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– ARTICLE –

The Field of War: LiDAR identification of earthwork defences on Tongatapu Island, Kingdom of Tonga

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ABSTRACT

Warfare and conflict are associated with complex societies in Polynesia where competition and coercion were common in island chiefdoms. In prehistoric Oceania, Tonga was unique for an Archaic state that under the Tu'i Tonga dynasty established control over an entire archipelago from AD 1200 to AD 1799 prior to a prolonged period of warfare. Lidar data was used to identify earthwork fortifications over the entirety of Tongatapu and to examine the conflict landscape using lidar-derived attributes in tandem with archaeological and historical information. The distribution of earthwork defences indicates a complex history of conflict and political machinations across Tongatapu beginning with the Tu'i Tonga chiefs at Lapaha, but resulting in a mid-19th century civil war ending with a new royal dynasty. Fortifications offer important evidence of social-political change, and the heritage condition of earthwork defences, many of which are under threat from development, was assessed with lidar.

Keywords: fortifications; lidar; warfare; Pacific; Tonga; state development

INTRODUCTION

Lidar is a core component of prehistoric site prospection and provides geospatial data on how complex societies rise, expand and decline (Chase *et al.* 2014; Evans and Fletcher 2015; Evans 2016; Lucero *et al.* 2015; Rosenswig *et al.* 2014). Chase *et al.* (2012) described the adoption of new remote sensing methods in archaeology as a paradigm shift equivalent to radiocarbon dating due to the number of prehistoric built remains that can be accurately mapped with lidar over large areas even under heavy vegetation. While the costs and administrative requirements associated with acquiring and using airborne lidar remain high, archaeologists have been able to source lidar acquired for topographic mapping or climate change/disaster management purposes. Archaeologists have examined prehistoric landscapes at high spatial resolution using lidar in Tonga, American Samoa and Hawaii (Freeland *et al.* 2016; Ladefoged *et al.* 2011; Quintus *et al.* 2015), and lidar data to model coastal inundation in areas of New Guinea, Vanuatu and Samoa may become available to archaeologists in the near future. Although remote sensing data is of obvious benefit to Pacific archaeology, the sheer number and density of ancient sites and features recorded with the technique poses a challenge to the developing cultural heritage resources of many Pacific Island nations. For this reason, the identification and assessment of lidar-identified archaeological sites is important as it contributes to cultural heritage policies and community site management strategies in Small Island Developing States as well as to Pacific prehistory.

In this paper, we present the first lidar-based inventory of earthwork defensive sites on Tongatapu which represents a conflict landscape that developed over centuries. Fortifications are the most important surviving archaeological evidence for conflict in Tonga as weapons were made in perishable materials that do not survive in the tropics and there are no skeletal remains with unambiguous evidence of warfare (Scott and Buckley 2014). Fortified sites provide insight to the actual practice of prehistoric warfare, but are also symptomatic of social and political instability as Webster (1998: 313) noted in a cross-cultural comparison of warfare among the lowland Maya with warfare in Polynesia: 'conflicts are arranged and carried out by at least one of the factions with the intent of maintaining or shifting power relations'. For example, when the Vava'u chiefs in northern Tonga attempted to become independent they built a large fort capable of holding the entire population of 8000 people (Martin 1991: 107). The distribution and size of earthwork forts has the potential to shed light on political changes in Tonga, particularly during the lengthy Civil War era (AD 1799–1852). In addi-

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tion, historical sources can be used to identify recent fortifications from those that may be of prehistoric age. This is important as the role of warfare and competition in the development of complex societies like the ancient Tongan state (AD 1200–1799) is poorly understood (Turchin *et al.* 2013).

TONGA ISLANDS: LIDAR DATA AND METHODOLOGY

The Kingdom of Tonga consists of around 170 islands spread over 700 km from Ata in the south to Niufo'ou in the north (Figure 1). The archipelago is divided into four groups. In south to north order they are: Tongatapu Group (Tongatapu and 'Eua); Ha'apai Group; the Vava'u Group; and the Niuas (Tafahi-Niuatoputapu and Niuafo'ou). Tongatapu is the main island (259 km²), had the largest population estimated at 18,500 people in late prehistory (Burley 2007), and was the political centre of the Tongan state for 600 years (Campbell 2001; Clark *et al.* 2008; Kirch 1984). Composed of coral limestone, Tongatapu is a low, raised island with soils that have been enriched by volcanic ash. The vegetation of Tongatapu is highly managed with ~66% of total land area under swidden horticulture (subsistence/cash cropping) providing ideal lidar survey conditions although associated ploughing and mechanical levelling of fields has impacted earthworks.

Aerial topographic lidar and aerial photography were acquired by the Tongan government as a component of the AusAid funded Pacific Adaptation Strategies Assistance Program over the islands of Tongatapu, Lifuka and Foa to inform coastal and planning management and climate change. The lidar was captured on six flights carried out from 3–24 October 2011 with 104 runs, and eight cross runs flown at 750 m above ground level. The Optech ALTM-Orion sensor collected four discrete returns and intensity. The swath width of the lidar was 578 m and overlap between flight lines was 20%. The project was designed to meet project specifications of 4 pt/m²; however, post survey checks indicate that 7.87 pt/m² was achieved with all returns and a 5.67 pt/m² density with only first returns (a pseudo pulse density). The survey was conducted on the WGS84 horizontal datum and projected to the Tonga Map Grid 2005. Vertical datum for the survey was the EGM2008 geoid and a local adjustment of 0.77 m was made by the contractor to adjust the vertical datum of the project to Mean Sea Level at the benchmark TON1 vide the Nuku'alofa SEAFRAME tide gauge. The GPS base station was located at the Fua'amotu International Airport and the entirety of the survey area was within 50 km of the base station (AAM Pty Ltd 2011).

Figure 1. Map showing Tonga and the island of Tongatapu (inset) with significant locations mentioned in the text.

Raw laser data was classified by the contractor into ground or non-ground classifications according to ICSM Classification Level 2 Ground Surface Improvement standards. Independent survey checks indicate that the vertical accuracy of the project in Tongatapu is 0.15 m at 95% confidence level. The density of points classified as 'Ground' was calculated at 1.04 pt/m². Point cloud data was stored in the binary LAS format where derivative products, such as Digital Elevation Models, intensity imagery, and foliage models, were created by the contractor and delivered to the Tongan Government. Approval to use the lidar dataset for archaeological research was granted by the Tongan Government and Geosciences Australia to the Australian National University.

Lidar data processing and feature identification

The low relief and generally gentle topography of Tongatapu allowed standard lidar visualisation techniques to view and interpret archaeological features. In some areas, however, urban development had severely degraded or even destroyed portions of earthworks and several techniques (see below) were used to identify fortifications in a second round of processing. All lidar visualisations used the contractor supplied 1 m Digital Elevation Model as a base from which additional visualisations were prepared.

The first examination of the Digital Elevation Model was made using 'default' hillshade models that are standard in GIS packages. The basic visualisation revealed a number of archaeological features present in the lidar data, including mounds, chiefly tombs, sunken roads and defensive structures. The default hillshade proved to be a useful first examination of the data; however, it was apparent that features of low topographical relief were not readily visible and that details of some linear features were hidden when features were at the same orientation to the point source used to illuminate the surface. Three additional lidar visualisations were produced in the second round of processing: (1) an advanced hillshade; (2) a trend removed DEM, and (3) 'bonemapping'. In addition to the lidar visualisations, aerial photography and lidar intensity imagery were used to distinguish between modern infrastructure and archaeological features with field visits made to 35 defensive sites (see Burley *et al*. 2016).

1. Advanced hillshade

The 'sky' model hillshade simulates natural, diffuse, lighting on the ground surface by using a routine that creates hillshades from over 200 different azimuths and elevations (Kennelly & Stewart 2014). These 200 plus hillshades are weighted and merged together using parameters from a predefined model to create the final, multi-source hillshade. The hillshade was created using 'overcast' parameters with no vertical exaggeration and while computationally intense it was superior to the 'default' hillshade in identifying subtle features such as borrow ditches used for mound fill. Varying the histogram stretch when visualising the hillshade inside the GIS package was also useful in analysing aspects of the earthworks. Visualising a narrow range of values helped to identify the status of the fortification, such as rampart condition, whereas visualising a wide range of values refined the morphology of deeper ditches and excavations.

2. Trend removed DEM

The trend removed DEM aims to normalise the lidar DEM to highlight local topographic anomalies. To create the trend removed DEM, the DEM is first generalised using a low pass filter with a 10 m kernel diameter. The generalised DEM is then subtracted from the high resolution 1 m lidar derived DEM with the result highlighting local topographic variation above and below the generalised terrain. When visualised within a narrow range of pixel values in the GIS (−0.5–0.5) features of low topographical relief like low mounds and highly eroded ditch and bank constructions, particularly those located in present day towns, are visible.

3. Bonemapping

The bonemapping visualisation was primarily used to investigate the shape of some of the highly degraded fortifications in urban areas. Developed by Pingel *et al*. (2015), bone mapping improves on the typical slope products by amplifying discontinuities in the slope surface. It was found that this technique was quite susceptible to 'noise' when lidar ground point density was low. While mounds and noise can have similar signals, degraded linear earthworks could be clearly seen.

IDENTIFYING FORTIFICATIONS

Researchers in Tonga have previously identified defensive earthworks from traditional information about sites, historical observations of warfare and the similarity of earthworks to those with a known military purpose (McKern 1929; Pepa 1997; Spennemann 1989a; Swanson 1968). Straight-sided and circular fortifications were made in the 19th century by excavating one or more ditches and the removed sediment was used to make a rampart. The interior space of historic earthworks protected a military force or community group led by one or more chiefs. Most ramparts were positioned on the inner ditch edge, but could also be located on the outer ditch edge (as common in Fiji; see Parry 1987) or the spoil deposited on both sides of a ditch. Europeans observed that a strong palisade around 2.5–3.5 m in height was built on the rampart(s) consisting of interwoven screens of bamboo/reed attached to upright posts (Martin 1991: 79).

The rampart was interrupted by entranceways that were protected by cantilevered platforms that projected over a gate. Elevated platforms were protected by screens which had gaps to launch projectiles through (spears/stones/arrows) as did the main palisade (Erskine 1853: 148; Martin 1991: 79–80; Wilkes 1985). Entranceways and gates might be protected by flanking defences (bastions), outpost mounds/banks and pit traps. Linear defences were also constructed. In 1827, Captain Dumont d'Urville used cannon to bombard the sacred precinct of Ma'ufanga, but found it had been protected by a large sand rampart and ditch that had been built along the beach edge (Rosenman 1988 Vol. 1: 122–123).

The impact of European weapons and tactics likely led to relatively minor changes to Tongan fortifications including increased bank thickness and height to stop cannon shot entering a fort, loop holes and flanking positions for musket/cannon fire, and access ways for the movement of cannon (e.g. Erskine 1853: 148; Martin 1991; Wilkes 1985: 14). Forts could be quickly built and were maintained and enhanced during periods of conflict. The defences of the warrior chief, Finau 'Ulukālala, who was the first to use cannon against an earthwork fort on Tongatapu in 1807: 'underwent frequent examination and improvements' (Martin 1991: 254). When hostilities ceased palisades could be removed, and ramparts and ditches levelled or neglected (Home 1849: 581; Latukefu 1967: 521; Rosenman 1988 Vol. 1: 125)

Historical observations summarised above indicate two broad types of earthwork which are supported by Tongan traditions and some archaeological results (Burley 1995; Clark *et al.* 2008; McKern 1929: 93). The first type of earthwork consists, minimally, of a ditch and rampart enclosure (*enceinte*) that protected an interior area of variable size. Enclosure forts could have a coastal or swampy perimeter that was be left open for canoe access (Erskine 1853: 148), but earthworks defended most of an enclosure. We recognise that not all enclosure walls were defensive, and in Tonga temples, chiefly compounds, tombs and refuges could be walled (e.g. Orange 1998: 97), but in the historic era these structures lacked earthworks defences except for a few chiefly compounds that were likely enclosure forts during periods of political turmoil (see below). In Tongan traditions, earthwork enclosures protected lookout positions, political centres and village/community and military groups (LTC 2012; McKern 1929; Spennemann 1989a: 331–333;).

Linear features comprise the second form of defensive earthwork and these have received little attention and might represent peaceful barriers and sunken roads with no military function. Keeley *et al.* (2007: 79) notes that ditches, especially V-shaped and deep ditches, if backed by a palisade and rampart are likely to be defences against human attackers. Ditches with trapezoidal and semi-circular cross-sections might have been excavated to provide material for the defensive palisade-rampart wall or been used for irrigation; but the latter is not feasible on limestone Tongatapu which has no standing sources of freshwater. Sunken roads are long, relatively wide and shallow structures that do not have a rampart(s) (Spennemann 1989b: 86–87). We consider linear earthworks as potentially defensive if they have one or more of the following: (1) V-section/probable V-section ditch; (2) ditch accompanied by a rampart; and (3) linear earthworks that define a distinct area or territory including earthworks that cut of headlands, peninsulas and larger areas of an island (Spennemann 2002; and see Davidson 1971: 35 for an example in Vava'u).

SITE DESCRIPTIONS

In previous work, McKern (1929), Swanson (1968) and Spenneman (1989a: 483) recorded between 13 and 34 fortifications on Tongatapu. Our lidar survey and analysis identified 51 enclosure earthworks on the island of Tongatapu and six linear defences (Figure 2, Supplemental Material). Defensive earthworks are listed by site number and name to distinguish between forts located in the same area as well as those which have evidence for multiple construction events. Lidar derived details of earthworks, including site condition incorporates observations from aerial imagery collected in 2011 and site visits by the authors, is given in Table 1 (see Supplemental Material). Site condition was assessed as 'Good' if the earthwork was largely intact and had only minor damage (e.g. 4WD tracks, shallow horticulture), 'Average' if a fort had been impacted in some way by development with loss of ramparts or areas of ditch infilled, but parts of the earthwork were still in good condition, and 'Poor' if a fort has been severely impacted by development with all rampart(s) removed and only traces of the ditch remaining. We do not consider the degree of natural erosion which needs to be examined by excavation of the ditch-rampart.

Terminology to describe earthworks follows Keeley *et al.* (2007) with 'baffled gates' used to describe an indirect or flanked entrance passageway that was often created by placing a section of earthwork/palisade in front of an entrance to stop attackers from making a frontal assault on the gate, and 'bastions' that are an external projection of a barrier that create a flanking position for defenders. Enclosure earthworks are described first followed by linear defences. Enclosure forts vary in shape and are subdivided into four general categories to facilitate description: 1. Complex; 2. Rounded; 3. Sub-rounded and, 4. Straight-sided (Figure 3, Supplemental Material).

Enclosure forts

1. Complex forts (n=2)

This fortification type has three or more major earthworks as the majority of enclosures on Tongatapu are made with one or two earthwork defences. Only two complex forts were identified and both are in the west of Tongatapu (Fig-

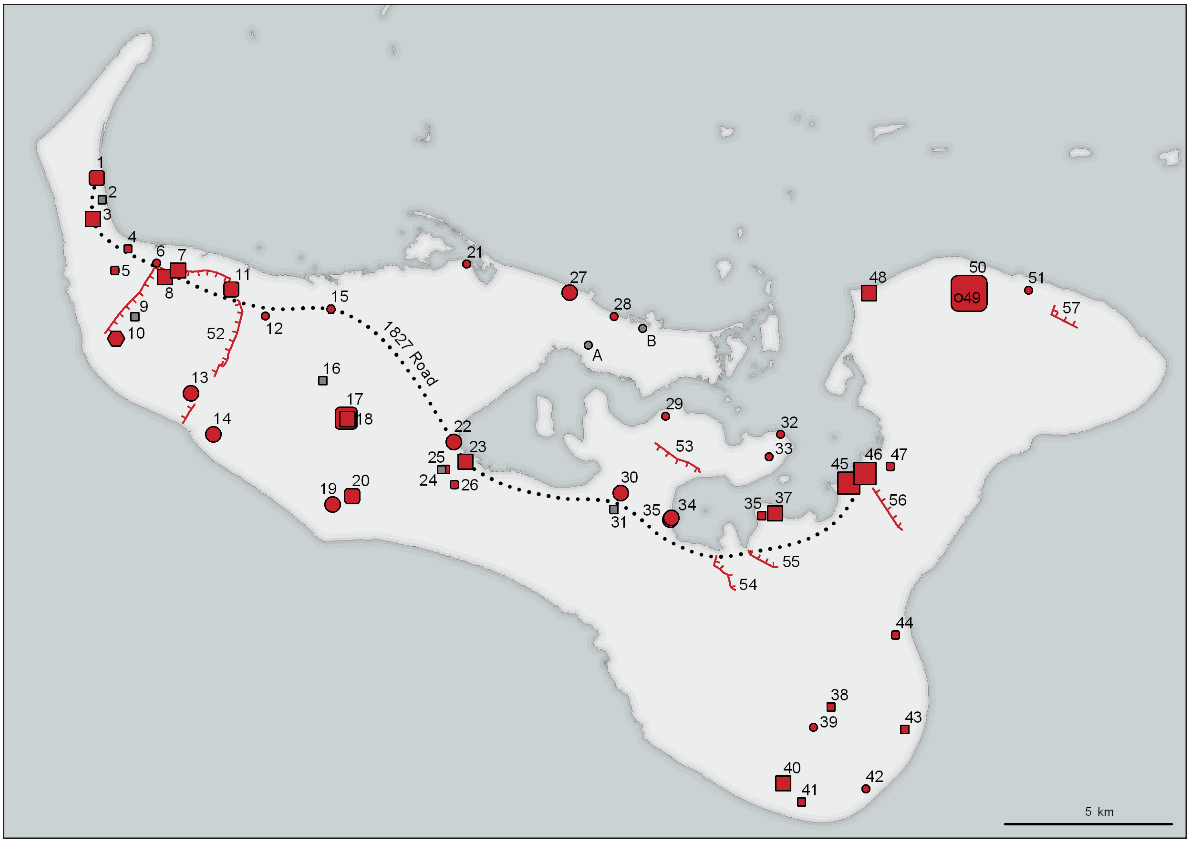

Figure 2. Defensive earthworks of Tongatapu. Enclosed fortifications (n=46) are identified by symbols. Complex forts (n=2) = octagon, Rounded forts (n=19) = circle, Sub-rounded forts (n=10) = rounded square, Straight-sided forts (n=20) = square. Gray symbols indicate incomplete (n=5) or destroyed (n=2) fortifications. Symbol size is scaled to represent fort size (Table 1, Figure 4). Linear defences are red lines with tick marks indicating the position of the rampart. The Locations 'A' and 'B' indicate the approximate position of the Ngele'ia (A) and Ma'ufanga (B) fortifications which were built in the Civil War (AD 1799–1852), but have since been destroyed. The approximate position of the major road recorded by Dumont d'Urville in AD 1827 is marked by black dots (after Paris 1833). See digital manuscript for colour interpretation of figure.

ure 2). The best example is 15-Manahau which was built in AD 1804 and consists of an inner straight-sided fortification (~12,000 m²) surrounded by two outer walls with a total area of 44,000 m². The fort has a large bastion on the west side and a baffled gateway controlling access to the inner fortification (Figure 3). The other fortification that might represent a complex fort is 10-Fāhefa which comprises either two separate fortifications or a single complex fort. Fāhefa has a similar total area (47,000 m²) to Manahau and a large bastion, but the main fortification appears to be a single round earthwork with a bastion made from two earthwork sections that join to the round earthwork (Figure 3). The forts differ in rampart position with outer ramparts at Manahau and inner ramparts at Fāhefa, which has a centrally located mound that may have functioned as a lookout, but is now a village cemetery. The Fāhefa bastion is flanked by two mounds that may have served as outpost/lookouts.

2. Rounded forts (n=19)

These forts have a circular or sub-circular shape with changes to enclosure rampart-ditch direction marked by rounded contours (Figure 3). Rounded forts vary in size with the internal area of the smallest only 1550 m² (6-Teʻekiu) and the largest over 120,000 m² (22-Pea). They are distributed throughout Tongatapu except for an area along the inner Fanga ʻUta Lagoon (Figure 2). Most are single ditch-rampart earthworks (n=13) that are simple and lack bastions and three appear to have baffled gateways (6-Teʻekiu, 32-Kauvai, 39-Malaʻe Vakapuna). Eight forts have mounds located centrally, or close to an inner or outer rampart. While central mounds could have been used as lookouts/refuges those associated with ditch-ramparts may have been used as bastions (6-Teʻekiu). At 33-Kauvai lidar data shows the large central mound has a depression which is a characteristic feature of chiefly pigeon snaring mounds (*sia heu lupe*), and the earthworks defend a portion of the 30 m high hilltop containing the mound. The

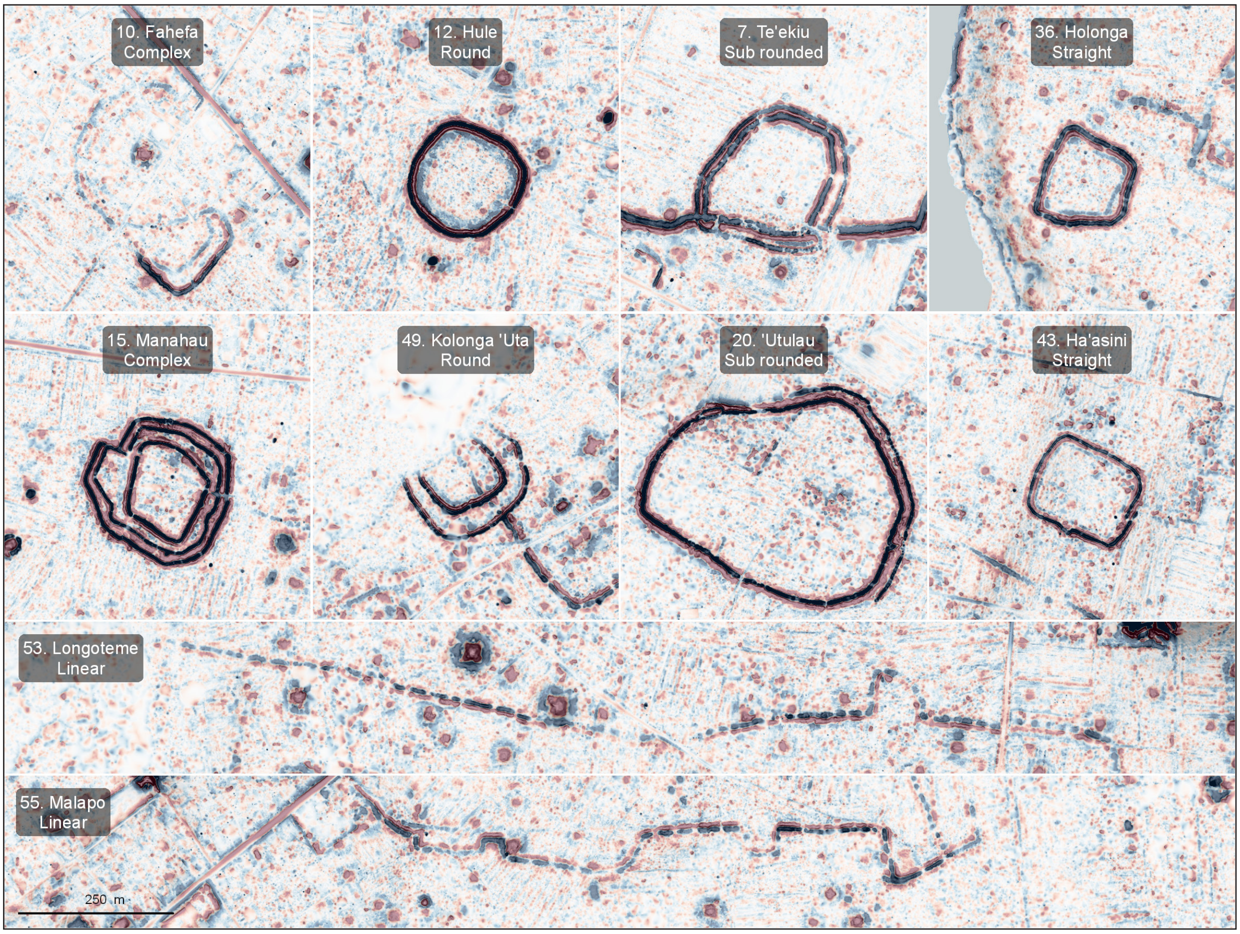

Figure 3. Examples fortification shape categories identified with lidar (see Supplemental Material for additional images). Images show lidar hillshade visualisation with detrend DEM overlaid with red indicating surface above trend and blue/black surface below trend (see digital manuscript for colour interpretation of figure). All examples are at a uniform scale for comparison.

centre of the 42-Nakolo fort is marked by a large cave entrance with limestone solution passageways to the south and northeast that was likely a refuge and source of freshwater. Several round forts were built, or are recorded as being used, in the 19th century (e.g. 12-Hule, 14-Houma, 22-Pea, 27-Nuku'alofa, 28-Takaunove, 34-Vainī, 35-Vainī) and while most are in good-to-average condition, urban development and construction have destroyed/degraded eight forts and four could only be identified in advanced lidar visualisations (14-Houma, 19-'Utualu, 34-Vainī, 35-Vainī). Three mounds within rounded forts are currently used as cemeteries (14-Houma, 19-'Utulau, 22-Pea).

3. Sub-rounded forts (n=10)

Forts in this group are morphologically varied and characterised by a shape that includes both round and straight-sided sections of ditch-rampart, particularly 'D-shaped' forts (Figure 3). These are found in the west of Tongatapu, but extend to Lapaha which has distinctive D-shaped fortification that has deepest ditch of any fortification in Tongatapu that enclosed a small inner area of only 2700 m^2 (Figure 2, Table 1). The 47-Lapaha fort has been radiocarbon dated to AD 1300–1400 and lidar analysis demonstrates that the amount of sediment removed to make the ditch was much greater than used in the rampart indicating that material was likely used in construction projects undertaken by the early Tongan state at Lapaha (Clark *et al.* forthcoming). At the other extreme, 50-Kolonga 'Uta is a large sprawling fortification with a perimeter that backs onto a mangrove swamp with an inner area of ~280,000 m^2. The fort has a probable bastion/lookout in the south that utilised an existing rectangular earth mound, and 4-Masilamea also has a possible bastion position in the south. Three forts have additional sections of earthworks in front of the inner ditch-rampart that are potentially the remains of baffled gates (4-Masilamea, 5-Masilamea, 20-'Utulau), one fort has a central mound (11-Nukunuku), and another four have mounds located toward the rampart (1-Kolovai, 5-Masilamea, 26-Pouvalu, 51-Kolonga). Two mounds in forts are now used as village cemeteries (1-Kolovai, 11-Nukunuku). A minimum of three sub-rounded

Table 1. *Tongatapu earthwork defences identified with lidar. The site name can vary among informants and the numeric label is added to avoid confusion. Defensive earthwork (1–51) morphology is listed under in 'Shape Category' (see text) and fort size in 'Size Group' (Figure 4). Site names Metric attributes calculated with lidar data and earthwork 'Condition' assessed with lidar, aerial photography and site visits (see Supplemental Material).*

Site Name	Shape Cat.	Condition	Area Outside (m²)	Perimeter (m)	Area Inside (m²)	Size Group	Rampart No.	Rampart Position	Ditch No.	Ditch Width (m)	Ditch Depth (m)
1. Kolovai	3	Average	115566	1330	93845	2	2	Both	1	15	–
2. Ha'avakatolu	4	Average	–	–	–	–	2	Both	1	12	–
3. Foui	4	Poor	33594	723	25584	1	2	Both	1	10	–
4. Masilamea	3	Good	16764	503	10979	1	1	Outside	1	9	1.3
5. Masilamea	3	Good	21091	543	14765	1	2	Both	1	7	1.1
6. Te'ekiu	2	Good	3903	228	1547	1	1	Inside	2	12	0.8
7. Te'ekiu	4	Good	46600	811	24413	1	3	Both	2	7.5	0.5
8. Te'ekiu	4	Poor	109532	1239	78962	2	2	Inside	2	6.5	0.6
9. Fāhefa	4	Average	–	–	–	–	1	Outside	1	7.2	0.85
10. Fāhefa	1	Poor	47176	788	36434	1	2	Inside	2	13	–
11. Nukunuku	3	Poor	44132	770	31104	1	1	Inside	1	7.5	0.7
12. Hule	2	Good	28770	609	19121	1	1	Inside	1	11	1.8
13. Vaotu'u	2	Poor	44366	772	34651	1	1	Inside	1	14.5	–
14. Houma	2	Poor	71665	1014	57700	2	1	Outside	1	10	0.6
15. Manahau	1	Good	44135	790	11927	1	3	Outside	3	10	0.9
16. Matangiake	4	Average	–	–	–	–	1	Outside	2	22	0.8
17. Hauloto	3	Average	222459	1891	196431	3	2	Both	1	7.5	1.3
18. Hauloto	4	Average	123475	1427	105884	2	1	Outside	1	7	1.1
19. 'Utulau	2	Poor	39243	706	30920	1	1	Outside	1	9	–
20. 'Utulau	3	Good	123967	1373	93324	2	1.5	Outside	1.5	9	1.8
21. Puke	2	Good	9034	358	6751	1	1	Outside	1	6	1.2
22. Pea	2	Poor	133562	1440	123981	2	1	Inside	1	10	0.5
23. Ha'ateiho	4	Poor	119721	1398	109003	2	–	Unknown	1	11	–
24. Tokomololo	4	Average	–	–	–	–	1	Inside	1	12	0.6
25. Tokomololo	4	Good	16867	597	11631	1	1	Inside	1	6	0.6
26. Pouvalu	3	Poor	27649	614	21230	1	1	Inside	1	11.5	0.5
27. Nuku'alofa	2	Poor	34629	672	27791	1	–	Unknown	–	–	–
28. Takaunove	2	Poor	24149	598	18929	1	–	Unknown	1	17	0.5
29. Navai	2	Average	16514	463	10751	1	2	Both	1	14	0.7
30. Tapuhia	2	Average	98230	1179	74650	2	2	Both	1	13	1.8
31. Nualei	4	Poor	–	–	–	–	1	Inside	1	12	1.3
32. Kauvai	2	Good	23970	614	15623	1	3	Inside	2	7	0.6
33. Kauvai	2	Good	14680	478	10719	1	0	None	1	19	1.1
34. Vainī	2	Poor	76939	1052	69522	2	1	Inside	1	–	–
35. Vainī	2	Poor	91639	1169	81979	2	1	Inside	1	8	0.3
36. Holonga	4	Good	21916	559	14340	1	1	Inside	1	12	1.1
37. Holonga	4	Poor	125107	1568	105715	2	1	Outside	1	24	1.2
38. Havelu Lahi	4	Good	19201	527	13903	1	1	Inside	1	9	0.6
39. Mala'e Vakapuna	2	Good	9334	346	6345	1	1	Outside	2	5	0.6
40. Fua'amotu	4	Poor	44942	774	35290	1	–	Unknown	1	–	–
41. Fua'amotu	4	Good	10445	400	5557	1	1	Outside	1	10	1
42. Nakolo	2	Good	13296	426	4516	1	1	Outside	2	7	0.6
43. Ha'asini	4	Good	26079	625	18636	1	2	Both	1	8	0.4
44. Lavengatonga	3	Poor	15969	471	10937	1	1	Outside	1	11	0.3

Table 1 cont.

Site Name	Shape Cat.	Condition	Area Outside (m^2)	Perimeter (m)	Area Inside (m^2)	Size Group	Rampart No.	Rampart Position	Ditch No.	Ditch Width (m)	Ditch Depth (m)
45. Tatakamotonga	4	Poor	175938	1705	155383	3	–	Unknown	1	13	–
46. Olotele	4	Average	182144	1840	143931	3	2	Both	1	26	3.4
47. Lapaha	3	Good	20352	680	2721	1	1	Inside	1	23	4.8
48. Niutao	4	Poor	61230	963	45338	2	1	Inside	1	11	0.4
49. Kolonga 'Uta	2	Good	25267	621	8864	1	2	Inside	2	7	0.7
50. Kolonga 'Uta	3	Good	315042	2287	287909	4	1	Inside	1	11	0.8
51. Kolonga	2	Average	29075	614	21246	1	1	Inside	1	11	0.5
52. Keli 'o Pelehake	Linear	Good	–	8900	–	–	1	–	1	18	1.8
53. Longoteme	Linear	Good	–	1700	–	–	1	–	1	15	0.8
54. Hu'atolitoli	Linear	Good	–	1400	–	–	1	–	1	11	0.9
55. Malapo	Linear	Good	–	1400	–	–	1	–	1	10	1.1
56. Fisi Tea	Linear	Good	–	1530	–	–	1	–	1	20	5.0–1.0
57. Afā	Linear	Poor	–	1200	–	–	1	–	1	18	1.3

forts were made/used in the early 19th century (1-Kolovai, 11-Nukunuku, 18-Hauloto [Table 2]).

4. Straight-sided forts (n=20)

Forts are located in west and central Tongatapu and often occur in close proximity to another straight-sided fort (Figure 3, n=13). Many (60%) are associated with the main road recorded during Dumont d'Urville's AD 1827 visit to Tonga that ran from the Kolovai area through Foui and Te'ekiu then along the lagoon shore past Vainī and Holonga to Mu'a, which incorporates the chiefly villages of Tatakamotonga and Lapaha (Figures 1–2, Paris 1833). A separate cluster of four straight-sided forts is located in the south of the island. The only straight-sided fort in the east is 48-Niutao located in low-lying mangrove swamp ground which local traditions identify as a lookout fort. Niutao was in poor condition when visited in 2017 as it was built with sandy sediments which have eroded. The majority of forts (n=17) have a single ditch-rampart and lack elaboration. There is a possible bastion on the east of Niutao, and baffled gates at 8-Te'ekiu and 43-Ha'asini, but seven forts were assessed as in poor condition and the complexity of their earthworks cannot be determined (e.g. 23-Ha'ateiho and 37-Holonga). Some earthworks surveyed with lidar in 2011 have now further deteriorated including 46-Olotele at Lapaha where parts of the ditch system are being progressively infilled for urban development.

The largest straight-sided earthworks are at Mu'a (Figure 1), which incorporates the chiefly villages of Tatakamotonga and Lapaha. The 46-Olotele fortification marked the residential area of the Tu'i Tonga (144,000 m^2) with the ditch dug into the limestone bedrock and in places reaching the freshwater aquifer. A water-holding function for the northwest part of the ditch is indicated by the termination of the ditch inside the old shoreline and that it held freshwater when excavated (Clark *et al.* 2008: Figure 7) while the southern part of the ditch could not have held water as it cuts through the shoreline toward the lagoon. Tomb building within the Olotele enclosure appears to have begun with Tuofefafa (J04) a large earth burial mound surmounted by two walls of beach rock slabs that was placed over the ditch and that the defences were no longer needed. The Tuofefafa tomb was likely built 300–400 years ago (Clark 2014). Extensive earthworks in the adjacent village of 45-Tatakamotonga marked the residence of the Tu'i Kanokupolu as recorded by McKern (1929: 95, 99), but have now been destroyed (Spennemann 1989a: 476). Lidar analysis and interviews with local Tatakamotonga residents indicate the likely presence of an infilled straight-sided ditch enclosure recorded by McKern (1929) with an area of ~150,000 m^2, but the earthwork extent needs to be confirmed by field investigation.

A minimum of six forts were built or used in the Civil War including 45-Tatakamotonga in Mu'a where the defences observed in 1840 included a shallow ditch backed by an earth and log rampart on which a palisade was erected. Narrow and low entranceways in the rampart were protected by a guard house and a strong inner fence (Wilkes 1985: 22). Although the fort description has been attributed to 46-Olotele and 47-Lapaha the reference to a shallow ditch does not match either site where the ditch depth exceeds 3 m (Table 1). The association of straight-sided earthworks with the main west-east road suggests these forts may be of recent age. However, the straight-sided form is probably older with traditions indicating the 46-Olotele defences were built/rebuilt by the 23rd Tu'i Tonga Takalaua (~AD 1500) and 48-Niutao associated with the 11th Tu'i Tonga Tuitatui (~AD 1250) (Alexander and Wordsworth 2013: 78; McKern 1929).

Table 2. *Tongatapu Civil War fortifications (AD 1799–1852) recorded in historical sources. Where several fortifications exist in an area it is not possible to identify which earthwork the text refers to.*

Site No.	Site Name	Approximate date	Reference
1	Kolovai	1800, 1827	Thomas in Statham 2013:34 Paris 1833
3	Foui	1837	Thomas in Statham 2013:301 Gifford 1929:217
6, 7, 8	Te'ekiu	1804, 1827	Thomas in Statham 2013:34 Gifford 1929:209, 215 Paris 1833
11	Nukunuku	1804	Thomas in Statham 2013:40 Martin 1827:279
12	Hule	1817, 1827, 1837	Gifford 1929:210 Paris 1833
14	Houma	1804	Collocott 1928:92 Gifford 1929:210
15	Manahau	1804	Thomas in Statham 2013:41
17, 18	Hauloto/Polonga	1801	Thomas in Statham 2013:36
19	'Utulau	1804	Collocott 1928:92 Thomas in Statham 2013:41
22	Pea	1804, 1849	Collocott 1928:92 Thomas in Statham 2013:41 Martin 1827:110 Erskine 1853:148
27	Nuku'alofa (Nakelo)	1804	Thomas in Statham 2013:40 Martin 1827:94
28	Takaunove	1805	Thomas in Statham 2013:44
34, 35	Vainī	1810	Thomas in Statham 2013:55
45	Tatakamotonga/Mu'a	1810, 1839, 1840	Thomas in Statham 2013:55 Erskine 1853:140, 153 Wilkes 1985:22
40, 41	Fua'amotu	1817	Gifford 1929:210
52	Keli ʻo Pelehake		
Destroyed	Ma'ufanga	1827, 1837	Dumont d'Urville in Rosenman 1988:122 Gifford 1929:216
Destroyed	Ngele'ia	1837	Gifford 1929:215

Linear defences

Six linear defensive earthworks were identified with three in central Tongatapu (53-Longoteme, 54-Huʻatolitoli, 55-Malapo, Figure 3), one in the west (52-Keli ʻo Pelehake) and two in the east (56-Fisi Tea and 57-Afā). Linear defences typically start near a waterbody, either a swamp, beach, or lagoon and extend inland (Figure 2). Two earthworks may have outlined very large enclosures (52-Keli ʻo Pelehake and 57-Afā) while the Longoteme earthwork spans a small peninsula separating the two branches of the Fanga ʻUta Lagoon. All sites have evidence of ditch and rampart construction, although at Afā the rampart is severely degraded. Linear ditches have areas where a probable V-shaped ditch cross-section was observed in lidar visualisations, although infill prevents a conclusive assessment. Two linear earthworks have bastions (53-Longoteme, 55-Malapo) and the 52-Keli ʻo Pelehake also appears to incorporate bastion positions.

Linear fortifications represent some of the largest earthwork constructions on Tongatapu and all are over 1 km in length. When the length of linear defences is compared to the perimeter length of enclosure fortifications even the smallest (57-Afā) exceeds the perimeter of most enclosed fortifications. The 52-Keli ʻo Pelehake is the largest earthwork and has a length of 8.9 km (Figure 2). Spennemann (1989a: 480) identified Keli ʻo Pelehake as a sunken road because no ramparts were seen, however inner ramparts are clearly visible in lidar visualisations. Keli ʻo Pelehake is reputed to have been built in a single night during a war between the men of west (Hihifo) and east (Hahake) Tongatapu: '… at some undetermined time probably in the early 19th century' (Wood 1943: 81). Others such as 56-Fisi Tea probably date centuries older given the similarity of its ditch dimensions with those of 46-Olotele and local traditions that have the 57-Afā earthwork built before the Civil War.

DISCUSSION

Lidar data, historical records and field visits have populated the landscape of Tongatapu with at least 57 defensive earthworks. Forts occur in most parts of Tongatapu with higher densities in the west, along the lagoon shoreline and in the south of the island. The lowest density of defensive earthworks is in the area east of Mu'a. There was likely 'ribbon development' of forts along major communication routes that ran from the west to central Tongatapu (Spennemann 1989a: 494). Three main issues from the lidar survey and analysis are discussed below: 1. Variability in enclosure fort size; 2. The age of earthwork defences and, 3. Implications for heritage management. Consideration of other topics, including the development of an absolute chronology for earthwork defences from ^{14}C dating, the reconstruction of warfare from historical observations of inter-group violence and lidar, the location of forts in relation to resources such as arable land and fresh water, and the degree to which defensive earthworks represent political upheaval, will be examined in future research.

1. Enclosure fort variability

Enclosure forts are the most numerous earthwork and exhibit significant variation in their size, shape and complexity. Univariate and multivariate statistical methods (PCA/DFA/Cluster analysis) were used to investigate variation in enclosure forts with area/perimeter variables the most important due to the relatively simple design of many enclosures which lack bastions, baffled gates, platforms and other defences that may have been made in perishable materials.

The dimensions of an enclosure fort relate to the size of the workforce, the time available for its construction, and especially the number of people requiring protection. Increase in the size of a fort might occur as a result of natural population growth or an increase in group size from conflict migration and population amalgamation to defend against a large force. A number of enclosures have earthworks consistent with expansion including 17+18-Hauloto, 34+35-Vainī and 22-Pea. Alternatively, large earthworks that may have been difficult to defend could be strengthened by building smaller enclosures as with the 49-Kolonga 'Uta fort that was made over the eastern part of the 50-Kolonga 'Uta enclosure. In Figure 4, the size variation of 46 enclosure earthworks is plotted using the inner and outer areas with four informal size groups observed (data in Table 1). Inner area is defined as the internal, habitable area of the fortification and excludes all defensive structures. Outer area measures the complete footprint of the fortification and is inclusive of all defensive structures.

Group 1 (n=30)

Consists of the smallest forts and some may be lookout/refuge positions as well as forts built to hold a military force. The average inner area of Group 1 is ~17,000 m² (range 1550–36,000 m²). The number includes forts that are not mentioned in historical accounts as well as Civil War forts such as 12-Hule, 15-Manahau and 27-Nuku'alofa suggesting that many of the forts in this group were community fortifications built by one or more chiefs.

Group 2 (n=12)

Includes larger forts (average interior=105,000 m²) with nine associated with the main communication route from west to central Tongatapu and most are mentioned in Civil War accounts as population centres (Beveridge in Spennemann 1989a: 267). The increase in the size of Group 2 forts (with the exception of 48-Niutao in east Tongatapu that may be older) appears to be a defensive response to the growing scale of warfare during the Civil War. By the 1830s, political and religious divisions had coalesced into two main parties, and when some 300 inhabitants of the fort of 12-Hule (Group 1, interior area=19,000 m²) were killed by the forces of the Methodist chief Taufahau in 1837: '… the heathen abandoned nearly all their villages … and concentrated themselves at three principal places, at Mu'a [155,000 m²)], Bea [Pea, 124,000 m²] and Houma [58,000 m²] (Thomas in Statham 2013: 341).

Group 3 (n=3)

Comprise the adjacent enclosures of 45-Tatakamotonga and 46-Olotele in the east and the expanded 17-Hauloto fort in central Tongatapu. These large earthworks have an inner area of 144,000–196,000 m² and were the defensive compounds of three paramount chiefs. As mentioned, 46-Olotele, belonged to the Tu'i Tonga, 45-Tatakamotonga to the Tu'i Kanokupolu/Tu'i Ha'atakalaua and 17-Hauloto to the chief Vaha'i, who was the main war leader (*hau*) in the early 19th century (Thomas in Statham 2013: 56). Large sites appear to be the central places of paramounts and associated lineages, and to have functioned as both political and defensive centres.

Group 4 (n=1)

The largest enclosure fortification is 50-Kolonga 'Uta in the east of Tongatapu with an inner area of ~290,000 m². The sub-rounded earthwork has a perimeter of 2.2 km and terminates in swampland. Regardless of the age of the earthwork we interpret 50-Kolonga 'Uta as a regional 'superfort' used by the inhabitants of eastern Tongatapu (alternatively the fortification was used by a large occupying force).

In enclosure forts, a large difference between the inner and outer area indicates a preoccupation with defence from wide ditches and multiple ditch-ramparts that create significant obstacles to attackers. These forts fall below the trend line in Figure 4 and include 46-Olotele and

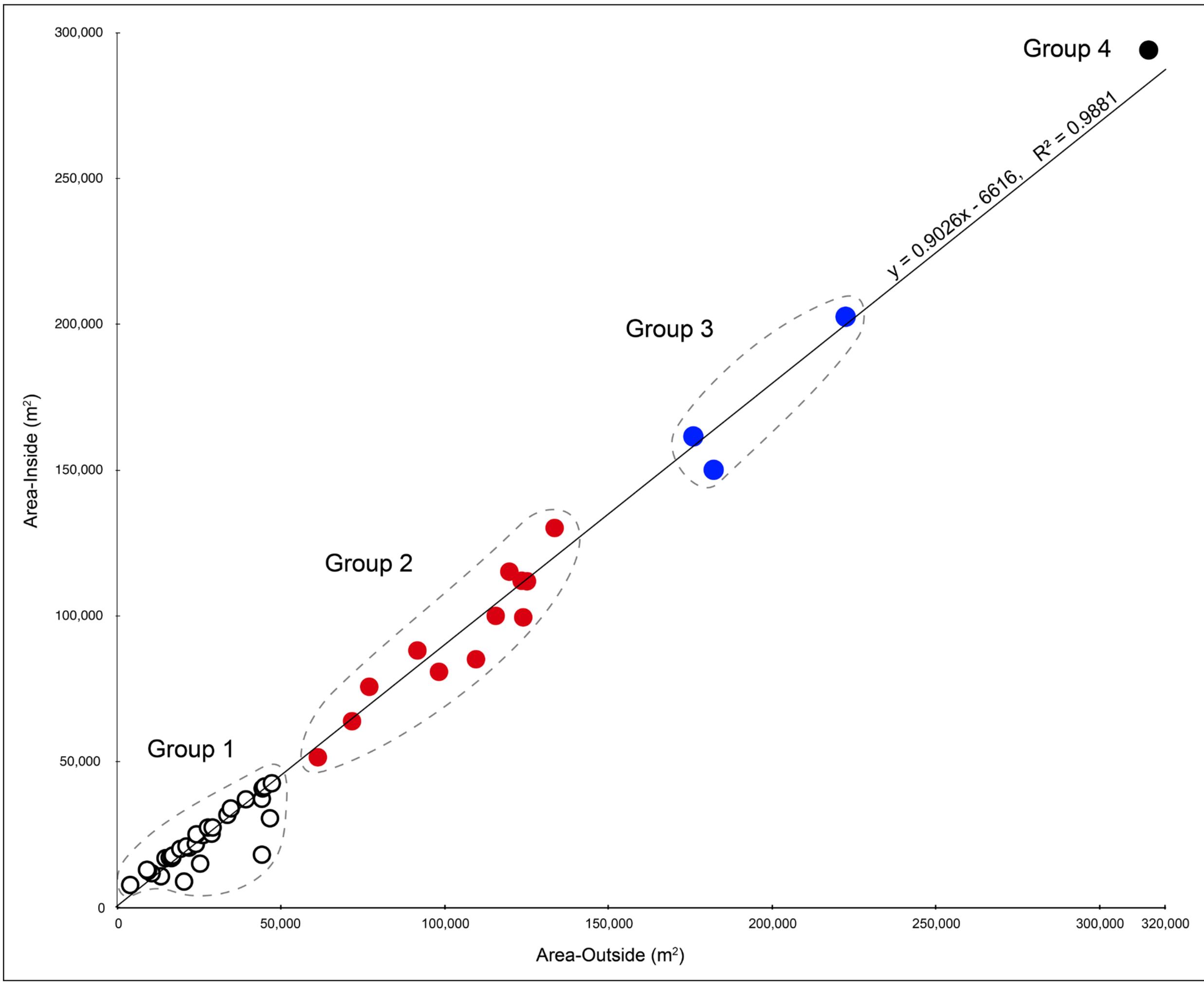

Figure 4. Plot of enclosure fort area (inner and outer) showing variation in the size of earthwork enclosure fortifications. Fort size groups are outlined in the Discussion with fort data listed in Table 1. Forts that fall below the trend line have a strongly defended inner area protected by wide ditches or several ditch-rampart enclosures.

47-Lapaha which have broad and deep ditches, and forts with two or more ditch-rampart earthworks like 8-Te'ekiu and 15-Manahau.

2. The age of defensive earthworks

The chronology of Tongatapu forts is unclear as few have been excavated and radiocarbon dated, in part, because the majority are assumed to be historic: '… most, if not all other fortifications visible in Tonga today date to the last period of civil warfare (1799–1852)' Spennemann (2002: 19). As noted above and in Table 2 there are potentially 20 enclosure, and one linear (52-Keli 'o Pelehake), earthwork recorded as being made or used on Tongatapu in the 19th century. There are also forts at 10-Fāhefa, 13-Vaotu'u, 40-Fua'amotu, and 51-Kolonga that occupy the centre of modern villages. It is thought that the establishment of modern villages arose from population clustering in and around fortifications made during the Civil War (e.g. Spennemann 2002; Swanson 1968). These forts share similarities with other Civil War forts such as 1-Kolovai, 14-Houma and 22-Pea which also occupy the site of modern villages and have a chiefly burial place located within the fortified area. Adding these four forts to the 21 defences noted above suggests at least ~45% of lidar identified earthworks on Tongatapu are of Civil War age and an unknown proportion of the remainder might therefore be prehistoric. In addition, some Civil War forts could represent the reuse and refurbishment of older defences, but this can only be determined with archaeological investigation.

In east Tongatapu the 46-Olotele, 47-Lapaha, 48-Niutao and 56-Fisi Tea earthworks indicate that sub-rounded, straight-sided and linear defences have a significant antiquity as they were constructed during the reign of the Tu'i Tonga political system (~AD 1200–1799). The oldest site may be 48-Niutao traditionally associated with the 11th Tu'i Tonga followed by the 47-Lapaha fort attributed to the 12th Tu'i Tonga – and radiocarbon dated to

AD 1300–1400 – and the 46-Olotele earthworks that may have been built/rebuilt by the 23rd Tu'i Tonga. It is significant that these early defences were potentially made during periods of political stress. The Lapaha fort was traditionally constructed by the 12th Tu'i Tonga when threatened by an ambush (Clark *et al*. Forthcoming), while the assassination of the 23rd Tu'i Tonga led to widespread warfare and a new diarchic system of chiefly rule in Tonga (Gifford 1929).

Absolute dating of defensive sites on Tongatapu is being currently undertaken by the authors to resolve the age of enclosure and linear earthworks. Lidar, in some cases, also indicates a relative chronology when fortifications interact with earthworks such as mounds, sunken roads and other defences. Construction of large mounds on Tongatapu began at least 700 years ago and likely declined during the early 19th century (Dumont d'Urville in Spennemann 1989a: 475). At 18-Hauloto and 24+25-Tokomololo it appears that parts of the ditch-rampart have been destroyed to make way for the construction of large mounds, and at 12-Hule, 21-Puke and 32-Kauvai mounds have been cut by defensive ditches. Mounds were built directly over a section of ditch-rampart at 46-Olotele and 57-Afā, while at 50-Kolonga 'Uta and possibly 48-Niutao pre-existing mounds were incorporated into the ditch-rampart and possibly used as lookouts/bastions. Long shallow depressions identified with lidar may be sunken roads that intersect 24+25-Tokomololo and 50-Kolonga 'Uta while enclosure forts have been cut by other defensive earthworks (8-Te'ekiu is crossed by the 52-Keli 'o Pelehake) or built over an existing defence (49-Kolonga 'Uta is built over 50-Kolonga 'Uta). Excavation and radiocarbon dating of different earthwork components will show how defences incorporated existing sites and were themselves incorporated into settlements after conflict had ceased.

3. Heritage implications

Lidar is an excellent tool to assess the condition of built cultural heritage sites at the time of survey. Even poorly preserved earthwork features can be identified, but tracking landscape changes and particularly ongoing impacts to heritage sites in many Pacific nations will be difficult given resource constraints, particularly the frequency of lidar survey. The 2011 lidar survey of Tongatapu and site visits identified enclosure earthworks threatened by development with 20 (39%) identified as in 'poor' condition (Table 1). These earthworks are all located within the boundaries of a modern town, with another ten identified as in 'average' condition are located in, or near, urban areas. The 19th century forts of Ma'ufanga and Ngele'ia mentioned in Civil War accounts (Figure 2 (A, B), Table 2) have been completely lost from the development of the capital, Nuku'alofa, and the defences of 27-Nuku'alofa (Nakelo) and 45-Tatakamotonga are so poorly preserved they are essentially gone although subsurface remains may be present. Since 2011, the forts of 28-Takaunove and 31-Nualei have also been largely destroyed and parts of 46-Olotele have been infilled. Urban development is clearly the biggest threat to the earthworks of Tongatapu as many defensive sites are in, or near, urban areas and can be demolished easily with modern equipment when land pressure is high. Demolition of fortifications to improve access for mechanised agriculture is a growing threat to earthworks located in garden tax allotments and rising sea levels also threaten a number of sites located on low lying areas around the Fanga 'Uta Lagoon. In addition to infrequent lidar records of defensive earthworks, the growing cube satellite and drone industries can produce high-quality site data for ongoing research and heritage documentation. The coming 'flood' of data will strain existing analysis methodologies, but will also usher in opportunities to enhance management of cultural heritage in many parts of the Pacific. A central challenge is to ensure that local communities have access to geospatial data to manage and preserve heritage sites.

CONCLUSION

A recent lidar study of Tongatapu identified some 10,000 earth mounds that are interpreted as prehistoric house and burial sites of families, communities and chiefly elites (Freeland *et al*. 2016). Our focus on earthwork defences has increased the number of known fortified sites and afforded preliminary site groupings based on defensive area. The advantage of lidar over traditional archaeological survey and aerial photography is indicated by the identification of three enclosure forts and one linear defence east of Lapaha compared with the complete absence of defensive sites recorded in this area previously (Spennemann 1989a: 482). There are more fortifications in the west of Tongatapu than in other parts and the uneven distribution is likely to result from significant socio-political events. Traditions and archaeological results indicate that east Tongatapu was an early centre of the Tu'i Tonga lineage with the first monumental architecture built at Afā and Heketā (Clark and Reepmeyer 2014). There are no major defences associated with this area except for the linear/enclosure earthwork at 57-Afā that lies south of a group of three early tombs that are associated with the 11th Tu'i Tonga, as is the 48-Niutao fortification. The relocation of the chiefly centre to Lapaha by the 12th Tu'i Tonga ~AD 1300 was accompanied by massive construction projects that included large tombs (Clark *et al*. 2016), the reclamation of land, canoe facilities and a variety of defensive earthworks (sub-rounded, straight-sided, linear). The defensive sites at Lapaha were clearly directed toward the west and created a formidable barrier that protected the precinct of the paramount Tu'i Tonga and other high chiefs who regularly assembled at Lapaha. Defences were primarily meant to deter a Tongan rather than an external force as suggested by traditions that have several Tu'i Tonga assassinated by people from Hamula and Toloa that are located west of Lapaha (Thomas in Statham 2013: 29). The rise of west Tongatapu under a junior lineage known as the Tu'i Kanokupolu was accompanied by the Tu'i Tonga losing political influence. The number of fortifications in the west of Tongatapu was an outcome of chiefly competition for the paramount position in addition to episodic raiding and conflict for short-term gain from within Tongatapu as well as frequent raiding/aggression from chiefs in the outer islands of Ha'apai and Vava'u (Martin 1991). The development of Nuku'alofa as a new capital begun by King Tupou I (who held the Tu'i Kanokupolu title) has several parallels with the 'old' central place of the Tu'i Tonga. These include an association between the new paramount and religious (Methodist) leadership, construction of a monumental royal burial ground for the ruling dynasty (at Mala'e Kula), and not least, a fortification containing the ruler's residence (27-Nuku'alofa). In short, the distribution of defensive earthworks revealed in the lidar data offers strong support for the rise and decline of a political centre at Lapaha followed by extensive chiefly rivalry and warfare in the west prior to the formation of a new political system – a Christian constitutional monarchy – centred on Nuku'alofa. Thus, the remains of fortifications identified with lidar are important cultural heritage sites that should be protected as they epitomize the role of conflict in the rise, fall and reconstitution of a complex Pacific Islander society over the past 700 years.

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