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– ARTICLE –

LiDAR in New Zealand Archaeology: prospects and pitfalls

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ABSTRACT

Airborne LiDAR has become a valuable tool for archaeologists and heritage professionals around the globe. The use of the technology has been relatively limited in New Zealand; however, the growing availability of data means this is beginning to change. In this paper we explore the prospects and limitations of LiDAR in two prosaic but core areas of archaeology: the detection of sites at the landscape scale and characterisation of features at the site-scale. In both cases we find LiDAR to be a generally effective tool. Larger sites (e.g. fortified pā sites) were nearly always located and could easily be mapped, whilst other like storage pits were identified at much lower rates depending on the intersection of factors like topography and land cover and were difficult to map. The general results of our analysis are intuitive, nevertheless they provide a useful case study for the capability of LiDAR for carrying out these key tasks and the situations in which greater confidence may be placed on LiDAR determinations. Ultimately, we suggest the integration of LiDAR with traditional field survey is a means to greatly enhance the understanding of archaeological sites in New Zealand.

Keywords: LiDAR, New Zealand, Pā, Remote Sensing

INTRODUCTION

The ability to identify and interpret 'lumps and bumps' using light detecting and ranging (LiDAR) has been of great benefit to archaeologists, particularly in cases where features are obscured from traditional survey techniques by vegetation or inaccessibility (Crutchley 2010, Chase *et al.* 2011). As such, LiDAR has been used in a variety of global contexts, including the Pacific, to discover new archaeological sites and to map, manage and interpret known sites (Crutchley 2006, McCoy *et al.* 2011, Freeland *et al.* 2016, Quintus *et al.* 2017).

Despite its successful application elsewhere, the use of airborne LiDAR for archaeological purposes has been relatively limited in New Zealand (Jones and Bickler 2017, 2019) due to the general absence of LiDAR datasets generated by industry or government and the lack of large-scale landscape studies of the sort that would gather LiDAR specifically for archaeological use. However, in recent years, this situation has begun to change with the growing availability of spatially restricted, variable resolution data collected by local authorities. The increased availability of data looks set to continue should a recently announced central government initiative to capture 1 m resolution LiDAR data on national scale eventuate (Beehive 2018). Likewise, positive results from the limited application of LiDAR for heritage purposes (e.g. Jones & Bickler 2017, 2019) together with recognition of the potential of advanced visualisations and automated feature recognition for archaeology (Jones & Bickler 2019, McCoy 2017), will further drive increased use of the technology.

The combination of these two factors leaves New Zealand archaeology poised for a rapid uptake of the use of LiDAR. Evidence from elsewhere in the world suggests this adoption will have positive effects on archaeology in the long-term; however, the path from initial uptake to widespread and productive use of LiDAR may not be linear. Indeed, as Gartner's hype cycle (Figure 1) predicts, we may expect rapid uptake and relatively indiscriminate use of LiDAR followed by a slump as the technological limits and context specific challenges are understood. However, as the experiences of early adopters are refined, best practices may emerge allowing the technology to be used to its full potential (Fenn & Raskino 2008, Collar *et al.* 2015). As the initial boom of LiDAR is in its early stages, we believe the challenge for early adopters is to explore both its potential (e.g. Jones and Bickler 2017, 2019, McCoy 2017) and, crucially, the limits of the technology in the domain of New Zealand archaeology to provide a smoother path toward its productive use.

To that end, this study uses open-sourced data to examine the utility of LiDAR for carrying out prosaic yet core archaeological tasks. In particular we focus on assessing

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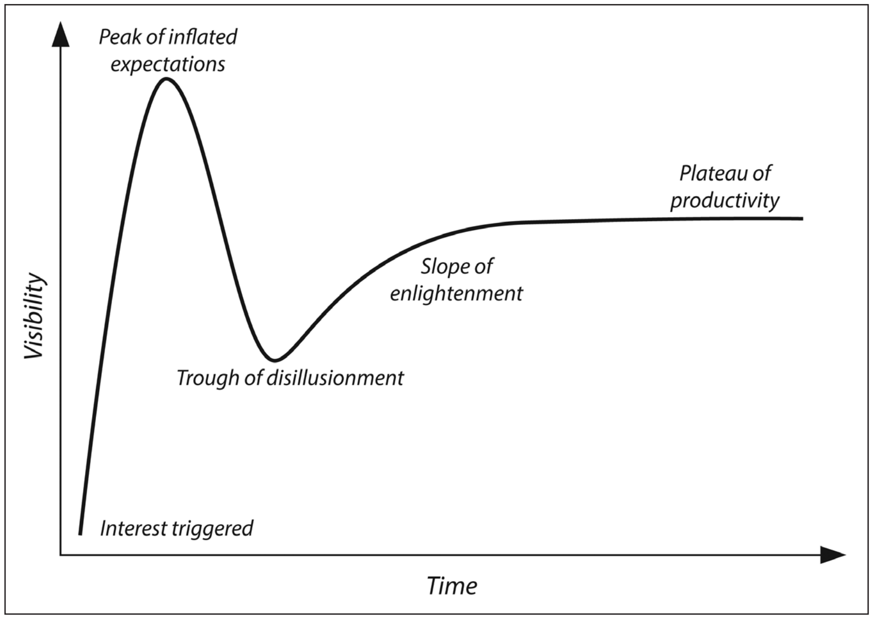

Figure 1. Gartner's hype cycle for emerging technologies (adapted from Fenn & Raskino 2008 and Collar *et al*. 2015).

the ability of 1m resolution LiDAR to aid site detection on a landscape scale and to provide finer-grained details at the site-scale across a range of topography, land covers and site/feature types in New Zealand. Finally, we discuss a set of conventions that may be useful when deploying LiDAR in both research and commercial archaeology within New Zealand.

STUDY REGION

This research was carried out in two study areas (see below) within Bay of Plenty region, on New Zealand's North Island (Figure 2). The region was selected for study for three primary reasons, which together provide a full and representative test of the capabilities of LiDAR.

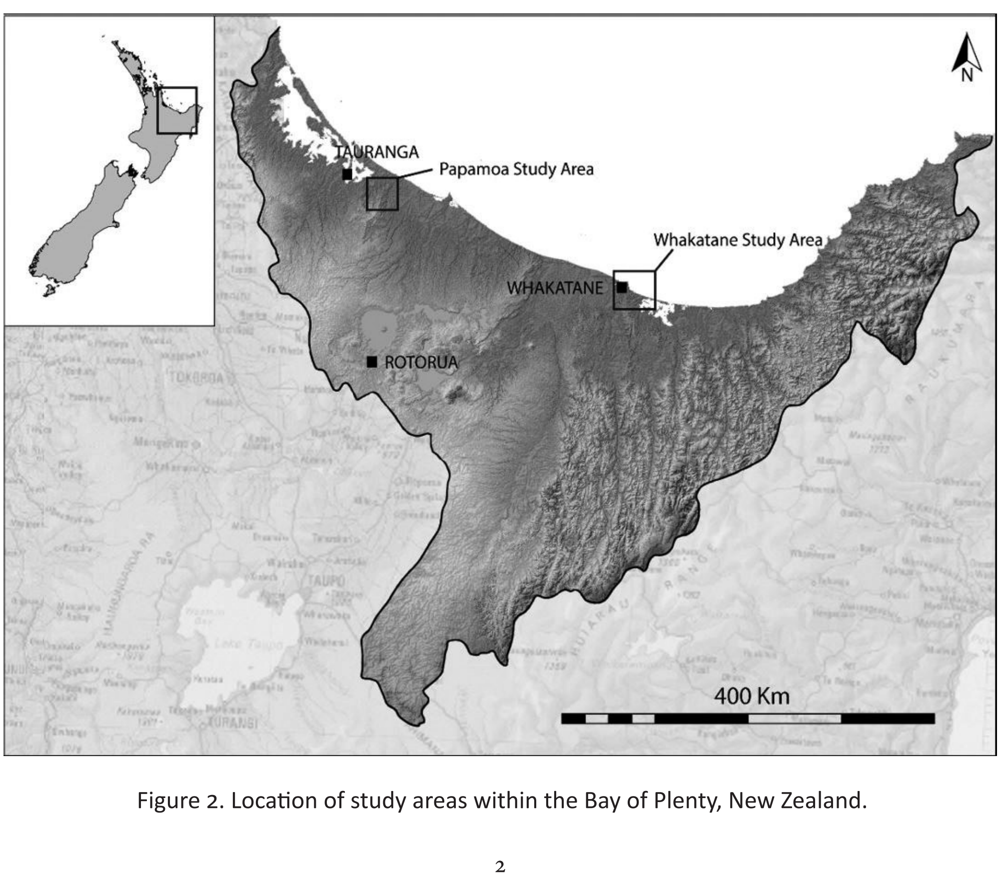

Figure 2. Location of study areas within the Bay of Plenty, New Zealand.

First, the Bay of Plenty has a wide range of topography and land cover, providing an opportunity to test LiDAR in different environmental contexts. In particular, we targeted flat to rolling coastal areas in grass and steeper areas covered in both regenerated native and exotic tree species (see below).

Second, Maori occupation in the Bay of Plenty was rich and extensive during the later end of the New Zealand sequence (post *c.* AD 1500; Law 2008). Terraces, subterranean storage pits and fortified pā sites are all common, and are representative of features encountered throughout the horticultural zone in New Zealand.

Finally LiDAR data has been extensively captured in the Bay of Plenty, with one metre horizontal resolution data available around coastal areas near to settlements (e.g. Tauranga and Whakatane). This data is typical of LiDAR throughout New Zealand; it is collected for planning purposes and therefore often lacks resolution or is not in the precise location that archaeologists may prefer. It also matches the proposed capture resolution of the central government LiDAR initiative, meaning the prospects and problems associated with this resolution of data are particularly pertinent to explore.

STUDY AREA 1: PAPAMOA

The Papamoa study area is located in the Papamoa Hills Regional Park, approximately 10 kilometres east of Tauranga (Figure 3). The Papamoa study area is 10 km²; its extent was determined by the availability of one-metre resolution LiDAR tiles, which accounts for its regular, if slightly arbitrary, shape. The area includes rolling hills mostly containing high producing exotic grassland (Ministry for the Environment 2012), which overlook expansive areas of flat former swamp-land. The study area was comprehensively mapped in 2003 and 2017 (Walter & Greig 2006, SPAR 2017), with a range of features including storage pits, terraces and fortified sites (pa) recorded to a high level of spatial accuracy. Thus, this landscape and the associated archaeological record, provide an excellent test of both the ability to identify features using LiDAR and the accuracy with which these identifications can be made.

STUDY AREA 2: WHAKATANE

The second study area is located on the hills immediately to the east of the Whakatane Township (Figure 4). The

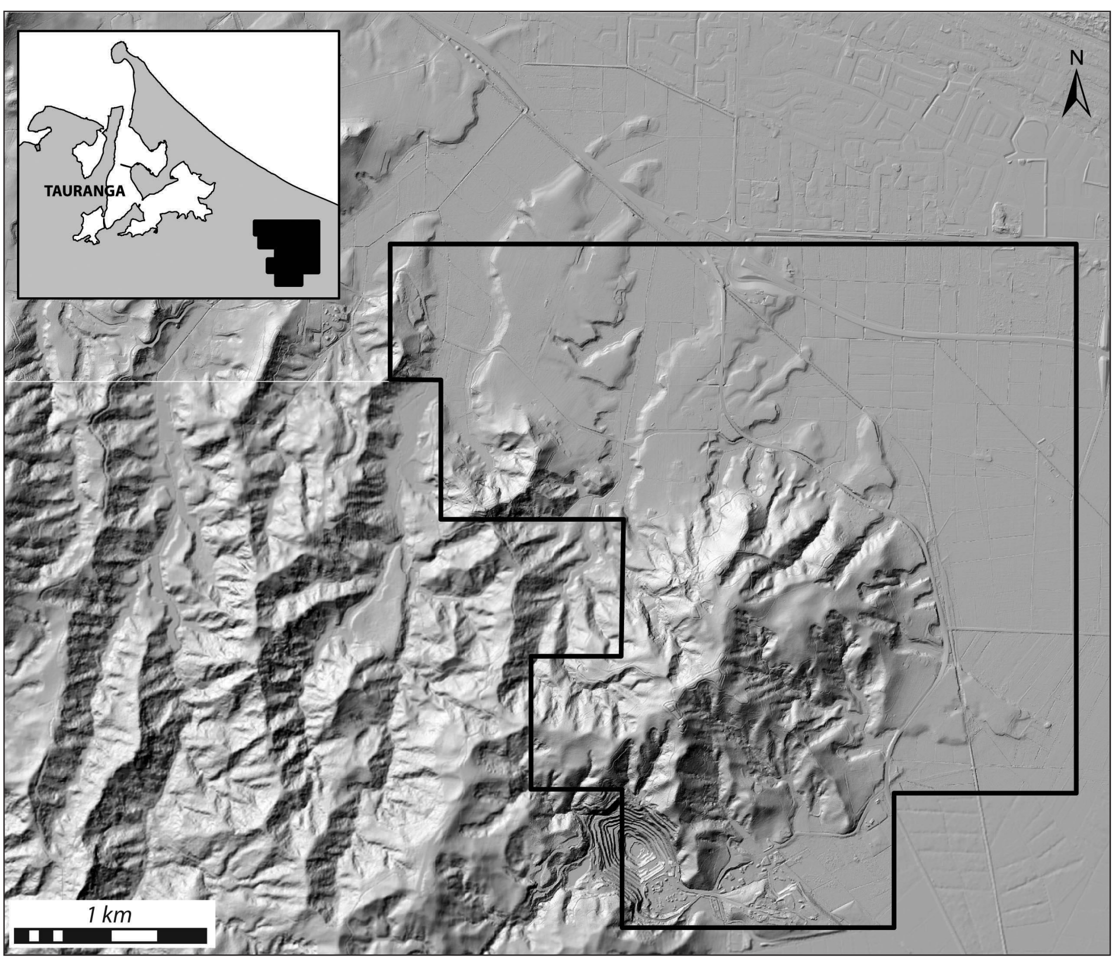

Figure 3. The Papamoa study region (black polygon), located on rolling hill country to the east of Tauranga.

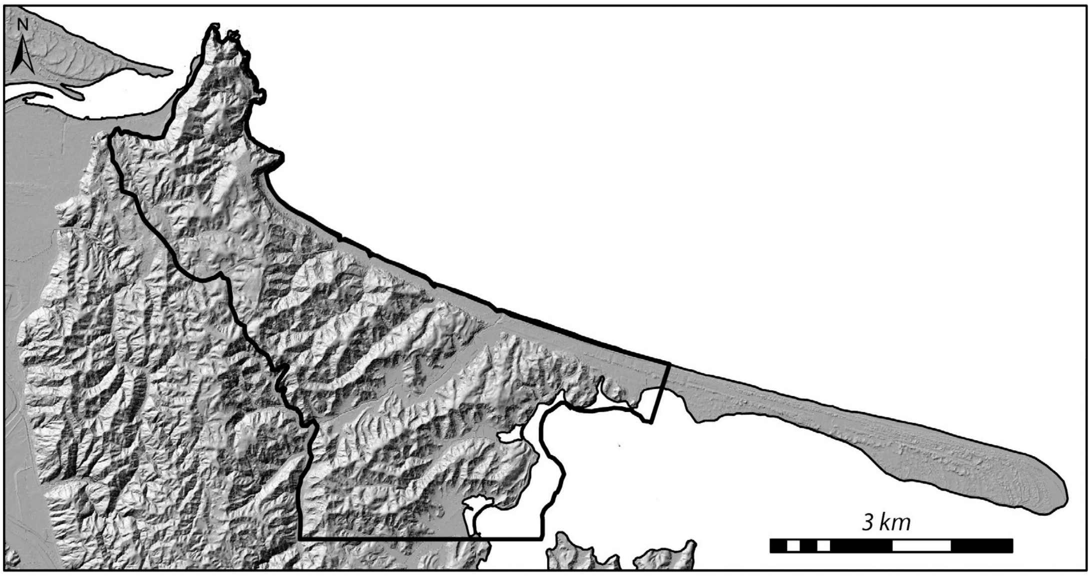

Figure 4. The Whakatane hills study area (black polygon), extending from the hills to the east of the Whakatane township to the Ohiwa Harbour.

Whakatane study area is approximately 23 km², the northern and eastern boundaries are determined by the coast, while the southern boundary was determined by the end of high-resolution LiDAR tiles. The western boundary follows the Burma Road, but also closely corresponds to the edge of the available 1m LiDAR data. The topography is mixed with broken, steep-sided ridges covered in indigenous/exotic forest and some high-producing grassland in the west, and flatter sand dune environments covered by built-up areas and grasslands in the east (Ministry for the Environment 2012). A number of sites have been recorded via traditional field survey in this area, including pā, terraces and pits. Recording quality in this area varies significantly between surveyed maps (total station and plane table) and sketch maps, and is therefore a more accurate representation of the general state of site recording in New Zealand.

MATERIALS AND METHODS

Data

This research uses LiDAR data captured for the local authority body BOPLASS in early 2015. Open source DTMs were accessed from both study regions via the Land Information New Zealand data service (data.linz.govt.nz) and had a horizontal resolution of one metre. The average ground return density on which these DTMs were based was 1.16 pts/m² in Papamoa and 0.76 pts/m² in Whakatane. Location data and site maps from previously recorded sites were sourced from Archsite, the New Zealand Archaeology Associations online site database (archsite.org.nz). The Bay of Plenty Regional Council supplied Shapefile data from the recent extensive mapping of features in the Papamoa study area.

Visualisation

This study applied a range of derived models (DMs) to determine the most effective for visualisation of the LiDAR data. We primarily relied on DMs, hillshade and slope. The hillshade model was developed using the standard settings in ArcMap; however, due to the presence of high relief topography, the slope DM was adapted to a contrast model, which has been successfully used to identify agricultural terraces in Hawai'i and American Samoa (McCoy *et al.* 2011, Quintus *et al.* 2015). Following McCoy *et al.* (2011) we categorised our data into low (0–4°), mid (4–40°) and high (40–85.78°) slope, which provided much clearer results. For mapping purposes we found the addition of local relief modelling (Novák 2014) and interpolation lines, to be beneficial in the interpretation or identification of small-scale features, such as pits, present within pā.

LiDAR prospection

The first goal of our research was to assess the effectiveness of LiDAR for identifying pā, terraces and pit sites in our study areas. Automatic feature extraction (AFE) techniques have shown promise in this area (Jones and Bickler 2019), and have particular utility where large, complex datasets are being searched (Cowley 2012). However, in New Zealand, the limited spatial scale of archaeological projects, particularly in the majority of cases where investigations are developer led, will ensure a continued presence of the manual inspection approach. This being the case, we decided to test the effectiveness of this approach using both a widely available, or soon to be available, data resolution and features present across much of New Zealand.

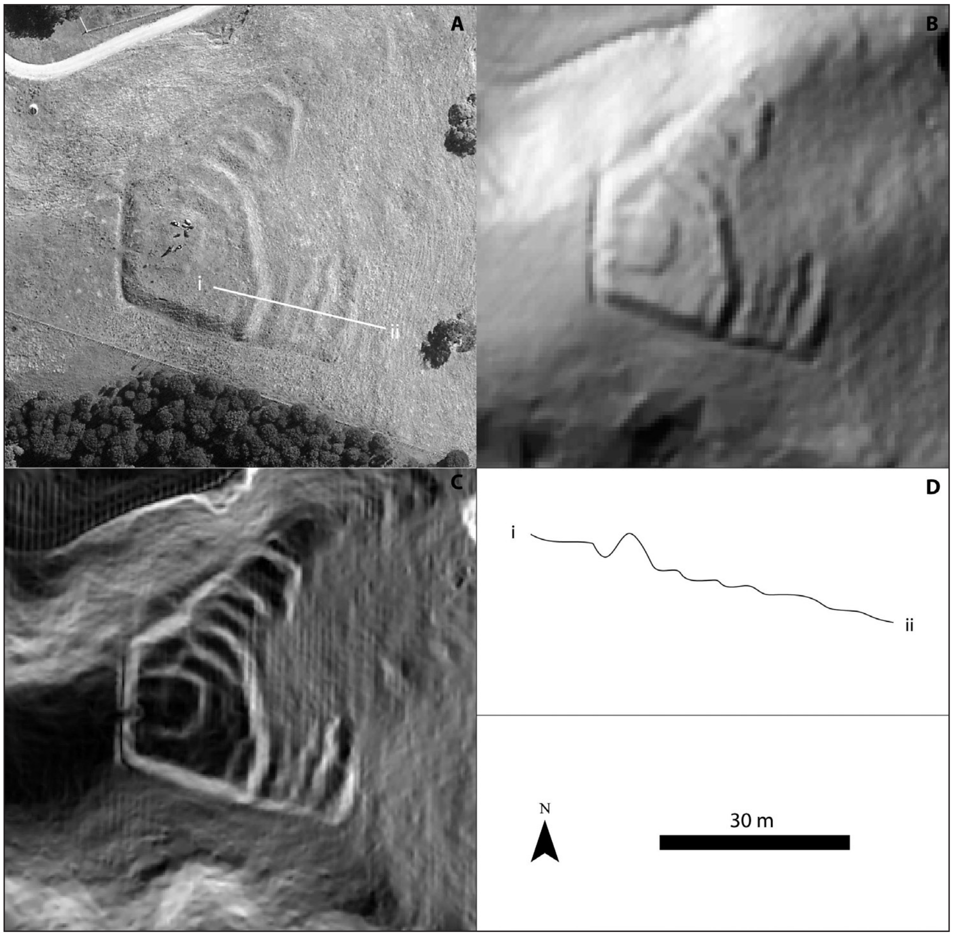

Figure 5. Comparison of visualisations of LiDAR data using hillshade and slope derived models. A) Aerial photograph of pā site with profile line displayed in white. B) Hillshade model of the pā. C) Slope model of the pā. D) Profile of pā to aid interpretation of different derived models.

The prospection for sites was carried out in three steps. First, DMs were visually inspected and areas of interest were recorded on our GIS system. We found the level of confidence associated with areas of interest was variable and that, for the purposes of assessing LiDAR, there may be value in recording the confidence associated with feature detection. Thus, in instances of where the nature and extent of features was clear we assigned a 'probable' status and in areas where, for instance, deviation from a natural slope was observed but we had less confidence determining the shape of the feature, we ascribed it a 'possible' status. Second, in Papamoa the spatial location of areas of interest identified in step one was compared to a feature level GIS map of area, which includes pa, terrace and pit features recorded with high levels of accuracy. In Whakatane, where such data was unavailable, the spatial location of recorded sites (sourced as point data) was taken from the New Zealand Archaeological Association's online spatial database (Archsite) and compared to the areas of interest identified in step one, information in Archsite was consulted to mitigate the effects of poor spatial resolution of site locations to ensure the we were identifying the same site as previously recorded. Finally, a field survey was carried out across the Papamoa study area and the area of public land in the Whakatane study area (i.e. Kohi Point and Ohope Scenic Reserves) . Following Bickler and Jones (2017) this survey targeted areas of interest (both possible and probable) and, to mitigate the possibility of false negatives, several areas deemed to have no archaeological significance based on the LiDAR data. The purpose of this survey was to confirm or exclude newly identified sites and to gain an understanding of the type and landscape context of features ascribed different levels of confidence.

Mapping sites using LiDAR

In order to assess the utility of LiDAR for remotely mapping archaeological sites we selected one previously mapped pā from each study region. In the Whakatane study area New Zealand Archaeological Association (NZAA) site W15/38 was selected. This site is located on a steep, forested ridgeline and was previously mapped by Peter Bristow in 1986 using a plane table. In the Papamoa study area we selected NZAA site U14/238. This site is a large pā, known as Karangaumu, located at the high point of the rolling pasture covered Papamoa hills. Southern Pacific Archaeological Research produced a high-quality map of the site in 2017 using robotic theodolite and differential GPS.

To carry out the mapping hillshade, slope and local relief models, were produced of each site. These DMs were then used to map archaeological features without reference to the terrestrial survey plans. Once mapped, the LiDAR derived shapefiles from each site were qualitatively compared to the survey plans to assess the accuracy of the LiDAR mapping.

RESULTS

Prospection

The combination of grassed land cover, topography and well-preserved archaeological features meant prospection was relatively simple in Papamoa. All 11 pā in the study area are highly conspicuous and their extents easily identified (Figure 6). Of the 735 terraces outside of the extents of pa sites identified during ground mapping in 2017, we were able to locate 657 with high levels of confidence and a further 51 with lower confidence. Those terraces that were missed had a median area of 7.25 m^2, against the overall median of 15.7 m^2. Thus, it is reasonable to suggest LiDAR is capable of identifying a majority of larger, or medium sized terraces, but at one-metre resolution smaller terraces (*c.* 2.5 m × 3 m) are beyond the limits of detection. We also identified a further 131 areas of interest, 71 of which corresponded to features identified in a 2003 survey of the Papamoa study area by Geometria (Boffa Miskell 2003), but not found in the later survey and the remaining 60 had not previously been recorded. A high proportion of this group were recorded with low confidence (94/131), with 'probable' features generally being larger (median area 14.2 m^2 v. 6.2 m^2 for possible sites). The high number of features identified as 'possible' in Papamoa reflects the subjective nature of the visual inspection method. Here, with the benefit of hindsight, we can see that the incredibly rich cultural landscape may have led to the positive identification of features that would have been disregarded in other areas.

The identification of storage pits was the most difficult aspect of the prospection process. Although we have encountered very clearly defined pits in other regions of New Zealand (Figure 7), this was not the case in the Papamoa region where, outside of some pits within the pā sites, they presented an ambiguous pattern (Figure 7). Prospection therefore required further investigation using the interpolation line tool in ArcMap, which, when drawn across a platform or series of pits, provides a surface profile that allows the identification of discrete features. This tool is useful although it is relatively time consuming and first requires that ambiguous features are detected, something that cannot be guaranteed. These difficulties led to a relatively poor level of pit identification with only sixty per cent of pits (48 of 79) whose presence was confirmed in 2017 being identified using LiDAR.

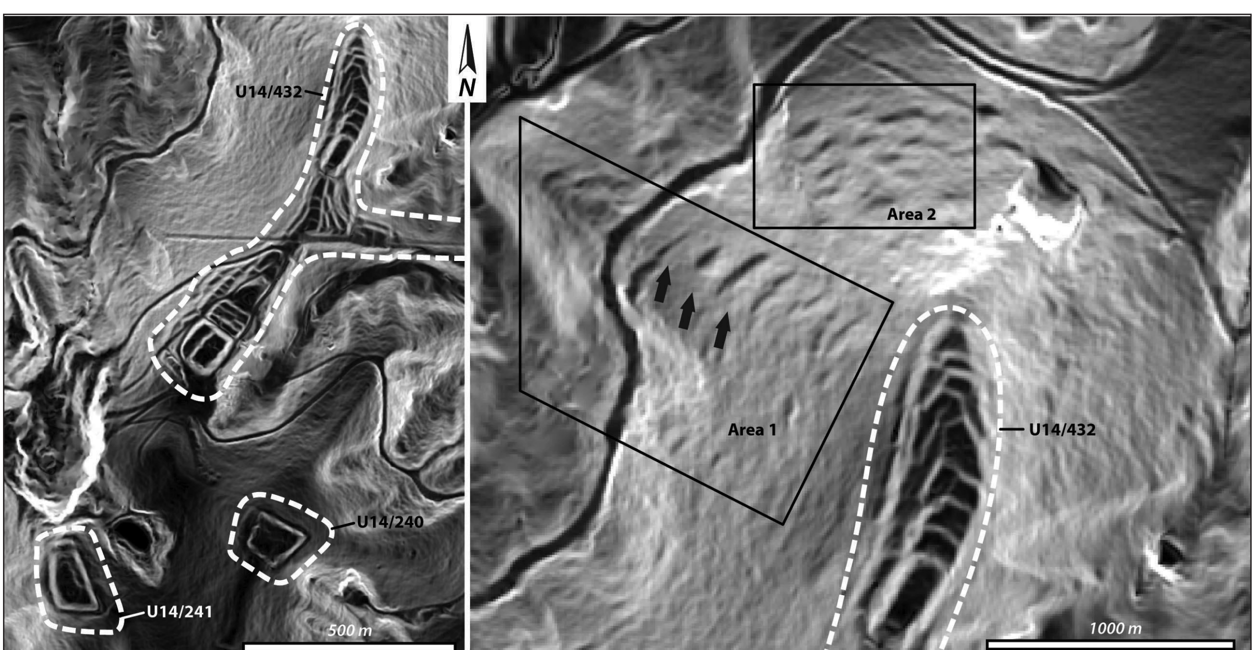

Figure 6. Left: examples of clear features associated with a pā sites (U14/432, U14/240 and U14/241). Right: recorded terraces (Area 1) and previously unrecorded terraces identified via LiDAR (Area 2) adjacent to U14/432

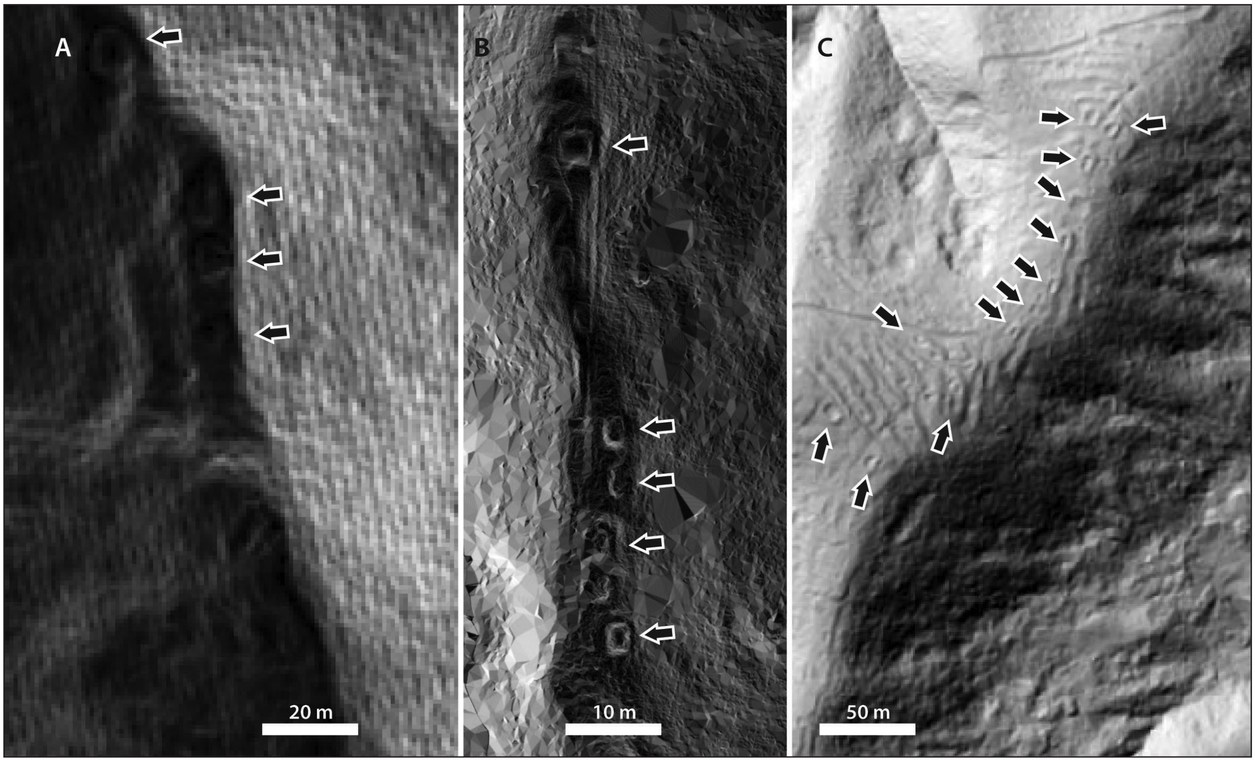

Figure 7. Pit sites located using LiDAR. A – Open rectangular pits (7 × 4m), B – Open rectangular pits (4.5 × 3m), C – Raised rim pits associated with a pā site on the East Coast of New Zealand.

Whakatane

The dense forest and rough terrain of the Whakatane study region presents considerable challenges for terrestrial survey and remote sensing. Nevertheless, prospection for pā sites proved highly effective. Across the 38 recorded pā sites only one site was not identified (Figure 9). This site (W15/28) is located in an area of housing that has been substantially modified, which may account for it being missed. We also identified two areas of interest, which we regarded as 'probable' sites at the western end of the Whakatane study area. Ground truthing of these areas confirmed these were pā, one of which was crossed by a major walkway yet had remained undetected.

The absence of accurate feature level recording in the Whakatane study area required us to check our identification of areas of interest against terrace and pit sites recorded in the New Zealand Archaeological Association site recording scheme. These sites can represent single or multiple features. Where multiple terraces were present within a site we regarded a successful identification as an instance where we accurately placed an area of interest around the site extent detailed in site record forms. While in practice the identification of a single feature within a site may lead to the identification of others during survey, our chosen method offers a better means of assessing the capability of LiDAR alone in identifying features.

The identification of terrace sites in the Whakatane study area was less successful than was the case with pā although the majority of recorded sites were located. 45 of the 65 terrace sites in the area were identified as areas of interest with high levels of confidence and a further 15 identified as possible sites. Unsurprisingly, terrace sites identified with high confidence were larger in terms of feature size compared with areas of interest ascribed as 'possible' sites (30 m² v. 16 m² median size). As well as greater size, the median number of features at 'probable' sites (4) was larger than 'possible' sites (2). Sites identified with relatively high confidence were almost all (41 of 45) located on major ridges or larger spurs while areas of interest identified with lower confidence were located on smaller spurs on the margins of ridges (12 of 15) or in heavily forested areas (11 of 15). In the four cases where terraces were in recorded in areas without landcover *and* along a major ridgeline, 2 occurred in areas where substantial ground modification had occurred, which may account for the lower confidence associated with their location. The five sites not located were all in areas of high relief and within bush, three of these sites were noted by the site recorders as indistinct or poorly defined and all consisted of 3 terraces or fewer.

A majority (10 of 15) of the recorded pits were either not identified (6) or identified with very low confidence (4). Like terraces, the recorded locations of the pits not identified in this study were on smaller spurs off the main

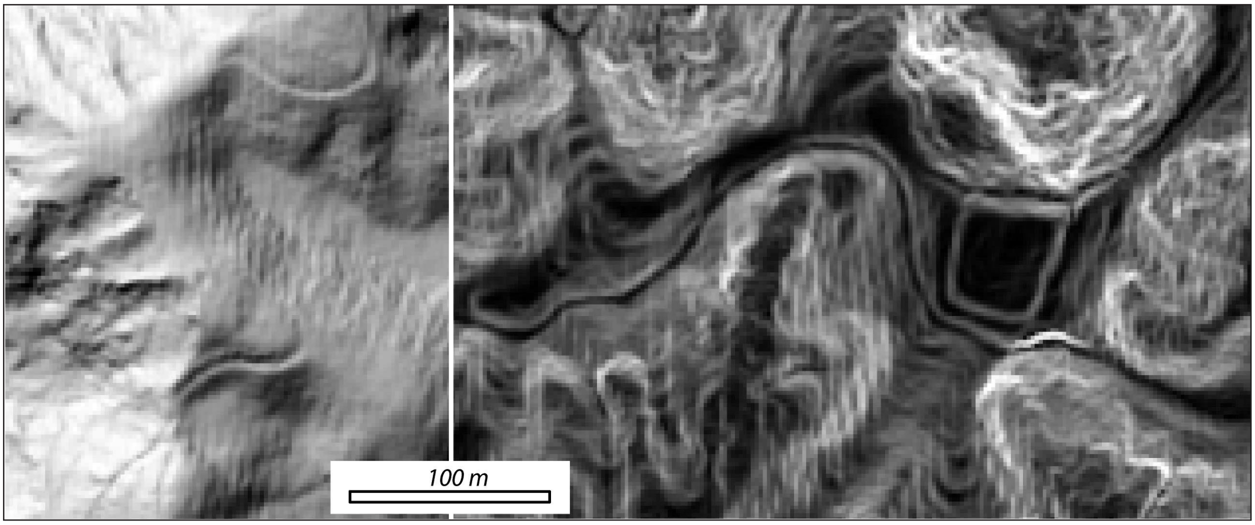

Figure 8. Examples of pits (left), terraces (right, arrows) and pā sites located during prospection.

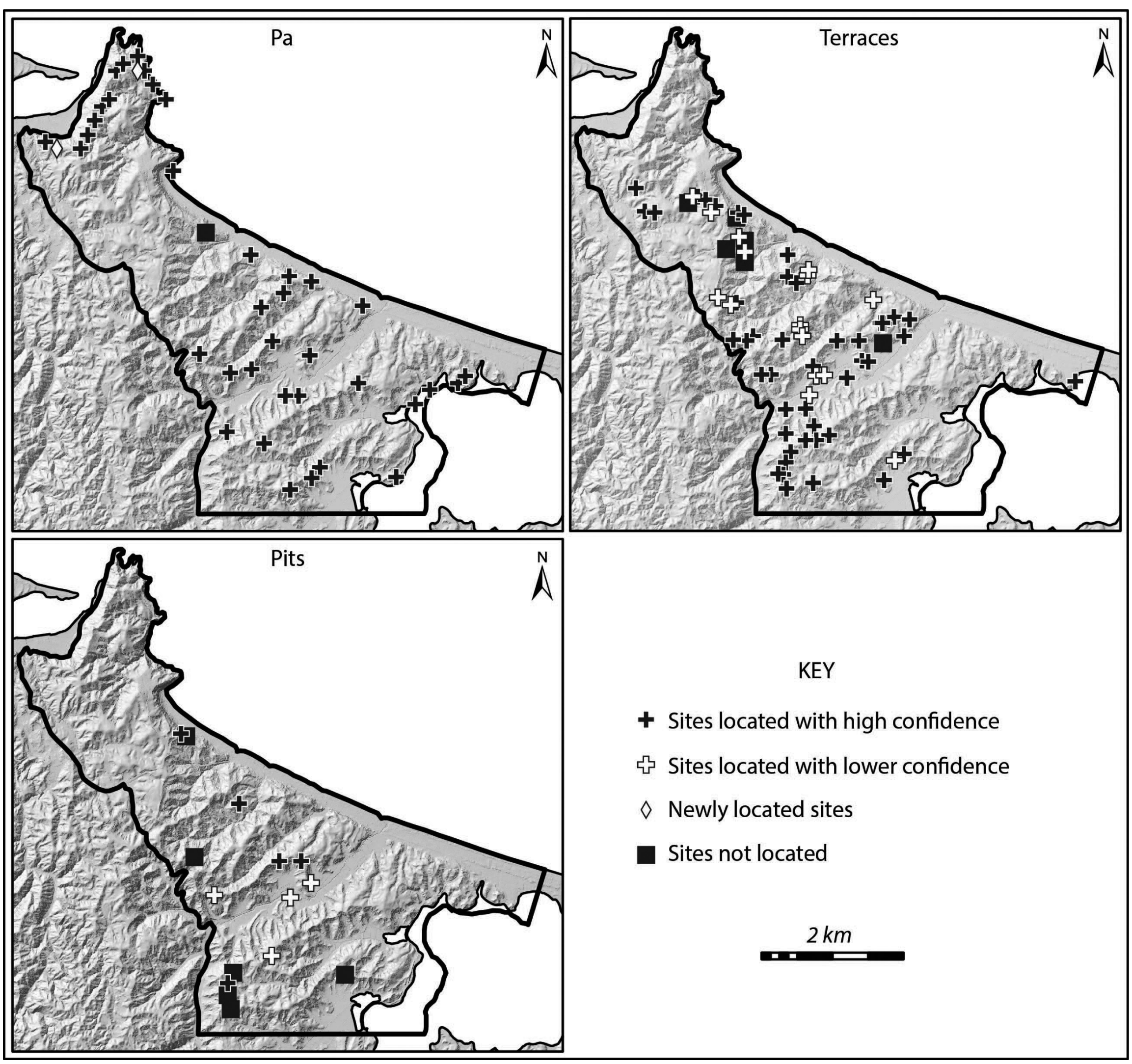

Figure 9. Results of prospecting for pā, terrace and pit sites in the Whakatane hills study area.

ridgelines or in areas of forest cover. Those pits that were identified were in association with terraces and, like the located terraces, were identified on top of ridgelines.

Finally, field survey of areas deemed non-archaeological based on LiDAR visualisations found no visible archaeological features. Thus, LiDAR can be regarded as a useful tool for the detection of sites, but just as importantly, can also be regarded as a reliable indicator of 'empty' areas.

Mapping pā sites

Our second aim was to ascertain the usefulness of LiDAR for remotely recording archaeological sites. Figures 10 and 11 show the comparisons of LiDAR derived maps with those created by traditional terrestrial mapping methods. Both figures reveal a similar pattern whereby the spatial extent and form of larger features are consistent across both methods of mapping. However, LiDAR-derived maps typically contain lower levels of detail, particularly in terms of smaller features like pits. In special circumstances, this is overcome with high-resolution data sets, like the 10cm point spacing used at Stingray point (McIvor 2015), which is capable of detecting smaller features, including pits, as was found in the study. In the case of public accessible LiDAR, such as the quality used in this study, resolution is likely to be much lower, although still effective for mapping key features. Karangaumu pā (Figure 10) offers a clear example, wherein many pits could not be confidently identified and mapped using 1 m resolution LiDAR. Similar fine detail from the terrestrial map in the Whakatane study area was not replicated in the LiDAR-derived map; however, here, the overview offered by LiDAR allowed the detection of peripheral features of sites, which seem to have been missed on the ground (Figure 11).

DISCUSSION

LiDAR has proven a useful tool for archaeologists around the globe and with increasing availability of data at a resolution of 1m or higher is likely to contribute significantly to New Zealand archaeology. Given the majority of archaeology in New Zealand is developer led and relatively small-scale, it is our contention that the vast bulk of LiDAR-related work will involve the two areas covered in this paper: prospection for sites and mapping or increasing the quality of individual site records.

Prospection

Consistent with the earlier study of Jones and Bickler (2017) we have found LiDAR to be a generally effective tool for archaeological prospection in our study areas. Exactly how effective depends on the intersection of topography, land cover, and the nature of the archaeological features

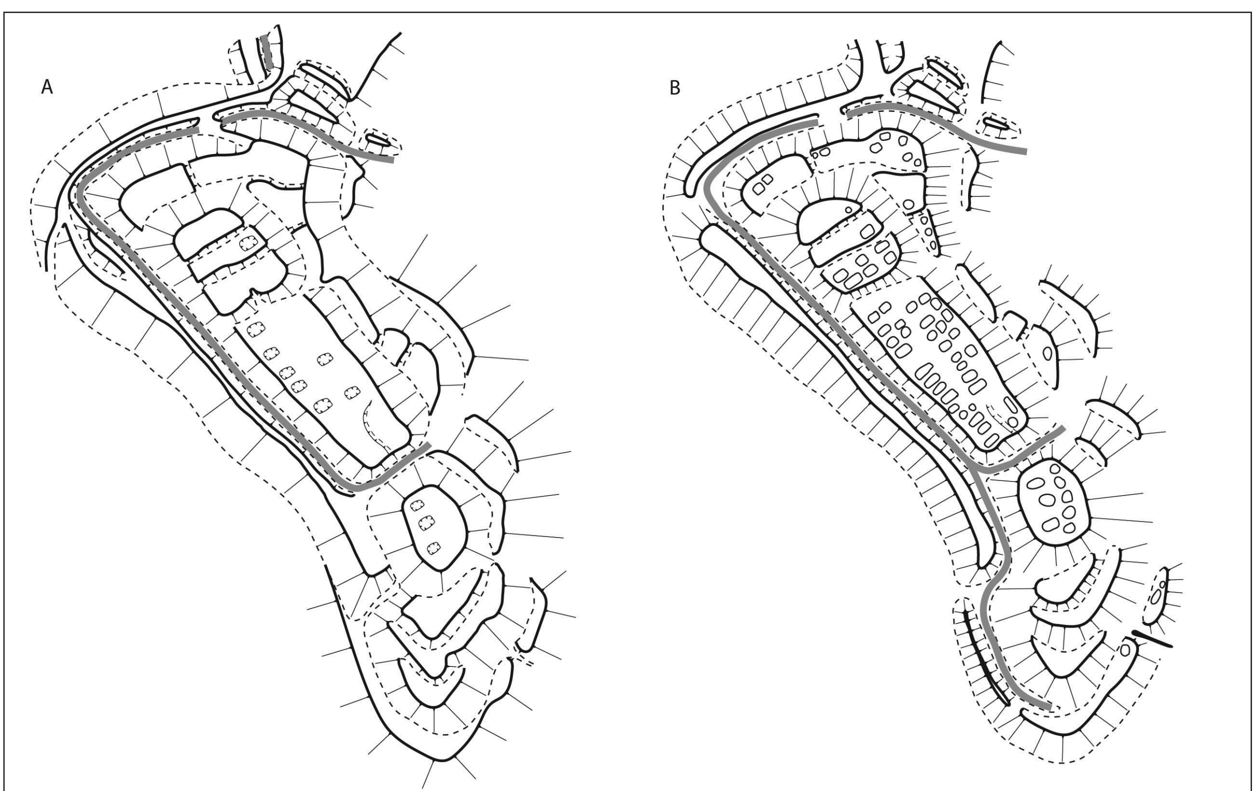

Figure 10. Comparison between the features identified from the LiDAR (A) and via ground survey (B).

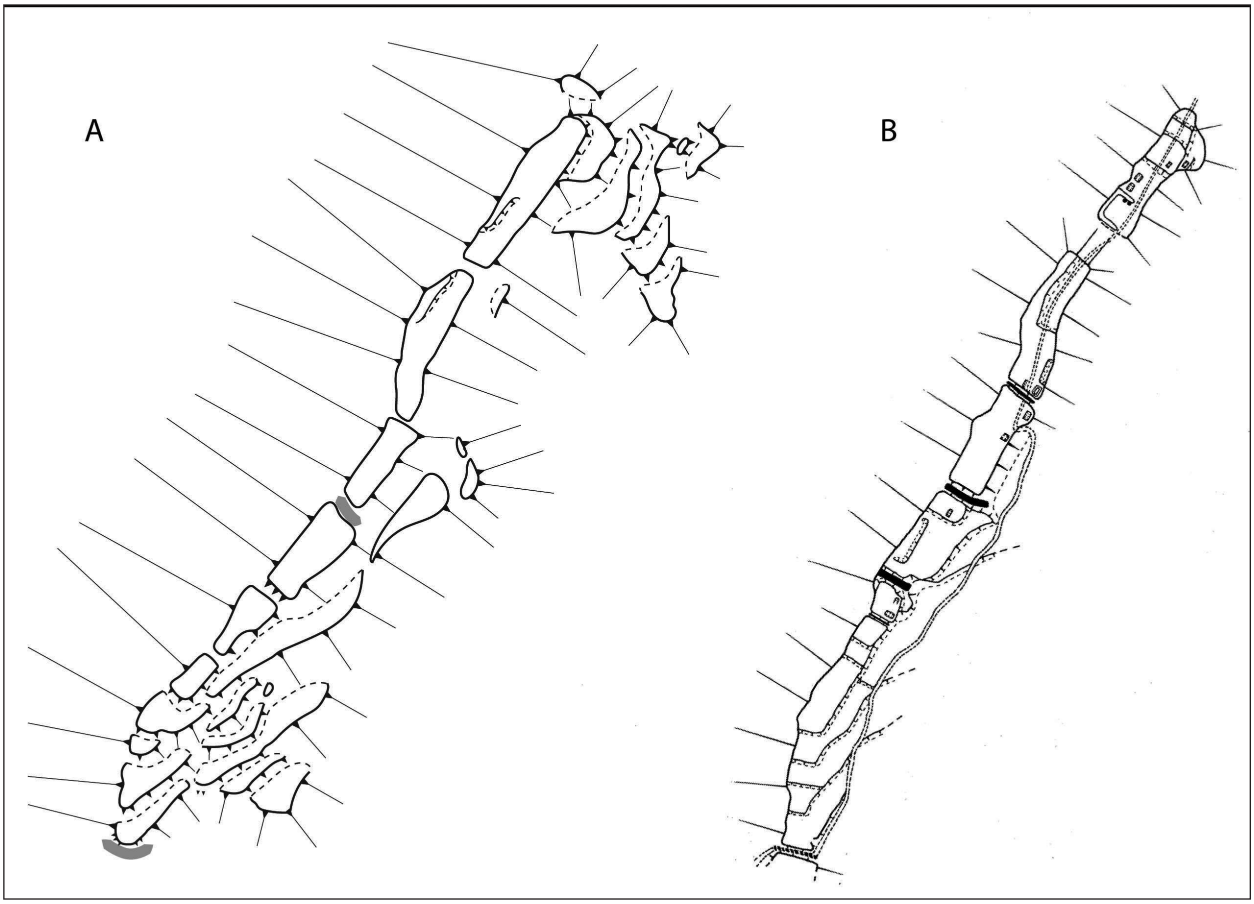

Figure 11. Comparison of the LiDAR derived map (left) and plane table map (right) of the Whakatane pā site (W15/38 & 39).

(i.e. preservation and size of feature). Of the external factors, land cover had the greatest influence of the clarity of derived models irrespective of the processing pathway followed. In general, within forested areas we found it possible to identify larger features, such as large terraces or banks and ditches, but the clarity and confidence associated with some of these features was reduced.

Topography also played a key part in the success of prospection where high relief overlapped with wooded areas. In forested areas we had the greatest success identifying sites located along major ridgelines; sites on secondary spurs and on slopes were very difficult to identify with any level of confidence. Topography did not have the same influence in open areas like Papamoa, where relatively small features could be confidently identified away from the hilltops or ridges.

Unsurprisingly, the nature of archaeological features was also a major factor in our success. Large and conspicuous features were easily detected, whereas smaller terraces and pits were often beyond the detection of 1m resolution LiDAR. However, both with smaller features and larger pā and terrace sites, site condition is also a significant factor. For instance, in other work near the Papamoa study region, we were able to clearly identify pits in grassland and less clearly under exotic pine forest. A similar thing was found on the East Coast of the North Island, where 'raised-rim' pits – pits with a small bank around their margins – were also clearly identified using 1m resolution data (see Figure 5). The difference between these cases and our own study regions was the generally poorer condition of pits in the latter.

Finally, while anecdotal, our experience with prospection in our study regions highlighted several other factors worth considering. First, sites are not located independently from one another, and therefore the chances of identification are also not independent. Rather, site clusters or conspicuous features, such as ditches and banks, attract attention and often led to the identification of more ephemeral features that may not have been identified on their own. This is particularly true in the case of pits associated with terrace sites. The relationship or proximity between features observed in the LiDAR can also play a part in influencing the confidence of the practitioner. Second, a key first step in the use of LiDAR is to engage with the specific archaeological context of the region being worked, to understand relative preservation and form of features likely to be encountered. Finally, while it was conducted in regions that have received a high level of archaeological interest, our study mimicked the expected conditions in sparsely or un-surveyed areas (i.e. we did not use available site records to aid prospection for sites). Thus, we believe LiDAR at a comparable, or better, resolution would be an effective tool with which to search areas that have hitherto not been subject to intensive survey. However, we suggest that LiDAR should not be seen as a means to record new sites, but rather as a means to identify areas of interest within a landscape, which can lead to carefully targeted field survey.

Mapping

Our mapping exercise met with many of the same constraints as outlined above. Despite variations in the environmental factors between each study area we were able to produce reasonable approximations (based on comparison with existing maps and ground-truthing) of the two pā sites. However, in each case, we were not able to confidently map smaller features, such as pits. This result has two clear implications. First, as with prospection, LiDAR has limited utility in characterising sites with only smaller-scale features. And, second, at the site scale LiDAR can map larger features, but is perhaps best suited to identify spatial extents of sites. While this does not offer the same level of information as mapping, in concert with existing records, at minimum, cross-referencing LiDAR data with existing records could provide a more accurate point location than is currently available for many sites and, with the addition of minimal ground truthing, the spatial extents of sites could quickly and accurately be updated.

Finally, in both research and commercial contexts the cost effectiveness versus accuracy of LiDAR is important to consider (Gallagher & Josephs 2008). In this regard the study regions present different answers. The Whakatane mapping identified key aspects of the site represented in the earlier terrestrial map, but lacked smaller-scale detail shown in that map. In the first instance this leads to the conclusion that LiDAR is not effective in such places. However, given the rough terrain and tree cover of the study area, the production of detailed maps may have a relatively high cost. Thus, an indicative map of the site, while not having the accuracy may provide enough detail and certainly is superior to point location. The Papamoa mapping presents a compelling case for the use of LiDAR when conditions suit. Here, the processing and feature identification took seven hours, which, given the accuracy of the map is likely to be extremely cost effective compared to terrestrial survey. Of course, such a claim can only be made because we have a map to compare with our data. Therefore, it is more correct to suggest LiDAR is not a replacement for field survey, but used in parallel may limit the time spent in the field and therefore costs.

Other Prospects

While we have focussed on the prospects and problems associated with a relatively narrow use of LiDAR, the technology provides many other research and heritage management opportunities in New Zealand archaeology. With appropriate resolution data, more studies like McIvor's (2015) analysis of the social use of space within Matakawau pā may be possible. Moreover, improved locational information for pā, coupled with rapid, if relatively course, gathering of the spatial scale of sites can be gained using LiDAR. This would greatly enhance computational analyses of pā using methods such as point process modelling, from which new insights have already been gained (e.g. Smith 2017).

Jones and Bickler (2017) have suggested a range of useful computationally-based directions, which may aid site monitoring and identification. Additionally, we believe there is scope to use LiDAR data to increase the awareness of sites. Pā are often located at key focal points in landscapes and, as such, see more visitors than many other site types in New Zealand. For instance, in the Papamoa study area lies within a regional park where much of the visitation to pā is incidental to other activities, such as exercise, and therefore there is an opportunity to engage people outside of the disciplines normal constituency. The ability to quickly and cost-effectively produce 3D models from LiDAR data provides a great opportunity. Physical 3D models, such as that installed in the Rangihoua Heritage Park in the Bay of Islands of New Zealand, are tactile, engaging and can be easier to understand than 2D hasher plans. Thus, they have the potential to provide a greater understanding of pā and the surrounding landscape increasing the awareness and education potential of these key sites.

CONCLUSION

The growing availability of data over the coming years coupled with its demonstrated utility for archaeological purposes means LiDAR will see increasing use in New Zealand. It is therefore important in our view to take stock and ask what we can and cannot do with LiDAR data in New Zealand archaeology. Drawing on previous work, the results presented here and experimentation in other regions of New Zealand we believe 1m horizontal resolution LiDAR is capable of detecting sites with varying confidence depending on the intersection of key factors such as site size/preservation, land cover and topography. Given the difficulties encountered in this study within forested high-relief areas it is clear that LiDAR cannot replace traditional field inspection, but can allow a remote first pass of land, which can facilitate targeted survey. At the site level, we believe LiDAR is perhaps best used to determine site extents, and provide greater spatial accuracy to site records.

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