the four HFD zones on Ofu encompass only ~31% (~1.26 km²) of the interior land of the island (~4.11 km²).

These zones match well the distribution of areas with less than 20 degree slope (Fig. 2b), indicating that slope was a factor in the distribution of archaeological remains to some extent. However, there are areas of Ofu that could be conducive to human settlement (under 20 degree slope) where terracing is lacking, especially inland of the Tufu HFD zone. This contrasts with the situation on Olosega where Sili-i-uta is situated within a landscape that exhibits slope well over 20 degrees, the lone HFD in such a location.

The documented terraces (n = 399) from the intensively surveyed zones range between 14 and 2,035 m² with an average size of 218 m² and a median value of 162 m². Tamatupu is an outlier among the settlement zones in relation to the size of terraces, while the other three zones are relatively consistent (Fig. 3). These features also vary by surface treatment, namely the presence or absence of coral. Waterworn coral rubble, often used as a paving for residential structures (see above), is present on 62% of terraces (177 out of 286), when only considering features for which data are available to evaluate surface

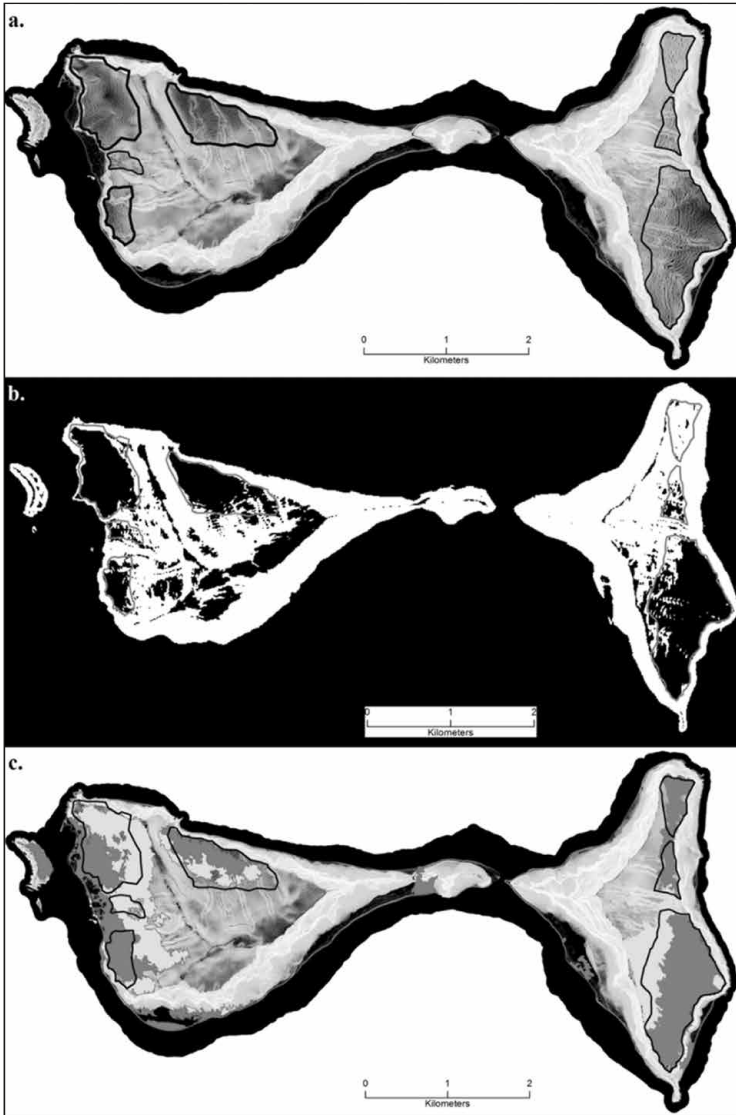


Figure 2. Patterns on Ofu and Olosega. a) Distribution of HFD zones. Darker colours are indicative of lower slopes. Those small polygons of contiguous low slope are terraces. b) Relationship between HFD zones (outlined in grey) and areas of below 25 degree slope (black). c) Relationship between HFD zones and economic (dark grey) and secondary (light grey) vegetation.

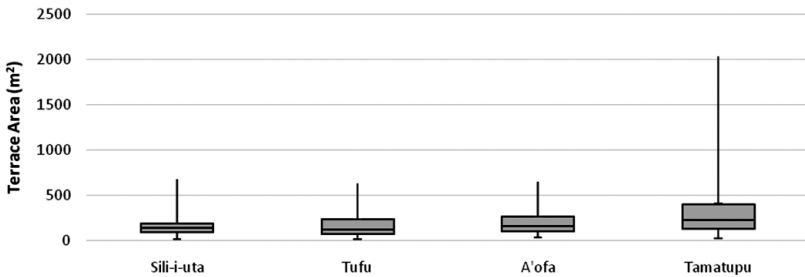


Figure 3. Differences and similarities in terrace size between the four investigated HFD zones. Box plots represent the median, quartiles and range of documented terraces for each HFD zone.

treatment or secondary features (Tamatupu, Tufu and A'ofa). The proportion of terraces on which coral was found ranges among the three zones from 58% to 70%, with the lowest percentage in Tamatupu and the highest in Tufu. In all zones, those terraces on which coral was found are larger than those on which coral was absent (Quintus 2015; Quintus and Clark 2016). The presence or absence of coral and terrace area are the characteristics that have been used to broadly define feature function and differentiate between residential (e.g., features on which structures were built for sleeping or cooking) and non-residential (e.g., bush shelters or workshop areas) features (Quintus 2015: 214–18). Here, it is estimated that 51% of terraces served primarily residential purposes (defined as those over 200 m² with coral). It should be noted that those terraces with coral that were smaller than 200 m² and those without coral over 200 m² were not classified as residential.

VARIATION IN FOOD PRODUCTION

As noted above, different vegetation communities on the two islands, namely agroforests and secondary forests (Liu and Fischer 2007), have been shown to co-vary with archaeological remains (Fig. 2c; Quintus 2012, 2015). The modified agroforest vegetation zone is dispersed amongst archaeological remnants of residential features. This patterning, wherein tree crops are grown within and near to villages, is found throughout the region (Kirch 1994; Watters 1958), and because of this the vegetation group is used here to model the extent of tree cropping in vertically stratified gardens. Secondary vegetation is found immediately inland of agroforests along with a low density of archaeological remains. Given the unlikelihood of this vegetation patterning being the outcome of either storm destruction or natural fire, and position directly inland of archaeological remains, one reasonable explanation for the presence and location of secondary forest is that it marks the extent of shifting cultivation in the past. This patterning, wherein shifting cultivation

is practiced inland of villages and arboricultural zones, is well documented ethnographically for the region (Kirch 1994).

Other forms of cultivation can also be inferred. Ditches are present on Olosega that appear to be boundaries on the landscape separating vegetation types and terraces of different characteristics. At least at Tamatupu, terraces upslope of the ditch (Feature 38) tend to be small and are less likely to exhibit coral on their surfaces (Quintus and Clark 2016). The ditch itself is located at the interface of modified and secondary forests, potentially the division between arboriculture (downslope) and shifting cultivation (upslope) (Quintus 2012). Another possible ditch is present at Sili-i-uta, visible in slope and hillshade maps derived from a LiDAR dataset (Quintus *et al.* 2015b), and this feature, too, is located at the upslope boundary of modified forest as proposed in Liu and Fischer (2007). Both of these ditches spread across of the length of their associated HFD zones, with the example from Tamatupu measuring around 1.2 km long and the possible example at Sili-i-uta some 400 m. One function of these features was as sediment and runoff traps to ensure eroded sediments from upslope were not deposited on residential features downslope (Quintus 2012). This interpretation is further evidenced by cuts in the downslope bund of the ditch at Tamatupu in low-lying areas and streams.

Ditching is also found on Ofu, although at a more localised scale. Instead of separating large expanses of land as on Olosega, ditching on Ofu bounds plots or parcels ranging in size from 172 to 3,063 m² (Quintus 2015: 180, 198). The sloping nature of the parcels and the lack of structural remains on the surface suggests that they were cultivated, with the ditches serving to bound and protect those cultivated parcels by channelling high-energy surface runoff and sediment away from cultivated plots (Quintus *et al.* 2016: 284–86). Reducing overland runoff might have reduced erosion of the soils in cultivated plots as well.

The hypothesised spatial extent of productive techniques is used to model potential production capacities that will allow for coarse comparison of strategies.³ Yields from shifting cultivation (n ~114.5 ha on Ofu; n ~52 ha on Olosega) can vary based on rainfall, slope and other factors, but an average of 11 t/ha is used to estimate the yields from multi-cropped (e.g., taro, yam, banana) shifting cultivation plots in colluvial slope environments (Kurashima and Kirch 2011: 3664). A fallow value of 50% is used for shifting cultivation. This takes into account the fact that some land would not be in production while other land would still be in production but not actively cultivated (perennial crops). Certainly, actual fallow periods could and would fluctuate widely. Yields from vertically stratified gardens

within residential zones (n ~81 ha on Ofu; n ~107 ha on Olosega) are more difficult to estimate, especially since the exact nature of these strategies is unknown (i.e., the mixture of different crops). Instead of assessing the yield of individual crops, an estimate from agroforestry zones of 12.46 t/ha is used (based on Hamilton and Kahn 2007: 146). This estimate takes into account mixed crops grown in agroforestry zones on the West Polynesian island of Futuna, the closest analogy available. It is assumed that 20% of land presently under modified forest cover would have been taken up by structures when the area was inhabited (from Kirch 1994: 181, based on work in Futuna). Ditch-and-parcel strategies, found only on Ofu (n ~3.3 ha), are likely to have been more intensively cultivated, as inferred from the fact that these are close to residential complexes and are permanently marked plots. I use the figure of 11 t/ha for this strategy as well, to highlight that crops grown in these locations may have been similar to shifting cultivation plots, but a low fallow figure of 10% is applied because it is likely these plots were more intensively cultivated than others. The results of this analysis are presented in Table 1. What is most apparent from these results is the differing ratio of calculated yields from shifting cultivation to vertically stratified gardens on Ofu (0.78) and Olosega (0.27).

Table 1. Production estimates based on the distribution of vegetation.

		Strategy	% Fallow	Cultivated Land (ha/yr)	Yield mt/ha/yr	Total Yield mt/yr	% of Total
<i>Ofu</i>							
Modified Forest	81 ha	Arboriculture	20	65	12.46	810	55
	3.3 ha	Ditching	10	3	11	33	2
Secondary Growth	114.5 ha	Slope Cultivation	50	57.25	11	630	43
<i>Olosega</i>							
Modified Forest	107 ha	Arboriculture	20	86	12.46	1,072	79
Secondary Growth	52 ha	Slope Cultivation	50	26	11	286	21

CARRYING CAPACITY AND ESTIMATION OF POPULATION SIZE

The distribution of terracing, and hypothesised differences in food production, hint at variation in population sizes and densities. Prior attempts at such estimates have been limited to general calculations based on land area and European approximations, with the entire population of Manu'a (Ta'u, Ofu and Olosega) estimated to range from 1,100 to 1,400 people (see Green 2007: 212, Table 11.4). The question of potential population size is addressed here by calculating carrying capacities and considering settlement patterns.

The production estimates for Ofu and Olosega were used as the basis for a first-order calculation of K. These results are presented in Table 2 based on a caloric return of 1,230 kcal/t for each cultivation strategy (estimated return from colluvial slope category in Kurashima and Kirch 2011: 3672) and an average 2,700-calorie diet (based on USDA-recommended values for active adults aged 19–30). If we assume that terrestrial production constitutes ~80% of the diet, a value derived from adult-human stable-isotope studies for the second millennium AD on the island of Tutuila (Valentin *et al.* 2011), the production system of Ofu could support a population density of ~315 people/km² and Olosega a population density of ~424 people/km².

Table 2. Carrying capacity calculations based on production estimates cited above.

System	Estimated Yield	Caloric Value	Caloric Output	Carrying Capacity	Total	Density (people/km ²)
<i>Ofu</i>						
Arboriculture	810	1,230	996,300	1,011		
Slope	630	1,230	774,900	786		
Ditching	33	1,230	40,590	41		
Total Population					1,838	252
Total with Proteins					2,297	315
<i>Olosega</i>						
Arboriculture	1,072	1,230	1,318,560	1,338		
Slope	286	1,230	351,780	357		
Total Population					1,695	339
Total with Proteins					2,119	424

The results of this carrying-capacity estimate were evaluated and supplemented by an examination of terrace density and house counts. Based on data from the four HFD zones subject to the most intensive survey, the number of terraces per hectare ranges from 3.3 to 5.2 terraces. This number was then modified to consider only residential features, using the definition of residential terraces presented above (average of 51% of total terrace dataset). Based on this, the density of residential terraces ranges from 1.68 to 2.65 terraces/ha with an average of 2.13 terraces/ha. The average is used to calculate the number of total households by multiplying the area of each settlement zone by the average density of terraces: a total of 273 residential terraces are calculated for Ofu and 326 for Olosega. An occupancy rate of 90% is used in this preliminary analysis following previous work in the archipelago (Jackmond and Holmer 1980: 151), a figure that likely results in a high estimation. Radiocarbon ages are absent from Olosega and single radiocarbon determinations from individual terraces on Ofu tell us little about actual use life (but see Quintus 2015). Based on this analysis (Table 3), the population density on Ofu ranged from ~101 (3 per household) to ~202 (6 per household) people/km² and on Olosega from ~176 (3) to ~352 (6) people/km². The maximum population density on either island was likely between these figures as the occupancy rate of 90% may never have been achieved. The estimate based on the assumption of a 90% occupancy rate and a household size of three would be similar to an estimate based on the assumption of a 40%–50% occupancy rate and a household size of six. Regardless of actual population size, the comparison is useful and relevant as long as the variables are held constant for both islands.

The estimate based on the assumption of six individuals per household and a 90% occupancy rate constitutes ~64% of estimated K for Ofu and ~83% for Olosega. These ratios are similar to those historically known for some Polynesian Outliers (Bayliss-Smith 1974), though carrying capacity was calculated differently in that instance. Both settlement patterns and carrying capacity are suggestive of a higher population size and density for Olosega relative to Ofu, even if the actual figures are approximations.

Table 3. Demographic estimates based on distribution and density of terracing (details in text).

	Total Area (ha)	Residential Terraces	10% Reduction	Population (3)	Population (6)	Density (3)	Density (6)
<i>Ofu</i>	136	290	261	737	1,474	101	202
<i>Olosega</i>	153	326	293	879	1,758	176	352

The Population size estimates reported here for Ofu and Olosega are also substantially larger than those recorded after European contact. Based on his assessment of the early historic record, Green (2007: 212) reported that populations in Manu‘a rose in the period from 1840 to 1853 from 1,174 to 1,275. If that was true, Manu‘a would be an outlier in the Pacific where population crashes were common following European contact (see Kirch and Rallu 2007). Alternatively, in light of this analysis, increased populations in Manu‘a after 1840 might be the manifestation of a small population rebound following earlier severe depopulation. Instead of stability between the pre- and post-contact periods, the results here, if correct, indicate a population reduction of well over 50% in Manu‘a following European contact. A population reduction of this magnitude by the mid-19th century is consistent with descriptions of potential disease in Manu‘a in the late 18th century (La P erouse 1798 [III]: 62).

DISCUSSION

Similarities in settlement systems between Ofu and Olosega are not surprising given how close they are geographically and how close they were socially (Mead 1969). The range of feature classes is similar for each island, and terraces constitute the majority of landscape modifications. These features had similar attributes and, presumably, similar functions. Still, proximity did not preclude the development of variation that aids in elucidating the potential relationship between the people that inhabited these islands (Table 4). Populations were modifying steeper slopes on Olosega relative to Ofu, evidenced by the percentage of the total inland area taken up by HFD zones and the location of Sili-i-uta as an outlier. Their production systems were qualitatively similar, but analyses presented here hint of quantitative differences in the use of strategies. Most noticeably, the cultivation of tree crops appears to have contributed more substantially to production on Olosega than on Ofu. Finally, both carrying-capacity estimates and settlement patterns seem to indicate a higher population size and density for Olosega relative to Ofu.

Table 4. Major differences between Ofu and Olosega.

Attribute	Ofu	Olosega
Largest terrace	681 m ²	2,035 m ²
% of interior in HFD area	31	61
Settlement pattern estimated as % of carrying capacity	64	83
Ratio of shifting cultivation to arboriculture	0.78	0.27

Generally, higher population size and density correlates with different forms of community organisation (Carneiro 1986). In essence, higher population size would translate to the availability of a larger labour force that could be drawn upon by community leaders, and higher density would require different mechanisms of organisation. This is particularly evident on Olosega by community-wide labour constructions in Tamatupu, such as star mounds and ditching, and more star mounds are found in association with Tamatupu relative to any other area of either Ofu or Olosega. Star mounds are associated with chiefly competition and, therefore, political competition (Herdrich and Clark 1993), and the sheer number of these monumental features on the ridgeline adjacent to Tamatupu speaks to the labour expended by the population toward this activity (Quintus and Clark 2012). Consistent with this, the largest terrace identified in Tamatupu (2,035 m²) is roughly three times the size of the largest terrace outside of Tamatupu (681 m²). Power is also apparent in the construction of a single long ditch stretching the length of Tamatupu as this would likely have required more sustained intra-community labour investment and buy-in from residents given its spatial extent and probable need for continued maintenance. This combined evidence hints that the Tamatupu settlement was politically prominent at one time.

Therefore, the subsistence system of Olosega apparently was capable of supporting a large population density and materialised political processes, but such densities and processes may not have been sustainable. Ethnohistoric records document Olosega as the instigator of or involved in aggressive actions by the late 18th and early 19th century (Krämer 1902–03 [I]: 597–98, 600–601; Wilkes 1852: 157; Williams 1837: 414), even though conflict in Manu‘a is thought to be minimal compared to the western islands of the archipelago (Goldman 1970; Mead 1969). This protohistoric conflict might relate to external factors (e.g., influx of Christianity), but a consideration of how production strategies and population density reduced settlement resiliency by creating vulnerability to periodic tropical cyclones provides another plausible hypothesis for such aggression.

Tree Crops and Rigidity: A Preliminary Hypothesis

The cultivation of tree crops appears to have been the chosen mechanism of increased production on Olosega, supporting higher population densities as it allowed exploitation of the arboreal niche. (after Latinis 2000) in the context of limitations to land availability (see Kirch and Yen 1982). As Huebert (2014: 289–90) notes, the cultivation of tree crops provides high yields for limited labour (see also Yen 1974: 278) and tree crops were an avenue to increasing food production since these trees increase the vertical capacity of production (Huebert 2014: 20–21). At least in Near Oceania,

these tree gardens are a significant component of production systems that support villages in the thousands (Terrell 2002: 198).

Based on the foregoing, I hypothesise that tree cropping on Olosega might have been a strategy that could be integrated within and around residential settings, transmitted to subsequent generations and expanded upon. Such a strategy is important in densely occupied areas since the loss of areas suitable for shifting cultivation through residential expansion could have been offset by further investments in tree cropping. However, this strategy could also present problems. Paulson (1993: 45) notes that as much as 100% of the breadfruit and banana crops were destroyed during Cyclone Ofa in the early 1990s. More recently, a cyclone in 2005 resulted in severe damage (i.e., uprooting or snapping) to 57% of all trees on Ta'u, with trees such as breadfruit and coconut being particularly susceptible to damage (over 70% severely damaged) (Webb *et al.* 2014: 35). Though some trees might survive, recovery of these systems happens on a scale of years to decades (Clarke 1992; Colding *et al.* 2003; Paulson 1993). This, in turn, means that reliance on tree crops increases the vulnerability of a population to stochastic environmental perturbations.

While the cultivation of tree crops on Olosega might have initially increased subsistence system diversification and risk management (after Latinis 2000), tree cropping in the late pre-contact and protohistoric period may have been geared toward product maximisation (after Allen 2004) to support both increased population and apparent social processes (e.g., construction of monumental architecture). This type of formation of feedback loops between subsistence and population can create rigidity traps. Rigidity traps, or lock-in strategies, are an outcome of decisions that create path-dependent trajectories, in this case the need to practice space-saving and high-yielding production strategies, which become increasingly inflexible over time (Hegmon *et al.* 2008; Holling and Gunderson 2002; Schoon *et al.* 2011). I hypothesise that a rigidity trap developed on Olosega as increased population density required further investment and increased reliance on tree crops as a strategy of increased production.

Path dependency becomes problematic when populations are overly reliant on one strategy (Kidder and Liu 2017). Reliance is an outcome of the lack of other options, especially as time passes. If the distribution of secondary forests accurately reflects the distribution of shifting cultivation, land suitable for expansion of shifting cultivation on Olosega was limited to areas of high slope (over 30 degrees). The strategy of cultivating steeper slopes would have been met with diminishing returns as soils eroded from these hillslopes, and experimentation with this strategy might be one reason why community-length ditching was necessary to protect residential areas. In this environmental context, investments in tree cropping were a robust

strategy in light of an increasing and expanding population, robust in the sense of ensuring the maintenance of performance characteristics (Hegmon *et al.* 2008: 321). But, increased robustness to some changes (i.e., population increase) created vulnerabilities because of overreliance and increased inflexibility. The solving of one problem can lead to another. In this case, increased dependency on tree crops translated to increased population vulnerability to cyclone damage.

Even while capable of supporting a higher population size and density, the system of cultivation on Olosega as defined here would have been more susceptible to production variation relative to that on Ofu because of the periodicity of cyclones, though this is not to say that there was a food shortage or demographic collapse. Instead, variation could have translated into a decreased ability of elites to mobilise surplus to fund initiatives in this small-scale society. Fluctuations that cause the shortage of either social or subsistence production can be met with alternative methods of food acquisition. This case of variation in population and production might have created conditions for increased conflict in the late prehistoric and early protohistoric periods (18th and 19th centuries), conflict that is recorded ethnohistorically and ethnographically. In this way Ofu and Olosega would appear similar to cultural sequences in several regions of Polynesia where late period conflict was the result of production variation (Kirch 1994, 2010; Ladefoged 1995). However, in the present case it is the population that controls the higher productivity environment that instigates conflict. This is the result of the social creation of vulnerability instead of the response to the variable productive potential of different environments, as is the case in Hawai'i and Rotuma.

This interpretation is based on the correlation between high population density and tree cropping on Olosega. Certainly, additional fieldwork and archaeobotanical data is needed to test these interpretations. The hypothesis presented here generates a new set of testable expectations regarding productive landscapes, settlement distribution and population estimates as they pertain to resilience and vulnerability. While the distribution of modern vegetation might be used as a rough proxy for a slice in time, there is also the potential for substantial error and limited ability to understand diachronic change. It is expected that tree cropping would expand over time, in concert with increased population density. This situation is also true of settlement patterns. The calculation of total residential terraces here was based on a robust dataset of features from these islands, but could and should be augmented and modified based on targeted household excavation to examine feature function and use life. One expectation from this hypothesis is that the settlement of Sili-i-uta occurred after considerable investments in the Tamatupu zone.

Variation in cultural practices will develop based on minor ecological differences and the cumulative effects of human decision-making. These cumulative effects can have a substantial impact on the nature of resiliency and vulnerability in island environments. On Ofu and Olosega, populations solved similar problems with, at times, different solutions. Those different solutions fed back to create conditions impacting the context of future decision-making. Importantly, population and production dynamics appear to have created a rigidity trap that might have made communities on Olosega more vulnerable to local environmental perturbations. These pre-contact, small-island societies serve as important models for contemporary populations in the region. As people continue to respond to changing landscapes, it is necessary to remember that even robust solutions to particular problems often have unforeseen consequences beyond the sight of a single human generation. Resilient solutions require the retention of flexibility in cultural practice, enabling response to a broad range of outcomes.

ACKNOWLEDGEMENTS

I extend my gratitude to the people of Ofu and Olosega who have supported this work. I thank David Herdrich and David Addison for logistical support during fieldwork. Jim Bayman, Jennifer Huebert, Melinda Allen and Jeff Clark provided critical comments on a rough draft of this manuscript. Finally, and most importantly, I would like to thank Jeff Clark for the over ten years of mentoring that has allowed me to pursue a career in Pacific archaeology.

NOTES

- 1 A 2011 version of this vegetation survey did not use the same classification system as the 2007 survey. The 2007 survey is used here since the 2011 classification system did not consider the class of agroforestry (Liu *et al.* 2011: 9). The agroforestry component of modified forest was confirmed by Satele (1999) for Sili-i-uta.
- 2 Activities such as eating and sleeping are defined as residential. A single terrace could support multiple structures serving different functions.
- 3 The coastal flats would also have been used by producers, but the area available for cultivation was minimal compared to the interiors. These areas are not considered here.

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ABSTRACT

The archaeology of Sāmoa has been structured around the investigation of settlement patterns and systems since the 1960s, and such investigations have been variously used to explore questions of temporal change relating to, among other things, political structure and subsistence. This same intellectual structure is applied here to the evaluation of variation between the geographically close islands of Ofu and Olosega, extending previous approaches by considering population estimates. These analyses, which include a calculation of carrying capacity and population estimates based on settlement patterns, suggest that Olosega supported a higher population density than Ofu, perhaps because of investments in tree cropping on the former. Variation in settlement distribution, subsistence strategies and population density has important implications for population resiliency and vulnerability in small-island societies.

Keywords: Sāmoa, population estimation, settlement patterns, vulnerability, Manu‘a Islands

CITATION AND AUTHOR CONTACT DETAILS

Quintus,¹ Seth, 2018. Exploring the intersection of settlement, subsistence and population in Manu‘a. *Journal of the Polynesian Society* 127 (1): 35-54. DOI: <http://dx.doi.org/10.15286/jps.127.1.35-54>

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