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The anthropogenic transformation of an island landscape: Evidence for agricultural development revealed by LiDAR on the island of Efate, Central Vanuatu, South-West Pacific

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ABSTRACT

Traditional agricultural systems have been a fundamental research focus of Pacific archaeologists for decades. In many island groups, it has been demonstrated that whole landscapes have been transformed to facilitate increased agricultural production. High-resolution digital elevation models (DEM) derived from recent LiDAR survey data from Efate, Central Vanuatu, have now revealed that much of that island was completely modified by human activity prior to European contact. There are a range of substantial and more minor linear mound and circular features associated with agricultural development and innovation, of which researchers and contemporary populations are largely unaware. Detailed analysis of the features across one alluvial plain provides some quantification of the scale of landscape modification. These new data radically change perceptions of the Efate landscape and contribute to a range of debates including traditional Pacific Island food production, its surplus and sustainability, sociopolitical development, environmental change and depopulation.

Keywords: LiDAR, Efate, Vanuatu, agricultural development

RÉSUMÉ

Les systèmes traditionnels de culture horticoles en Océanie ont fait l'objet de recherches détaillées de la part des archéologues depuis des décennies. Dans plusieurs régions insulaires, il a été démontré que des paysages entiers avaient été transformés pour faciliter l'augmentation de la production agricole. Les modèles numériques de terrain à haute résolution, dérivés d'une récente couverture LiDAR sur l'île d'Efaté, Vanouatou central, révèlent que cette île était grandement modifiée par les activités anthropiques avant le premier contact avec les européens. On observe une série de billons linéaires imposants et d'autres secondaires, ainsi que des aménagements surélevés de formes circulaires qui révèlent un développement et une innovation agricoles, très peu connus des chercheurs et des populations actuelles. Une analyse détaillée de ces formes sur une plaine alluviale permet une première quantification de l'ampleur de la modification du paysage agraire. Ces nouvelles données changent radicalement notre perception des paysages d'Efaté et contribuent à alimenter le débat sur les systèmes de production alimentaire en Océanie, les surplus, le contexte socio-politique, les changements environnementaux et la dépopulation.

Mots-Clés: LiDAR, Efaté, Vanouatou, développement agricole

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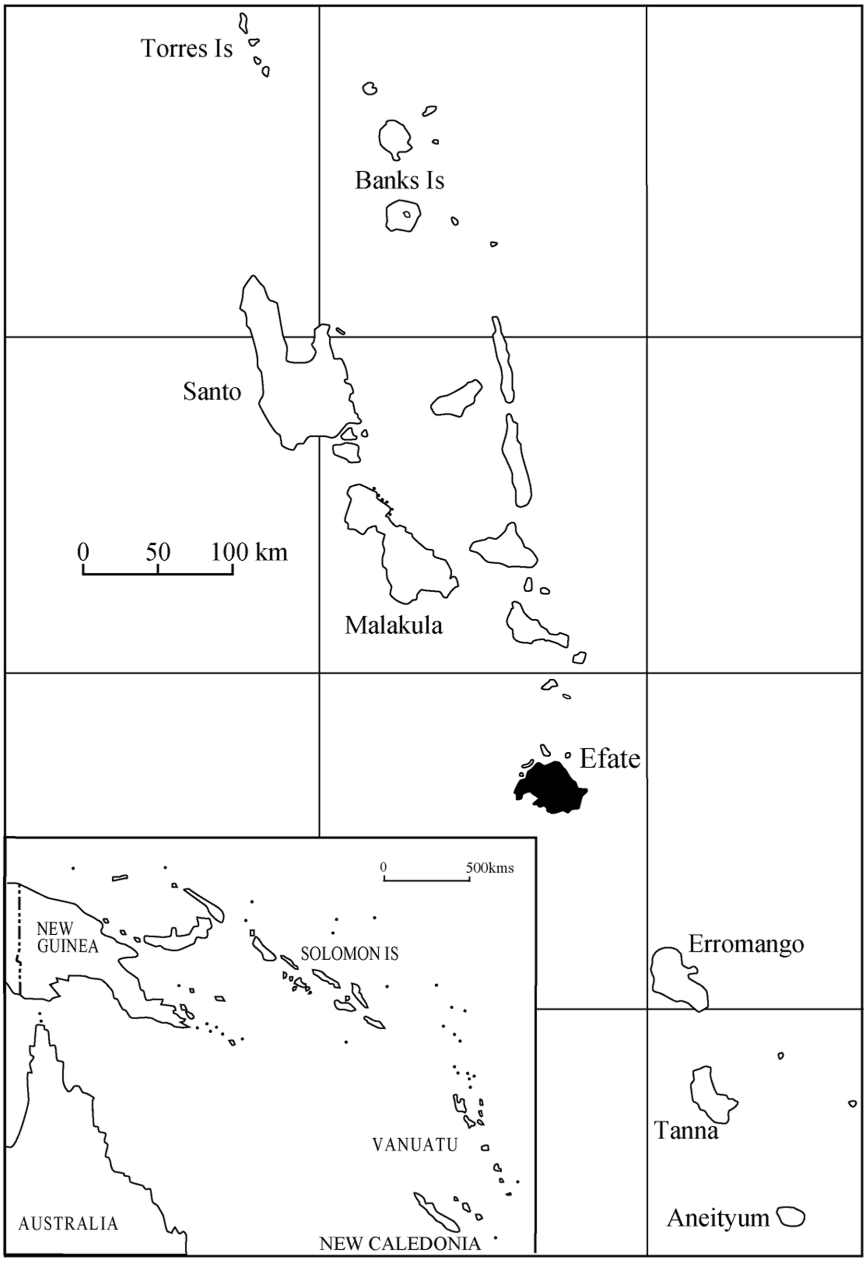
INTRODUCTION

Airborne Light Detection and Ranging (LiDAR) has revolutionised the study of prehistoric landscapes across the globe, dramatically demonstrating its effectiveness in revealing extensive sites such as lost or poorly detailed ancient population centres hidden under forest cover (Chase *et al.* 2012; Evans *et al.* 2014). In the Pacific, LiDAR coverage remains relatively limited, but in areas where it is available it is proving to be a powerful tool in contributing to our understanding of Pacific Island societies, providing archaeologists with the opportunity to study whole regions at a scale and level of detail not previously possible or even imagined. Studies have included agricultural systems of Hawai'i (Ladefoged *et al.* 2011; McCoy *et al.* 2011), settlement patterns in American Samoa (Quintus *et al.* 2015), and ceremonial complexes in Tonga (Freeland *et al.* 2016).

In 2014, Vanuatu (Figure 1) obtained a digital map database that had been generated from an airborne

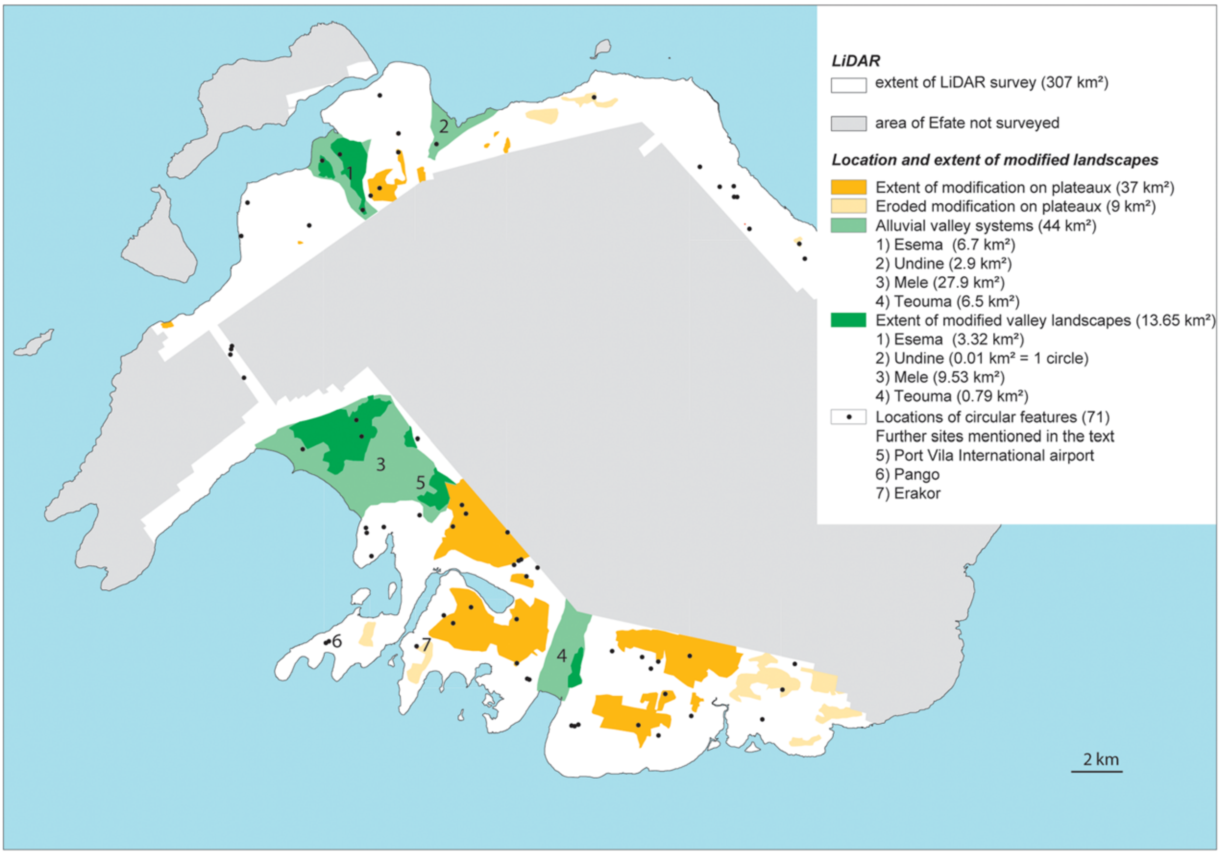
Figure 1. The Vanuatu archipelago and Efate (highlighted): the inset shows the South-West Pacific.



high-resolution LiDAR survey. It was associated with the Australian Government's International Climate Change Adaptation Initiative, designed to enable Papua New Guinea, Vanuatu and Tonga to develop coastal inundation models that would assist in understanding climate change risk (AAM 2013). In Vanuatu, three islands were targeted, namely Santo (south and east coasts), Malakula (east coast) and Efate (north, west and south coasts). Those areas surveyed were largely restricted to low-lying zones, which were identified as heavily populated, important economic zones that may be impacted on in the future (AAM 2013).

Here, we focus on the digital elevation models (DEM) derived from the LiDAR survey data generated from Efate, Central Vanuatu (Figure 2) where 307 km^2, or 34.2% of the island, was covered. The data reveal a landscape, from the coast to the high interior, heavily modified by human activity, that predates European contact. There are a range of features that we interpret as primarily being associated with agricultural development and innovation and others that may also have had a habitation and/or ceremonial role. Researchers and contemporary populations are largely unaware of this spectacular anthropogenic landscape. This is due primarily to a lack of archaeological focus, limited early historical records and substantial depopulation dating from initial contact. The archaeological focus on Efate has been overwhelmingly related to the establishment of first settlement, Lapita at 3000 BP, and the subsequent 1500 years of occupation, which has involved extensive subsurface excavations at a limited number of key sites (Bedford 2006; Bedford & Spriggs 2014; Bedford *et al.*

Figure 2. Efate Island, showing the extent of the LiDAR survey, alluvial valleys and plateaux, with identified modification and circular mound features.



2010; Garanger 1972). The only other major archaeological investigation on Efate was that of the burials associated with the death of the high Chief Roi Mata on Retoka Island that date to c.AD 1600 (Garanger 1972). Beyond these periods and sites, wider settlement pattern archaeology has not been initiated on Efate. Even aerial photographs of the island have never been the focus of any detailed study as they have been so effectively on other islands and archipelagos in the region; for example, Aneityum, southern Vanuatu (Spriggs 1986), New Caledonia (Sand 1995) and Fiji (Parry 1987, 1997). In these three cases, spectacular archaeological remains were identified across landscapes, including agricultural features, settlements and, in the case of Fiji, widespread evidence of distinctive fortified villages.

The early historical record for Efate, although extensive, as it was one of the earlier islands in the group to have experienced sustained European contact, is largely restricted to coastal regions and is very limited in terms of describing agricultural practice or forms of settlement in any detail. This is particularly the case for the first 20 years of increasing contact from the mid-1840s, when significant depopulation began to impact the island and disrupt traditional society. Depopulation appears to be a significant contributing factor both in relation to gaps in the historical record and also to a lack of awareness or connection with these features amongst the contemporary population. We interpret the features as primarily associated with agricultural activity and hence we assess them against a broad outline of agricultural practice on Efate and the wider archipelago, recorded in archaeological, historical and contemporary records.

These new data now radically change perceptions of the Efate landscape and can be used to contribute to a range of debates including those associated with the development of traditional Pacific Island food production, which embraces aspects relating to surplus and sustainability, sociopolitical transformation, environmental change and depopulation. We address a number of these aspects, which contribute to a broader understanding of the complex 3000-year history of human settlement of Efate and Vanuatu.

BACKGROUND

The geography and environment of Efate Island

The island of Efate is the third largest island in the Vanuatu archipelago, located in the centre of the group (Figure 1). It has a total land area of 897.8 km^2, and rises to a high point of 647 m. Nine offshore islands, totalling 72.4 km^2, are located off the south, west and north coasts. The capital, Port Vila, is located on the south coast. Efate was formed through ancient volcanism and subsequent development of Quaternary-age fringing reefs (Ash *et al.* 1978: 4). Uplift through tectonic activity has resulted in a series of elevated terraces that occurred in several stages. There are five principal zones where planar surfaces, such as plateau or terraces, can be observed, namely at altitudes ranging from 2 m, 45 m, 90 m, 200 m and 500 m ASL (Siméoni 2009: 78). The central and northern parts of the island comprise remnant plateau surfaces, with a height ranging from 350 m to 540 m, that are heavily dissected by water courses, while the coastal margins are generally low lying with undulating terrain (Ash *et al.* 1978: 2). The topography of the island is dominated by two major fault features, namely the Klem's Hill escarpment, above the Mele Plain, and the Teouma Graben, which virtually bisects the island and can be clearly traced northwards from the Teouma Valley. These features, along with the overall tilt of the island, influence the principal drainage on Efate, which is to the south and south-west. This orientation has led to the creation of alluvial valley flats such as those at Mele (27.9 km^2) and Teouma (6.5 km^2) (Ash *et al.* 1978: 2). Two other areas of alluvial flats include Marona (6.7 km^2) on the north-west and Undine (2.9 km^2) on the north coast (Figure 2, labelled 1–4). These four zones comprise a total area of 44 km^2.

Efate has a tropical climate with a warm humid wetter summer from December to April and a cooler drier winter, associated with the prevailing south-east trade winds, throughout the months of May to November. Average annual rainfall is 2142.9 mm and average temperature in the summer is 25.85˚C and 23.3˚C in the winter. Humidity ranges from 78–80% in the winter to 82–84% in the summer (Siméoni 2009: 130-6). There are other significant, although irregular, weather events, which also play a key role in shaping people's lives across Vanuatu. Tropical cyclones are an annual feature and at various times can completely devastate an island's infrastructure and subsistence base (Siméoni 2009: 139-44). The most destructive cyclones in recent times that directly affected Efate were Uma in February 1987 and Pam in March 2015. Drought is another event that occurs with variable intensity and spread across the islands, but is particularly severe during intensive El Niño cycles, such as those of 1997–1998 and 2015–2016, and which can significantly impact agricultural production.

Soils, along with climate, are key to the development of agriculture, influencing the range of crops that can be propagated and preferred and the form of intensification that might develop over time. Quantin, in his analysis of soils across the Vanuatu archipelago, rated their modern agricultural potential from the most fertile to those of no potential. In a summary, he identified seven types of soils with Types I to III (rich to moderate) rated as having high potential. Efate ranked as the island that has soils with the highest agricultural potential, at 64.9%, compared with an average for the archipelago of 42%, and in striking contrast to Aneityum–Futuna at 9.7% (Quantin 1982: 35-7, 46; Siméoni 2009: 117). The soils of Efate are dominated by ferrallitic soils (54%) on a range of elevated terraces. Those on terraces lower than 300 m are weakly unsaturated and humus-rich, fertile, free-draining and relatively deep (Quantin 1982: 5; Type I). Others that dominate are the generally shallow, fertile, humic rendzinas (11%) that have only developed on recently uplifted coral terraces surrounding the coast and, finally, the rich and deep alluvial soils (5%) found in the river valleys (Quantin 1982: 8; Type III). Relatively recent volcanic ash deposits have also contributed significantly to soil fertility on Efate (Quantin 1979: 19). All of these soils are usually fairly well drained and the humus horizon has a high capacity for the retention of water. However, in the case of the alluvial plains, poor internal drainage of the soil in the upper part of the profile can significantly affect fertility and flooding is evident during the rainy season (Quantin 1979: 7).

Traditional agriculture on Efate

On Efate, as elsewhere in Vanuatu, food crops are traditionally cultivated within diversity-rich agroforestry systems (Lebot *et al.* 2008; Weightman 1989), although a range of introduced cultigens and increasing reliance on imported products has greatly impacted on these practices, particularly on Efate (Siméoni & Lebot 2012). Traditionally, small plots of 1000–2000 m^2 are surrounded by tall trees and are exploited for 3–4 years of annual cropping. Native fruit and nut trees (*Canarium*, *Baringtonia* and *Terminalia* spp.) including coconuts are interplanted and then left to grow (Lebot *et al.* 2008). The plot is not tilled and plants are manipulated individually to compose intra- and interspecific associations, increasing in diversity with time. The first year is for the main crops and secondary species are intercropped in the following years. Yam (*Dioscorea* spp.) and taro (*Colocasia esculenta*) are the main staples, along with bananas (*Musa* spp.) and breadfruit (*Artocarpus altilis*). Other crops such as island cabbage (*Abelmoschus manihot*), a rich source of protein and calcium, are intensively cultivated in almost all food gardens (Walter and Lebot 2007). These major species are all cultivated within the same plot with other asexually propagated plants such as kava (*Piper methysticum*) and sugar cane (*Saccharum officinarum*). This cropping system functions with limited labour input, where weeding, planting and harvesting are often done simultaneously to optimise labour. This traditional Melanesian shifting cultivation system, characterised by Sauer (1952) and Yoshida and Matthews (2002) as "vegeculture", is based on vegetatively propagated species, which are always associated with arboriculture. This association is essential, as asexually propagated crops have no tap root, and their superficial root system is highly vulnerable to sudden drought. The large leaf canopies of these plants expose them to intense evapotranspiration and the shade of the surrounding trees, combined with the small size of the plots, have a beneficial protective effect against climatic variation. Compost and manure are not used and when signs of a decline in fertility appear, the plot is abandoned. However, as most of the soils on Efate are young and of volcanic origin, with a good level of fertility, the plot is often left to fallow simply because of weed infestation. There is no irrigated cropping practised on Efate, as it is on other islands of the archipelago such as Maewo and Aneityum (Weightman 1989: 88-95).

Archaeological perspectives and historical accounts of Efate agriculture

Many of the staple food crops associated with traditional gardening in Vanuatu appear to have been brought to the islands by the first colonisers. Introduced domesticated plants associated with the Lapita period have been identified at a number of sites through the analysis of plant microfossil remains from soil samples and dental calculus, providing direct evidence for yam, taro and banana (Horrocks & Bedford 2005, 2010; Horrocks *et al.* 2009, 2014). However, these crops were adapted to very different island environments over time, with increasing emphasis on particular crops and their intensification on different islands developing over the past 1000 years (Spriggs 1986).

Early historical accounts of Efate Island give some indications of the extent and form of agriculture being practised on the island and confirm a system involving shifting cultivations. Cook, arriving from the north in July 1774, noted that "the sides of this Isle opposed to us exhibited a most delightfull View, its Shores are low, the land rises with a gentle ascent to the hills, it is everywhere Spotted with Woods and Launds (grass lands) and has the appearance of great fertility …" (Beaglehole 1961: 473). Johann Forster, on the same voyage, described it as "one of the finest Isles we have hitherto seen, woods and clear ground being mixed in the most romantic manner" (Hoare 1982, vol. IV: 572-3). One of the earliest records that relates directly to agricultural production on the island is that of Reverend George Turner who, following a visit to a sheltered harbour on the west coast in 1845, said that "they cultivate the soil well, and grow yams in great abundance" (Turner 1845).

Very similar descriptions of the island were made, 75 years after Cook, by Commodore Erskine on board the *HMS Havannah*, on his visits in 1849 and 1850 to a harbour, subsequently named Havannah, on the west coast. This region was described as having "the usual belt of vegetation extended on all sides for a few hundred feet above the level of the sea, a white sandy beach running along its shores. Above the first range, … the surrounding hills are of varied and most picturesque forms, being in general bare of trees, but apparently covered in rich pasture, in some places brown, as if burnt for purposes of cultivation" (Erskine 1853: 322). On one of the few occasions that Erskine was able to visit the interior, he recounted that "a party of us landed accordingly, and were conducted by a good path, bordered in places by enclosed provision, apparently very productive, to the village" (Erskine 1853: 331). In conclusion, he emphasised the horticultural productivity of the island, "the land of Vate, of which a minute portion is cultivated, must be exceedingly fertile, and capable of supporting a very large population. In none of the islands did we see a greater supply of both vegetables and pigs" (Erskine 1853: 335).

Philip Vigors, on the same ship, described the landscape that surrounded Havannah Harbour as follows: "the land on this side is very high, the top is bare and green, and looked as though it had been recently cleared" (Vigors 1850: 40). He also noted "a very large quantity of cultivated ground" on both sides of the harbour (Vigors 1850: 32). Landing on south Efate, in Vila Harbour, he was guided to a village, and he "Passed some strong rude fences, enclosing young plantations of bananas and plantains etc., each enclosure the property of a separate family" (Vigors 1850: 45). In summary, he described Efate as "richly wooded and well cultivated (where inhabited) and with a large population". Vigors was a keen observer who had noted terraced irrigated taro gardens on Aneityum Island in the south before his arrival on Efate. He made no mention of such gardening techniques on Efate but recorded the busy trading with Efatese of bananas and yams, on the latter of which he commented "he had never seen finer …" (Vigors 1850). Julius Brenchley, on the *HMS Curaçoa* in 1865, noted that the "soil is of remarkable fertility" and again fences were mentioned as being substantial, "sometimes 9–10 ft high" (Brenchley 1873: 221, 225).

The historical accounts relating to Efate indicate that there was abundant evidence for agriculture, the island being described as having rich soils, productive gardens, particularly of yams, and pigs were also abundant. The food gardens were fenced and were concentrated in patches across the landscape indicative of shifting cultivation. Single fenced gardens were noted as belonging to single families. A striking difference between these early accounts and gardening practices seen on Efate today is the abandonment of fencing. It was standard practice throughout Vanuatu as protection against damage caused by pigs, but nowadays it has all but disappeared, as the much-reduced national stock of pigs tends to be individually tethered or fenced (Weightman 1989: 48-9). Also confirming what is observed today, the early historical records do not mention any form of irrigated gardening on Efate.

METHOD

The LiDAR survey

The LiDAR survey of Efate covered 34.2% of the surface of the island, and was very much coastally orientated (Figure 2). An Optech ALTM Pegasus LiDAR was operated with a laser pulse repetition frequency of 40 Hz, a maximum half-scan angle of 20° and 30% overlap between adjacent flight lines. Sensor to ground range was at least 700 m throughout the data collection. This resulted in a 0.14 m laser footprint, with an average point spacing of 0.32 m. The vertical accuracy of the survey was 0.3 m at 1 sigma (AAM 2013). Global Mapper software was used to manipulate the generated DEM data. Hill-shading using an azimuth of 45° and an altitude of 45° produced clear delineation of the archaeological landscape. This same hill-shading setting is used in all our figures highlighting these features.

The surveyed areas included the north, north-west and north-east of the island, covering about 48 km of the coastline located between Mangaliliu on the west coast and Ebao on the north-east. The width of the area surveyed, from the coast to the interior, varied between 2 and 4 km. The other major area of coverage was the south and south-west of the island, comprising some 65 km of coastline between Boukoura (Devil's Point) in the west and Enam in the east. Here, the survey width varied between 2 and 8 km. A single 4 km long by 450 m wide strip, which joined these two primary zones, was flown in the west. This is the only zone where LiDAR data is available across an elevated (up to 300 m) interior area of the island, although there are several areas near the north-west coast that are higher (up to 450 m) in elevation. The east and the centre of island have not been surveyed.

Analysis of identified features

The surface landscape generated through the LiDAR survey of Efate has revealed evidence for spectacular human modification across much of the investigated area. We have been able to identify four primary archaeological features associated with human activity that predate European contact. These are three types of linear mound features aligned in various configurations and located in various topographical situations and distinctive circular features identified across all types of terrain (Figure 2).

MapInfo™ was used to georeference the DEM data and then to analyse the remains identified, both calculating the extent of the areas modified and the scale and dimensions of the various features. The calculation of the surface area was made incorporating only features that were clearly visible, and had survived more modern development. We have been conservative in our calculations, not including features that were indistinct or only partly visible in amongst recent intensive peri-urban settlement, current and former airports, and areas of pasture that have been cleared by mechanical machinery. This has undoubtedly led to a substantial underestimation of actual pre-industrial modified areas. The circular features were identified across the entire LiDAR surveyed landscape and their dimensions measured. These tended to be more clearly defined even in areas where substantial disturbance had occurred. Examples of the various identified features were visited in different locations for verification following their identification on DEM maps.

Fine detail of the form, extent and layout of the anthropomorphic features was established through a focus on the Marona alluvial plain (Figure 3), located in Havannah Harbour on the north-west of Efate. This is the best preserved of the four river valley systems and all identified features are present either within the valley floor or on adjacent elevated plateaux. Comparisons made with the DEM data from the other much larger islands of Malakula and Santo can be found in the online Supporting Information. However, the coverage there (294 km^2, 6.8% and 488 km^2, 8% respectively) was much more limited, very much restricted to the coast and some areas are heavily modified by historical developments, particularly south Santo.

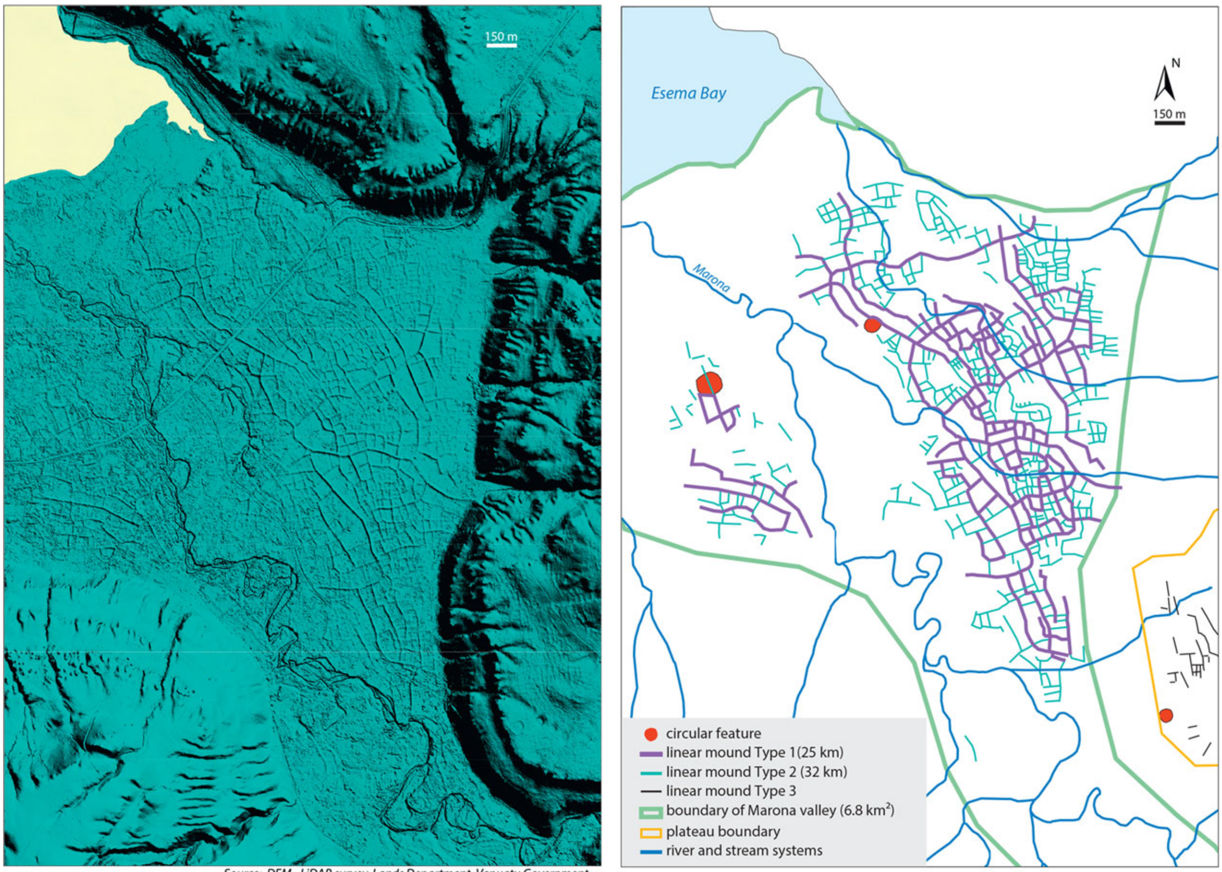
RESULTS

Identified features

The anthropomorphic features that dominate the Efate landscape are a range of linear mound features that in some cases extend for several hundred metres or form enclosures of varying size in an irregular mosaic or grid pattern. The three kinds of linear mound features identified are classified in relation to their distinctive form, dimensions and arrangement (Figure 3). The most spectacular (Type 1), in terms of dimensions, are those that measure up to 2.0–2.5 m high, 3–4 m wide and can both extend for several hundred metres or form large enclosures. Associated with these, but of much smaller dimensions, 50–75 cm high and 2 m in diameter, are linear mounds (Type 2) that tend to be laid out in an irregular mosaic pattern, primarily enclosing areas of varying size. These two types of linear mounds are found only on the alluvial plains. Mounds of the other type (Type 3), which appears in more concentrated irregular grid patterns enclosing smaller areas, and is generally no more than 30 cm high, are distributed across all elevated terraces both overlooking the river valleys (Figure 3) and elsewhere towards the interior to altitudes of up to 350 m.

Another very different feature revealed by the LiDAR survey is a distinctive type of circular feature, which at a first glance resembles a crater, and can be identified on most types of terrain. Seventy-one of these circular features were identified (Figure 2). Their sizes vary greatly, although this is skewed by several outliers. The vast majority (51) are between 50 and 100 m in diameter, 15 are between 100 and 145 m in diameter, and a single one is substantially larger, at almost 200 m in diameter. Three are below 40 m in diameter and there are two outliers that measure less than 30 m in diameter (Table S1). They are found at all altitudes, from 10 m to 260 m ASL, across the landscape (Figure 4). They can be identified amongst and are sometimes incorporated within the rectilinear grid systems, but are also found in isolated situations, particularly at higher altitudes. The majority of these features have a raised area in the centre, although a small number do not. They appear to have been formed through soil being shifted from the inside of the feature and out to the exterior. The dimensions of the circular walls vary, but they are generally 1.5–2.0 m high (measured from the interior) and 3–4 m wide. The exterior ground surface is higher than the centre, as it appears that it is only soil from the centre that has been used in the construction of the feature. A number of aspects provide chronological information. They appear to be an earlier feature that has subsequently been incorporated into the increasingly expanding linear mound systems (Figure 4b). A number of them at higher altitude exist in isolation (Figure 4h), most are associated with and/or have been subsequently incorporated within linear mound systems, and others have linear mounds that run through them. Most

Figure 3. The Marona Valley and the adjacent plateau. On the left is the DEM and on the right are the highlighted archaeological features.



Source: DEM - LiDAR survey, Lands Department, Vanuatu Government

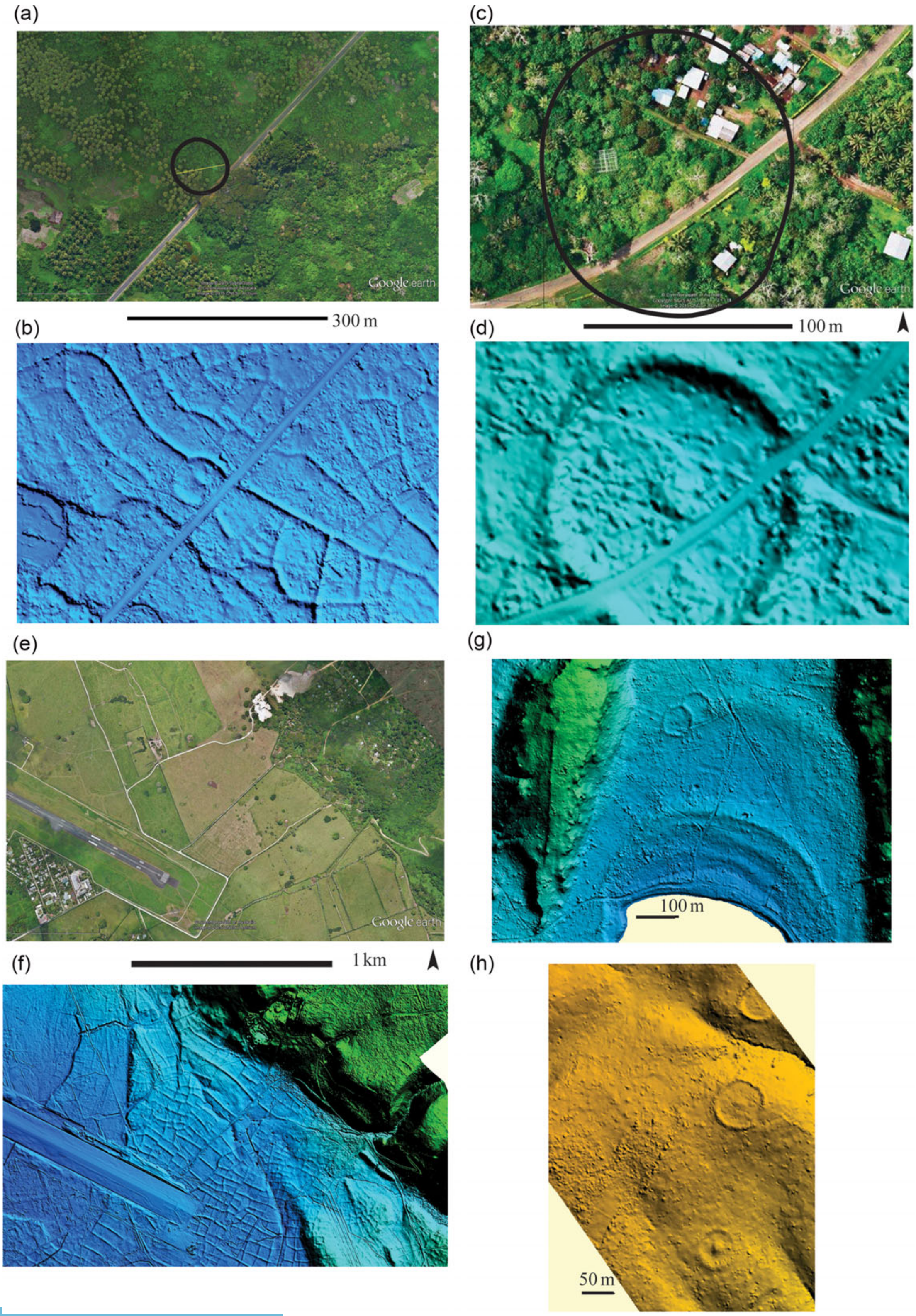
are very well preserved, but there are a number that appear to be heavily eroded, suggesting that they date to an earlier phase, and there is a single case of these features overlapping (Figure 4g).

In the Marona Valley, the larger Type 1 linear mounds run for a total distance of 25 km and the smaller Type 2 mounds for 32 km. There are three circular features within the valley (one located in the upper valley is not seen in Figure 3) and one on the adjacent higher terrace, itself next to a complex of Type 3 low mounds, laid out in a mosaic pattern (Figure 3). The diameters of the two circular mounds in the valley are 79 and 122 m respectively, encompassing areas of 4885 and 11662 m^2. Both appear to predate the expansion of the linear mound systems, as the former is incorporated into their construction (Figures 3 and 4b) and the latter has a mound running through its centre (Figure 3).

We estimate that on the four alluvial plains there is an area of 13.65 km^2, or 1300 hectares, that exhibits preserved and clearly visible pre-European landscape modification. This represents 30% of the total area of all of the alluvial plains on the island but is greatly under-representative, as two of these areas (Mele and Teouma) have undergone substantial historical modification (Figures 4e and 4f). Also, significant areas of the plains, namely the perennial river systems and the coastal zone, are not suitable for agricultural purposes. In the Marona Valley, the best preserved, we have calculated that ~50% of the landscape shows prehistoric modification, although the Marona River and a coastal band some 300–400 m wide can be excluded from the calculations. Removing these zones from consideration, the modified area represents closer to 75% of the plain. This percentage is likely to represent a more realistic figure of total land use on all the alluvial plains. On the terraces and moderately undulating slopes, there is 46 km^2, or 4500 hectares, of modified landscape still visible, comprising Type 3 mounded irregular grid features. This again is a conservative estimate, as these features are much less apparent and are more susceptible to natural erosion and easily destroyed by modern developments. These calculated areas combined amount to 20% of the area covered by the LiDAR survey where unambiguous landscape modification could be identified (Figure 2). The features are most concentrated on the alluvial plains and terraces up to 250 m in elevation, but the circular features and smaller areas of mounded irregular grid features (Type 3) can be identified at elevations of up to 350 m.

We visited a range of these site types in different locations to both ground-truth the digitally generated data and to get some indication of how these features were

Figure 4. A range of features found across the Efate landscape: (a) an aerial view of the central Marona Valley (circular feature highlighted) and (b) DEM of the same area, showing rectilinear and circular features (6–7 m ASL); (c) an aerial view of a cluster of houses on the Erakor Road, built amongst a circular feature, and (d) DEM of the same circular feature cut by Erakor Road (27 m ASL); (e) an aerial view of Port Vila International Airport on Mele Plain and (f) DEM of same area, showing rectilinear features (17.5–19 m ASL); (g) overlapping circular features, Pango (7–8 m ASL); (h) circular features located in the high interior, Metelama (260 m ASL). Parts (a), (c) and (e) generated from Google maps. [Colour figure can be viewed at wileyonlinelibrary.com]



constructed. Examples of both the large linear mounds and the circular features had been sectioned by road construction, which provided convenient and accessible profiles. Both are fundamentally created with the stripping and mounding of adjacent soil. For the linear mounds, this is generated from either side of the structure, and for the circular features from its interior. There is no sign that these are constructed with stone, although there are areas of Efate, generally near the coast, where dry stone (coral) alignments that demarcate garden boundaries have been recorded (Bedford 2006: 41, fig. 3.9; see also Figure S2).

Interpretation of the remains

There are a range of intriguing parallels and differences with neighbouring archipelagos in the features identified on Efate that provide some aids to interpretation. The historical record relating to agriculture for Vanuatu also provides key information. Two persistent aspects in relation to short fallow cropping systems that are noted by researchers across the Pacific are low walls or linear mounds, and the generally rectilinear shape of the areas enclosed (Kirch 1994: 108, 243). Their primary function has been interpreted as demarcating boundaries but in some cases the alignments are argued to have served as windbreaks, decreasing surface wind flow and reducing evapotranspiration (Ladefoged *et al.* 2003: 927). The Type 2 and 3 linear mound systems identified on Efate are most probably related to boundary delineation, and the repeated construction of associated fencing for protection against pigs along with dumping of garden debris along those boundaries has further contributed to their visibility.

Weightman discusses both fencing and the rectilinear form of Vanuatu garden layout in detail, citing early contact records and contemporary (1970s) observation (Weightman 1989: 48-9). Cook described the gardens on Pentecost, that appeared to stretch from the coast up to the summit of the high hills of the interior, as being "divided into rectangular fields by fences", and at Port Resolution on Tanna "the Plantations were laid out in a line"; in Big Bay, Santo, in the 1870s the gardens were described by Goodenough as being "carefully made, having reed fences, and being square and very clean"; and gardens on Ambae in 1890 were laid out "in squares, like the beds in a vegetable garden" (Weightman 1989: 49). Descriptions of fences on Tanna, dating to the late nineteenth century, say that they were "built of stones, logs, bamboo, reeds or of a combination of these. Sometimes they are very massive and high and form a barrier over which a man has some difficulty in climbing . . ." (Humphreys 1926, cited in Weightman 1989: 48). On visits to central Tanna, Weightman himself noted "the rectangular shape of ancient garden remains clearly marked by the metre or more high banks of earth that were formed, perhaps over many centuries, along the old fence lines where weeds, stones and trash were heaped" (Weightman 1989: 49).

The massive Type 1 linear mounds found in the alluvial valleys of Efate may have some parallels with dryland systems found in New Caledonia and Fiji. The extensive dryland systems of New Caledonia display a range of linear mound features laid out in various arrangements on terraces and alluvial plains that are primarily associated with yam cultivation. The agricultural systems of the Tiwaka alluvial plain, for example, cover an area of 35 hectares and comprise 150 large mounds that are 1–3 m high, 10 m wide and up to several hundred metres long. These have been interpreted as supporting both yam gardens on the mounds and taro cultivation in the hollows (Sand 1995: 171-85; Sand 2012: 175-6). In Fiji, extensive areas of dryland systems have also been recorded, both on slopes in the form of terraces and on flat areas, although the latter are poorly detailed (Parry 1987: 78-81). There are also other systems in the river valleys that comprise both mounds and ditches that supported crops suited to both wet and dry conditions (Parry 1977: 69-70). While the Type 1 linear mound systems in the alluvial valleys of Efate may have served as some form of boundary delineation, their primary function seems most likely to be associated with yam gardening, whereby they effectively provided deep, well-drained loose soils in a zone that is prone to waterlogging and flooding during periods of heavy rain. Crops such as taro, which are less affected by such conditions, could have been grown in the non-mounded zones.

The interpretation of the circular features remains much more speculative at this stage and will require focused multidisciplinary investigations to achieve clarity. They are located across the landscape, from near sea level to 300 m ASL (Figure 4h). They have some chronological depth, and may have initially been isolated or at least adjacent to agricultural systems and later absorbed into them. The only other circular features in the region that show any remote parallels are the generally circular fortifications, that in some cases also acted as permanent settlements, found in Fiji (Parry 1987: 93-102). However, the Fiji sites are generally defined by circular ditches and palisades with no substantial earth banks, apart from historical-period sites adapted to musket warfare. Intriguingly, the areas enclosed by most of the recorded Fijian fortifications have a very similar mean diameter (Parry 1987: 102) to the circular features on Efate (mean of ~84 m). The increased agricultural production across the landscape in New Caledonia and Fiji was also associated with changing settlement and habitation patterns. Villages tended to be established in close association with gardens and became less coastally orientated (Field 2004; Parry 1987; Sand 1995). The Efate sites may represent centres of settlement and/or ceremony that incorporated an agricultural component, which have begun to appear across the landscape in the past 1000 years.

MULTIDISCIPLINARY CONTRIBUTIONS: ARCHAEOLOGICAL, HISTORICAL, DEMOGRAPHIC AND PALAEOENVIRONMENTAL

Although no direct archaeological investigations have been undertaken on the features outlined here on Efate, there are a wide range of other data that can be drawn on to provide a broader level of interpretation of this extensive anthropogenically generated landscape. The modified landscape that has survived represents its zenith prior to European contact and the excellent state of preservation in areas where historic-era impact has been minimal further supports the idea that these systems were in use into the nineteenth century. However, while there is evidence of agricultural development from the coast to the high interior, the shifting cultivation system that was practised implies that much of the identified areas of modification was also left fallow for varying periods. There is also the palimpsest nature of the landscape to consider, as clearly seen in the valley system of Marona, which further complicates interpretation. A range of information provides us with some convincing evidence of when this increasing agricultural development and expansion was likely to have commenced.

Population growth and landscape transformation

The first human settlement of Efate began with Lapita colonisation around 3000 years ago (Petchey *et al.* 2015). Settlement during this period was very much coastally orientated, as it was during the immediately Post-Lapita Erueti Phase (2800–2300 BP), although during this latter period sites became much more numerous (Bedford 2009). All sites associated with this period that have been investigated tend to be buried by at least 50 cm of tephra-rich overburden and/or later midden deposits. Mangaasi-style pottery that develops from 2300 BP and continues to c.1200 BP, when pottery disappears altogether, is found on the coast and towards the interior, in both surface and buried contexts, and on all the offshore islands (Bedford 2006, 2009; Garanger 1972), indicating a substantially increased population, the settlement of which was distributed across the landscape. Another likely addition to population numbers within the past 1000 years was the massive explosion of Kuwae Island just to the north of Efate, at around AD 1450, when fleeing inhabitants who had long-standing connections with islands to the south would have sought sanctuary as their island disintegrated (Garanger 1972; Robin *et al.* 1994).

The archaeological record of an increasing population on Efate, significantly impacting on the environment from 1200 BP, is also supported in the palaeoenvironmental record. Although to date such analyses are limited for Efate, the palaeontological record of the Emaotfer swamp, located above and near the mouth of the Teouma Valley, provides confirmation of such a scenario. The record demonstrates significantly increased introduced taxa and micro-charcoal particles from between 1500 and 900 BP, which has been interpreted as relating to human impact (Combettes *et al.* 2015). The LiDAR survey of this broader area certainly reveals extensive evidence of agricultural activity in the form of a patchy mosaic of low rectilinear mounds (Figure 5).

Two other crucial geomorphological aspects when considering the development of the anthropogenic landscape on Efate are tectonic uplift and volcanic ash fall. Rates of uplift for Efate during the Holocene have been calculated at 0.55–1.0 mm per year or up to 3 m over a 3000-year period (Macfarlane *et al.* 1988). Such uplift rates indicate that much of the alluvial flats seen today would have been submerged during initial settlement and probably for the subsequent 1000 years of occupation, and consequently soil development at least at the mouth of the valleys would have been limited. Three thousand years ago, the Teouma Valley would have comprised half its area and Marona some 70% (Figure 6). It was the subsequent uplift, human-induced clearance of the landscape for gardening and tephra deposits from the nearby offshore island of Nguna that would have contributed greatly to alluvial build-up in the valley systems. This scenario then suggests that in the alluvial valleys at least, the agricultural landscape seen today has developed over the past 1000 years.

Sociopolitical transformation

A growing population, increasingly complex sociopolitical structures and pressure on production are seen as central drivers of agricultural development, innovation and intensification. Indications that a number of these aspects were developing on Efate are provided by the archaeology, in the form of the spectacular ceremonial activity associated with the grand funerary rights accorded to Chief Roi Mata at around 400 BP (Garanger 1972). The excavations of the burial site, on the small offshore island of Retoka, revealed more than 50 burials that were associated with a sacrificial performance related to the death of this revered chief, who was said to have brought peace to the region (Garanger 1972). According to oral traditions, he died after falling ill at a feast and he was subsequently toured throughout his domain before being buried on Retoka. This ceremony would have taken considerable time to prepare and involved people from all over Efate and the Shepherd Islands who were prepared to sacrifice a substantial number of high-status individuals as part of the funerary ritual. Grand feasts and displays of largesse would have been intimately associated with this lengthy process. While this specific ceremony is well documented both orally and archaeologically and may well have been the most spectacular of the period, other ceremonies and rituals involving substantial communal gatherings involving displays of surplus food production would have been a regular feature on Efate both pre- and post-Roi Mata. Festivities, for example, associated with yam harvest ceremonies that lasted several days in the late nineteenth century on Efate, are recorded as attracting 500–600 people (Hagen 1893: 347).

Population collapse

Significant decline and/or collapse of Pacific Island populations, following European contact, is well documented across much of the region (Kirch & Rallu 2007). In Vanuatu, the most detailed case is that on the island of Aneityum where, from a population of around 3500 in 1852, as recorded by early missionaries, it had been decimated three decades later, and by the early twentieth

Figure 5. The Eratap area, south-west Efate. The circular feature cut by the road and seen in Figure 4d is in the centre of the image. An extensive network of rectilinear mounds covers much of the adjacent landscape for more than a kilometre to the north and east. [Colour figure can be viewed at wileyonlinelibrary.com]

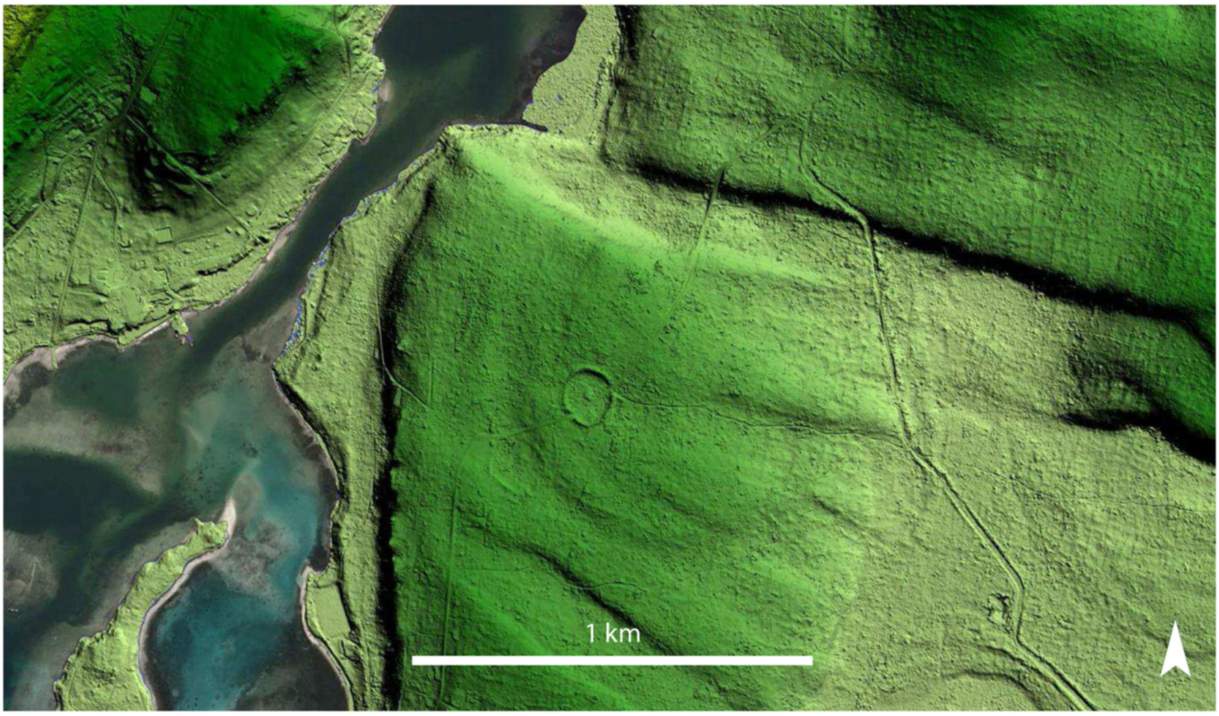
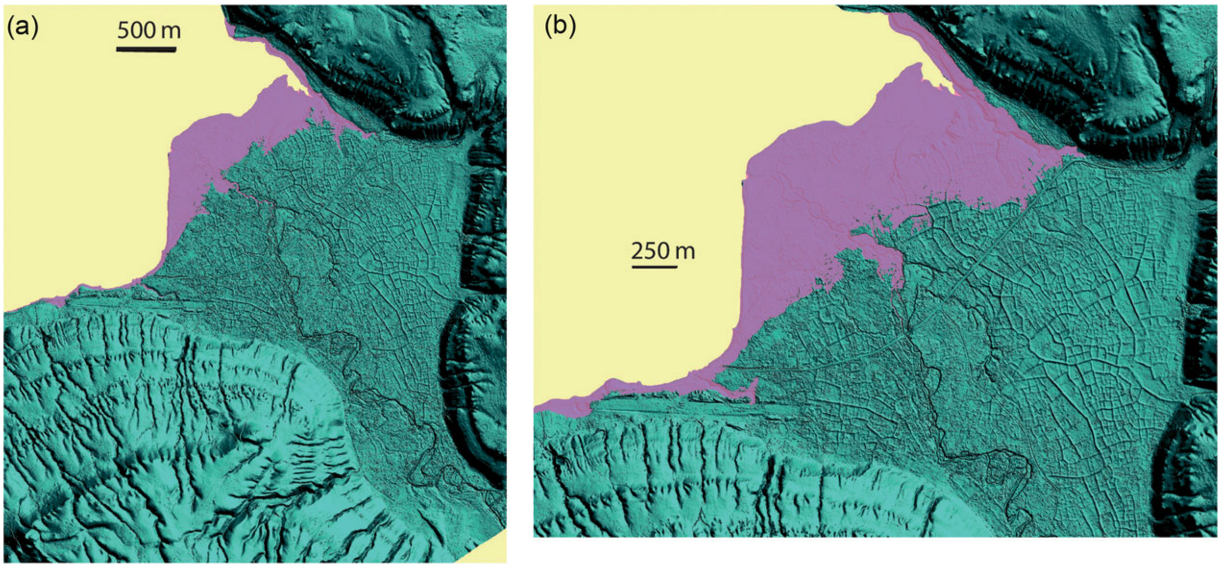


Figure 6. Simulated sea-level rise of (a) 3 m and (b) 5 m in the Marona Valley area, north-west Efate. [Colour figure can be viewed at wileyonlinelibrary.com]



century had lost 90% of the total (Spriggs 1997: 253-4). The remnant irrigated systems found across much of the island are testament to the much larger population. Efate too experienced significant population collapse and again the widespread evidence for agricultural activity attests to a much larger populace. Depopulation occurred through introduced disease dating from earliest contacts but also labour trafficking from the 1860s, where villages were stripped of their reproductive population (Scarr 1967). Dense populations are noted by some of the earliest visitors to Efate in the mid-1840s to 1850, and depopulation is frequently referred to by missionaries and others across Efate from the 1850s. While estimating population numbers and the impacts of disease can be a particularly fraught and contentious exercise, the general pattern of decreasing numbers is repeated in all historical observations. For a more detailed discussion, see the online Supporting Information.

DISCUSSION

Agricultural development and the associated extensive modification of landscapes facilitating both dry and/or wet cultivation systems has been widely documented across the Pacific region from New Guinea to Eastern Polynesia (Kirch 2000: 317-21). Efate is the latest addition of an island where human adaptation to changing social and natural environments led to innovative approaches to increasing agricultural output, which in turn transformed the landscape. Such transformation is well documented on two islands in Vanuatu, namely Maewo and Aneityum, in the form of the extensive remains associated with irrigated taro cultivation (Spriggs 1986). Similar elements of population growth, environmental change and sociopolitical transformation are elicited as contributing factors to these developments. However, as comparison with Efate demonstrates, there is a "multiplicity of possible agronomic responses to environmental, demographic and social changes" (Kirch 1994: 248). Unfortunately, apart from Hawaii, dryland systems tend to be much more under-researched than are wetland systems across the Pacific and the early ethnographic record also tends to be much poorer (Kirch 1994: 255). The latter relates to the other more insidious parallel found across the region that of massive depopulation following increased European contact. As is the case in Hawaii, it is only through archaeological research that the extent and importance of dryland systems in the Pacific will be revealed.

The widespread evidence of the rectilinear mound features across Efate indicates intensive cultivation of small plots. The explanation for the physical development of the mounds can be found both in the historical record and observation of modern practice. The boundaries of the gardens, that were once fenced, became the focus for the accumulation of both soil, organic matter and other debris over many decades. Volcanic ash falls would also contribute, as ash covering the food gardens would have been quickly shifted to the outer limits of the food gardens. These same mounds and processes are still seen today in areas where anthropic pressure is high, such as Mele village on Efate, or in the Middle Bush of Tanna.

CONCLUSION

This paper is very much a preliminary introduction to an extraordinary anthropogenic landscape that has only now been revealed by LiDAR survey. Many of the interpretations remain speculative, and the island now requires a multidisciplinary investigation of the modified topography, including areal excavation, microfossil analysis and detailed mapping of features and cultural boundaries. There is a range of both striking parallels and differences across the archipelago and wider region in the form and drivers that transformed the landscape, although population growth and its increasing density, environmental change and sociopolitical transformation are all seen as key elements.

The LiDAR data generated for Efate suggests that the research done to date on agricultural landscapes in the Pacific will turn out to represent a radical under-representation of the situation prior to European contact. Again, apart from limited areas of Hawaii, all studies have essentially gleaned information from conventional aerial photography or field surveys. Spectacular remains have already been revealed in New Caledonia and Fiji through these methods, but with the addition of LiDAR the record there and elsewhere will be significantly enhanced and expanded. The importance of developing a fine-grained understanding of agricultural development across the Pacific cannot be overemphasised, as it speaks directly to contemporary debates concerning population growth and food security. Many Pacific Island societies are grappling with these issues but the debates are often devoid of any historical depth or understanding. The direct archaeological evidence provided by the LiDAR survey of extensive agricultural remains, that once supported a much larger population on Efate at contact, highlights the crucial role of traditional agriculture into the future.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this paper at the publisher’s website:

Figure 1. a. Uripiv Island, north-east Malakula and (b) Tutuba Island, south-east Santo showing extensive areas of low rectilinear mound features in a range of configurations. [Correction added on 23 November 2017, after first online publication: Image for Figure S1 has been replaced.]
Figure 2. Mangaasi-Arapus area, west coast Efate. The eastern end of this site, across the stream, was the location of Chief Roi Mata’s village dating to c. 1600 AD. Mapping and extensive excavations have been carried on the terrace between these two streams (Bedford 2006; Bedford and Spriggs 2000). Low stone walls, built of coral boulders sourced from the adjacent upper beach have been recorded and there is some evidence of earlier phases of stone walls that have been are buried. The low stone walls still visible on the surface are clearly highlighted with LiDAR. These mark household and garden boundaries. Scale bar is 100 m.
Table 1. All identified circular features with details of location, size and altitude.