Reconstructing the Pa Bay, New Zealand Archaeological Site: A Spatial Analysis via Google SketchUp®

Ben B. Chiewphasa1,2,3
1. Department of Geological Sciences, University of Canterbury, Christchurch, New Zealand
2. Department of Geosciences, Denison University, Granville, OH 43023 USA
3. Department of Sociology/Anthropology, Denison University, Granville, OH 43023 USA

Abstract
High resolution spatial analysis of the Pa Bay archaeological sites on Banks Peninsula suggests that Maori material culture is influenced by the environment. Pa Bay was inhabited during the Protohistoric Period, a time when European settlers became more prominent throughout New Zealand. Geographical Information Systems, Google SketchUp®, aerial photography, and field observations are tools that were used to accurately model historical infrastructure alongside landscape in a three dimensional context. These tools provide in-depth spatial correlations with functionalities of the pa villages in a site and regional perspective. An archaeological map was georeferenced over aerial photos to accurately pinpoint areas of archaeological interest within a three-dimensional palette. Microclimate analysis through Google Earth® and Google SketchUp® were tools used to derive sunlight for identifying Maori horticultural practices. Three dimensional models of infrastructure, including houses and pas, were created using Google SketchUp®. The Pa Bay site was chosen for habitation because the landscape provided adequate microclimatic conditions and slope orientation for kumara horticulture. The layout of the site suggests possible Maori interest in conservation during a period of intensified deforestation in Banks Peninsula. Although Pa bay is a considered a post-European site, fortification and settlement patterns reflect pre-European contact trends.

Introduction
Specific topographic and landscape features at the Pa Bay archaeological site remind both archaeologists and geologists how spatial analysis is crucial for accurate interpretation of material culture. Artifacts retrieved from excavation can redefine how we think about Maori lifestyle but does not showcase how culture is dictated through the environment. Without research on spatial correlations with Maori infrastructure in Banks Peninsula, the potential for finding new sites is difficult to configure. Nature and Maori spiritual beliefs often go hand in hand; lore and oral histories
are often tied in with why the environment changes a certain way (McGlone, 1989). Thus, a thorough analysis of how Maori culture ties in with the natural sciences can reshape the way we understand the culture of those who arrived in New Zealand for the first time. Spatial analysis under a geoarchaeological lens can ultimately trace back to Maori arrival and reveal how they viewed their new land.

Multi-disciplinary approaches in archaeology of Pa Bay can produce high resolution spatial interpretations of 19th Century Maori lifestyle. Archaeologists (Ghilardi, 2009, Brailsford, 1981, Skinner, 1911) have begun to realize the potential in environmental reconstruction of historical settlements. Excavated materials can aid in the creation of an even greater picture when combined with research involving the Geographic Information System (GIS), computer cartography, and Digital Elevation Models (D.E.M.). 3D modelling programs, such as Google Earth®, have the capability to construct historical structures, showcasing why certain locations were chosen for infrastructure. (Ghilardi, 2009).

Objectives of the study are as follows:

1) Using both GIS and Google Sketch-Up®, simulate an environment where local geology dictates Maori land use and living space.
2) Interpret how slopes correlate with microclimates within a horticultural context.
3) Decipher spatial and ecological trends of Maori settlement at Pa Bay and interpret whether the location reflects a post-European or pre-European style site.

Ultimately, these objectives can be correlated with other Pa sites in the Canterbury region.

Background

Canterbury Archaeology

Archaeological research within the Canterbury region of New Zealand explores themes of environmental change and subsidence (Bassett et al., 2004; McGlone, 1989). Maori archaeological sites alongside slopes typically follow set trends and spatial criteria. Sites situated on foothills, basins, and valleys are typically allocated below 700m above sea level. Occupation sites were concentrated on coastal zones due to preferable climate that resulted in extensive food resources (Challis, 1995). The complex estuarine systems of Horomaka (Banks Peninsula) provided suitable irrigation for horticulture and constant supply of fish and shellfish. Northern and southern Horomaka’s geomorphology contains multiple estuaries and lagoons as a result of ponding streams.
and rivers in front of coastal bars (Challis, 1995). Not surprisingly, archaeological sites, especially pa and pit sites (rua), are clustered throughout the bays at Banks peninsula.

Properties of a Pa Site

Through oral histories and past archaeological data, pas of different tribes throughout the North and South Islands have been identified to have similar characteristics. Pas were first recorded in colonial texts by European settlers in the eighteenth century. They noted how the combination of banks, palisades, terraces, and ditches encompassing the physiography made the pa sites relatively inaccessible (Skinner, 1911). A pa is identified as a fortified infrastructure that incorporates environment natural barriers such as isolated hills and sea cliffs; these cliffs typically are about two hundred and twenty feet above sea level and drop sheer into deep water with about eighty to a hundred feet above surrounding topography (Skinner, 1911). Hillsides are typically carved out, producing terraces where houses were built. The summits of these terraces within Pa fortifications are known as tihi and were occupied by the chief’s family. Tihis are generally areas that provided to most in-depth view of the surrounding coastline; an outlook on other surrounding pas. The largest flat terraces were used as maraes: open plazas where communal meetings were held (Skinner, 1911). Erected wooden palisades protect entire villages or only more specific terraces based on a hierarchal archetype where only the tihi and certain houses are protected.

Fortified sites throughout Canterbury have been documented in different classifications. Some rely more on geologic or topographic features more so than others. One confirmed site and two possible sites rely only on defensive terraces. Four confirmed sites and two possible sites linger on either elevated or flat cliffs, terraces, or islands alongside transverse ditches and banks (Brailsford, 1981).

The basic function of Pas has been heavily debated in prehistorical and protohistorical contexts. Site pattern studies have suggested that in the Late Protohistoric Period (1831), pas have traditionally been seen as citadels, areas of occupation during times of danger. European influences and the decline of tribe-based warfare transformed the function of Pas into areas of permanent habitation. (Orchiston, 1979). Historical accounts reveal the constant threat of musket raids; earthworks were used as reinforced defences (Challis, 1995). Flat land hamlets became more common with the decline of warfare (Orchiston, 1979).

At a site context, the existence of fortification suggests the need of protection for social groups. The population of pa sites are typically small, consisting of 100 to 250 people; an assumption made by number of available terraces and surface area of defended areas (up to 6000 sq. m) (Challis, 1995). Most terrace sites around within Canterbury are small, suggesting small Maori population
distribution throughout. With the assumption that 9 people inhabit a terrace, terrace sites typically hold up to 125 people. One interpretation of small population densities is the regional topographic difference which could potentially limit infrastructure placement (Challis, 1995). Terraces contained rectangular infrastructure, an architectural trend associated with post-European contact. Before then, houses were constructed in pits similar to the round-raised-rim pit at Waikakahi (Trotter 1977).

**Horticulture**

With every settlement, the availability of natural resources determines the success rate of habitation. For pa sites established for permanent habitation, stable sources of food were needed. Doing so required extensive manipulation of the environment. The first recorded European surveys of the 1840s and the 1850s marked a period of heavy deforestation within Canterbury. However, vegetation was still relatively prominent in the Horomaka region (Banks Peninsula; Evison, 1993), inland north Canterbury and small forests scattered throughout foothills and plains (McGlone, 1989).

The basis of this study revolves around how spatial vegetation, in an anthropogenic sense, composes a snapshot of a specific terrain in a specific time in history. The foundations of phytogeomorphology have been implemented to explore success rates of kumara harvest; phytogeomorphology is a study which asks how distribution patterns affect overall vegetation patterns and consistencies (Howard and Mitchel, 1985). Patterns in horticulture can showcase a specific environment’s susceptibility to climate as well as the availability of water, a vital resource for any habitation. These correlations reflect why certain agricultural sites were established. From a global perspective, south facing slopes situated in the north of equatorial regions receive the most sunlight can ultimately affect evaporation patterns (Pianka, 1978). Topography influences the overall distribution of surface and groundwater which, in turn, can correlate with soils and vegetation (Guerra, 1980).

Past geoarchaeological records have found potential in the spatial analysis of agriculture in conjunction with slopes (Bassett et al., 2004). Terraced gardens are easily identified at Pa Bay and play an important part in the sustainability of the villages (Brailsford, 1981). Kumara, one of the major food sources for the Maori and was transported from Eastern Polynesia ~700 years ago. In the marginal southern areas of the Okuora Farm site, 7-20° slopes represent a hillside that receives substantial solar energy. During the planting season months of October to March, the maximum amount of solar energy is pinpointed at the 43° S, a correlation with the 22° and 30° of the Devil’s Knob site. (Bassett et al., 2004). Using Phtolith data, SEM, and geophysical methodology, Maori kumara horticulture geometry reflects the Maori’s knowledge of microclimates dictated by terrain.
Kumara pit locations were chosen based upon whether the area would be suitable for draining soil (Bassett et al., 2004).

The inconsistency of the kumara crop yield rate suggests that precision in site location was necessary for a sustainable garden. Kumara survives drought well but cannot withstand intense variability in weather patterns, especially during the pivotal spring sprouting. Rotting in the winter storage is also of major concern. Due to the probability of high crop failure, kumara has been thought of as a supplementary food supply alongside marine fauna (Challis, 1995). Despite inconsistencies, intensive upkeep had been documented in the early half of the nineteenth century; this was exemplified by the archaeological evidence: substantial findings of garden soils, burrow puts, and earth and stone rows (Challis, 1995). These findings suggest the possibility of European horticulture intervention. Potatoes were traded throughout Horomaka between Maori settlements during the 1830s and 1840s, coinciding with the increase in potato plantations (Anderson 1988).

Other significant horticultural activities included the cabbage tree (ti kouka, Cordyline australis) and the berries of the karakas tree (Corynocarpus laevigatus). Overall, horticulture, especially that of kumara, was unimportant in Maori economy pre-European contact within the Canterbury region but eventually become more prominent. Climatic factors that could affect kumara growth are a possible explanation for the distribution of small populations (Challis, 1995).

Fauna

Archaeological data suggests that the main diet for Maori in the Canterbury region consisted of fish, seals, and shellfish. Elephant seals (Ihupuku), leopard seals (rapoka), and whales were most likely taken when stranded or resting alongside beaches (Stonehouse 1969). Eighteen out of twenty-one harpoon points found throughout the Canterbury region have been found or excavated in Horomaka; it has been suggested to be have been used on dolphins (Challis, 1995). The consistency of finding shellfish made it a prominent source of food for sites throughout Banks Peninsula. The Horomaka contains a wide variety of species exemplified within shell middens; these include: the green edged mussel (kutai), black edged mussel (toritori), cat’s eye (pupu), rock oyster (tiokohatu), whelks (kawari), shield shell (rori), pink paua (mriri), and Cooks turan shell (pupu kaiwhiri) (Challis, 1995). Although the majority of inlets and harbours are suitable for shellfish gathering, the Canterbury Bight to the south is considered unsuitable for marine mollusca. (Challis, 1995). The demise of the Moa resulted in increase of shellfish harvesting alongside rocky shore, open beach, and estuarine environments (Yaldwyn, 1975). Paua and mussel shells were also used as ornaments or containers; some were drilled for suspension. In a geoarchaeological perspective, shell middens are key indicators of dating habitation periods. Radiocarbon dating of the lowest layer of
the Kairaku 13 (NZ 781) shell middens suggests occupation first occurred from the late fifteenth century up to the seventeenth century. Based upon the interpretation of Kairaku, sites on dune belts north of Horomaka relied heavily on shellfish right up to the European contact (Challis, 1995).

Pa Bay

The Pa Bay area consists of one pa (Te Puke-ki-waitaha), a garden, and two villages (Figure 1). Past archaeological work by Murray Thacker at one of the villages suggests that occupation of the bay was between 1820 and 1830 (Brailsford, 1981). With a population of about 250 to 350, the Pa Bay village had to use the landscape in creative ways to sustain itself. Despite having natural barriers etched by volcanic features, archaeological record reveals that food resources were considerably limited. To the northeast of the northernmost village, an exposed dike with splattered scoria deposits extends the peninsula due east; its surface truncates out of the ocean in relation to low tides (Figure 3). This prominent structure is an ideal resting spot for seal colonies which is in close proximity with the village. Past archaeological work suggests that the site contained 60 terraces with rectangular infrastructure scattered. The Brailsford (1981) Pa Bay archaeological map derived from Murray Thacker’s excavation suggests that a wall was built approximately 100m south of the edge of the eastern peninsula, separating a Pa site with terraces from the tribe’s garden and the overall village. Kumara was most likely grown on the terraces. A rectangular pit (K) 3 x 2 m across and 250 meters deep has been interpreted as a kumara storage unit with drainage system extending from the center on the downslope side. The hills behind the Pa were heavily forested. Mudsnails and welk findings suggest frequent fishing trips to the Okains Bay mudflats. Two barracouta hooks found indicate an intricate fishing technique for bottom-feeding fish. Another possible food source is seals: frequent visitors of Pa Bay (Brailsford, 1981).

Changes in Settlement

Trends in post-European contact include the increase in permanent settlement and the disappearance of “seasonal transit camps and specialist activities sites” (Challis, 1995, pp. 55). The permanent style settlement is observed throughout Horomaka with nucleations throughout Kaiapoi, Waihora, and Temuka. When the moa was an important fauna in the Maori diet, seasonal occupation was distributed throughout river mouth locations; this allowed for easy access to both rock shelters and open sites. However, settlement patterns of this sort became less apparently after the moa extinction. Rather, European contact brought about a more sedentary lifestyle as showcased by material culture (Challis, 1995).
Methods

The Brailsford (1981) archaeological map was scanned and digitized onto the ArcGIS© program also overlain and georeferenced over the map (Figure 2). Points of archaeological were digitized and made into separate layers; surface expressions were traced using auto-polygon tool. Elevation values were acquired from Google Earth Digital Elevation Models used for three-dimensional visualization of archaeological sites.

A blank Google Sketch-Up© file incorporated surrounding digital elevation models with models of archaeological infrastructure. Models of the garden terraces, known house sites (8, 9, 10, 13, 24, and 25), trees, the pataka post, and palisades were made using Google Sketch-Up© (Figure 4); dimensions were gathered from both Brailsford (1981) and Skinner (1911). Locations were plotted using the easting, northing, and elevations acquired from the georeferenced Brailsford (1981) map. Models were rotated in conjunction with house surface areas highlighted in the Brailsford (1981) map. In order to compensate for topography outlined by the DEM, it was necessary to alter the dimensions on House Sites 24 and 25 (up to .5 meters); this prevented models from “hovering.”

Using the Shadow Settings module within Google SketchUp©, sunlight distribution, in relation to DEM topography, was recorded on equinoxes and solstices (Figure 7). In each season, sunlight was recorded at sunrise, 10:00 AM, 3:00 PM, and sundown. Contacts between shadow and sunlight were drawn on a screen capture image of the Google SketchUp© palette. The amount of time sunlight hit a 50 m² plane drawn overlying topography of the pa, village, and garden was recorded and graphed. Time was rounded to the nearest half hour. The Lambert equation was used to calculate the incidental solar energy:

\[ I_c = I_{cO} \cos \beta, \]

where “Ic is incident photo flux density or solar energy measured in nm, Ic0 is photo flux energy perpendicular to incident solar energy, and \( \beta \) is the angle between Ic and a line perpendicular to the ground surface (pp. 195, Bassett et al., 2004; Tang, 1997).

Lastly, a table was made to compare and contrast trends of pre-European and post-European contact sites with Pa Bay. Categories include: settlement patterns, fauna, horticulture, fortification, and terraces & houses (Table 1).
Results

Modelling

3D modelling of features at Pa Bay showcased the relationship between horticulture, the surrounding non-anthropogenic environment, and the village. In terms of elevation, the village is highest with an elevation of approximately 67m based upon Google Earth; this estimation most likely has some varying degree of error. With a 360° view, Pa Island, Te Puke-ki-waitaha, the palisades, and the garden terraces are visible (Figure 6). The terraces are approximately 100-105 meters away from both the pa within the fortification as well as the center of the excavated portion of the village. The Google SketchUp© model reveals approximately 15-20° slopes allocated throughout the garden and home terraces throughout Pa Bay. Supply unit is the closest infrastructure in the village to the northernmost ridge, with the drainage system pointing north.

Solar Radiation Distribution

Solar radiation distribution is constant throughout all seasons although with larger variations of shadows in autumn and winter. Solar radiation during sunrise lingers within the edges of the Pa site and the village but does not touch the garden. Sunlight does not directly hit the village immediately with any given sunrise in every season; it lingers to the east. The pa site does not experience direct sunlight during sunrise with the exception of the winter season. By 3:00 PM in every season, a shadow is cast upon the same general eastern edge of the village; this is especially true when nightfall is earlier in the autumn and winter. The garden experiences sunlight by 10am during summer and by noon in the other seasons with winter and autumn being the slowest to allow maximum sun exposure as dictate by surrounding topography. Solar radiation during sunset during spring, autumn, and winter hits the garden before the sun completely sets. Although summer does not dictate this trend, sunset is much later than any other season by setting at 8:03 PM at the 43°41'44.18"S latitude at on December 21. The measurement of sunlight in time reveals that the village experiences the most sunlight whereas the pa site and the garden experience similar trends in solar radiation (Figure 8). Using the Lambert equation decreases the β angle on the 20° slope resulting in more solar energy compared to shallower slopes. The Google SketchUp© model reveals approximately 15-20° slopes allocated throughout the garden and home terraces (Figure 5).

Discussion

A three-dimensional perspective gives more insight as to how the Maori viewed and utilised their environment. Although a topographic map or aerial photography can reveal trends in elevation,
a ground view can simulate what the inhabitants actually saw in their surroundings. Although Pa Bay is an altered landscape, a canopy forest uphill from the terrace gardens are visible from both Te Puke-ki-waitaha and the village. The Google SketchUp\textsuperscript{©} interface’s shadow setting suggests that solar radiation distribution as determined by seasonal changes at the given latitude were taken into account when choosing the site location.

The placement of the K storage unit reveals how the Maori used the infrastructure as a storage space for kumara that was conveniently located in close proximity with the village. Unit K contains a floor drain where a slump in topography would allow gravity to remove excess water while also retaining cold air (Bassett et al., 2004). Although the pit associated with unit K has only been inferred to have been a kumara storage facility, its location implies that it was unlikely to have been for housing or cooking. Rectangular infrastructures instead of pit houses have been documented throughout post-European settlements. Unit K’s close proximity with the village can be a spatial recognition used as an argument to suggest that it was a cooking site; it would have been easy to distribute food. However, K is spatially allocated on the rim of the southern ridge; an unnecessary distance from the village that would require further hauling of kumara and fuel.

Solar radiation trends suggested that the Maori at Pa Bay deliberately chose their site in accordance sunlight hours at any given season. The need for adequate microclimates for kumara growth was necessary for Banks Peninsula because kumara requires > 15°C for 5 consecutive months (Bassett et al., 2004). Site selection was chosen in accordance with the solar angle of incidence alongside in conjunction with other microclimatic conditions suitable for kumara growth: proximity to the sea and shelter from the wind (Bassett et al., 2004). During the sprouting period, kumara is highly susceptible to damage caused by frost during the early periods of growth. As a result, these gardens are chosen to be close to the sea due to lower occurrences of frost (Leach and Leach, 1979). Pa bay follows horticultural trends throughout Banks Peninsula, suggesting consistency in kumara cultivation techniques.

Sunlight distribution in relation to sun angles and slopes potentially reveal everyday life routines of the Pa Bay settlement. After sunrise, sunlight first touches the village and the pa site; this could potentially wake the inhabitants. During the morning hours, the villagers could have attended the kumara before sunlight hits the garden terraces after 10 AM; this allowed for those working on the kumara to avoid enduring direct eye contact with the sun. Due to the required amount of sunlight and warmth required for the 5 month growth timeframe, the maximum amount of sunlight is crucial for success. The terraces’ allocation in a north north-western slope allows for a time gap where people could potentially attend the crop in the morning while allowing for the least amount of disturbance during the rest of the day.
The forest uphill of the terraces creates a stark contrast between an anthropogenic environment and a possible effort in conservation. The forest is reminiscent of the Canterbury region’s landscape before the arrival of the Maori. Beech had dominated in higher and wetter elevations (McWethy et al. 2010). Although deliberate forest fires had been prominent in conjunction with the moa extinction, such acts do not reflect the Maori connection with the environment. Through oral histories, Maori have reflected upon how the environmental phenomena shaped their landscape and overarching culture. For example, an oral history review dictates how the Maori were aware that Banks Peninsula was created by volcanic origins (Dwyer, 2013). Karakia performed by the tohunga for the protection of the sea deity reflects upon how Maori viewed their natural resources and its inhabitants as tapu (Barber, 2003). Archaeologists, on the other hand, interpret Maori occupation of New Zealand as a precursor to extractive opportunism; through foraging efficiency theory, resource depression lower populations of food sources (i.e. moa) (Nagaoka, 2002). Even with the Pa Bay site having been heavily altered by human contact, the proximal forest suggests the importance of how nature is a key component to their lifestyle. The forest could have been an important natural resource for native birds and edible berries. Totara and matai trees would have provided the timber for the palisades, home sites, and canoes (Brailsford, 1981). At any given sunrise, the forest would have been the first to be in contact with sunlight. Although it can be argued that this location was not chosen deliberately for conservation, such a natural phenomenon could have been important for reminding the Maori of their roots amongst continual European settlement; this is especially true with the rise in deforestation throughout the Banks Peninsula for European horticultural practices.

Although Pa Bay represents a post-European contact site, the palisades and local geology reflects a pre-European context. A valley eroded away by a stream creates a potential irrigation system for the gardens. This landscape feature was prominent for pre-European “speciality activities sites” where open sites made moa hunting an easy task (Challis, 1985). These mouths also provided adequate canoe landings which could have been incorporated in site planning of pa bay; canoes have been produced from wood obtained from the forest above the terraces (Brailsford, 1981). Although fortification was rare before 1769, palisades had been constructed adjacent to settlements as a means to provide refuge for a time when tribal conflict was more apparent. The fortification at Pa Bay provided protection for the terrace houses within the fortification. However, there was also an unfortified village 136 meters away from Te Puke-ki-waitaha. If an attack was imminent, villagers would have been forced to run downslope into the fortification. Fortification was more prominent for musket-based conflict while also creating separation with Pakeha. The lack of such protection for the village would then be questionable in a time when palisades were more common. However,
archaeological record shows that not all sites of the post-European context dictate the same trends. The Okaruru Pa at Goughs Bay was situated on an exposed beach front, lacking natural defences; it was built in the early 19th Century after the Kai Huanga feud (Brailsford, 1981; Dwyer, 2013). Although the village was not protected by palisades, high elevation could potentially provide a viewpoint for any approaching danger.

The Pa Bay site planning suggests hierarchal tiers within the settlement. The heart of Te Puke-ki-waikaha housed the chief and was protected by the palisades and the cliffs distributed around a peninsula made from scoria deposits. Just outside of the palisade walls lies the kumara source. The village’s location is even further from the pa site (~136 meters). The terraces are incorporated into the peninsula more so than the village, suggesting that even though the village’s high elevation produces a better outlook, there was lack of natural barriers. On a site scale, an interpretation could suggest that food resources were relatively scarce; the layout prioritizes the need to protect the garden terraces over a substantial portion of the population.

Conclusion

When used in the field of archaeology, Google SketchUp© modelling allows for environmental and landscape factors to be incorporated in the study of material culture. Although past excavations by Murray Thacker have revealed where the areas of horticultural significance were, microclimate analysis through sun angles reflect why certain features were situated in specific locations. Due to the difficulty to grow kumara in Banks Peninsula, topography alongside sunlight distribution had to have been taken into account during site planning. The great care taken into kumara horticulture suggests that it was an important food for the settlement despite an unsuitable climate in the larger scale. Pa Bay’s layout coincides with the post-European model but an unprotected village overlooking a fortified pa site is a trend attributed to pre-European sites. More research focused on finding accurate occupational dates of pa sites throughout the Banks Peninsula could further confirm pre-European and post-European trends. A study on whether the Maori acted upon conservation efforts could reflect their relationship with Pakeha during the 19th Century regarding natural resources. Due to the importance of natural surroundings for the Maori, it is necessary to interpret culture by connecting how material connects with space.

Acknowledgements

I would like to thank Dr. Darren Gravely and Dr. Samuel Hampton for facilitating the Frontiers Abroad program and their critical review of the project throughout its various phases.
would also like to thank Camille Dwyer for editing, aiding in the research process, and providing
thoughtful insight. Frontiers Abroad 2013 crew: Thanks for an experience of a lifetime!

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Figure 1: Map of Banks Peninsula. Pa Bay is shown at the red circle (Hampton, 2012, Figure 1.1)

Figure 2: The georeferenced Brailsford (1981) map overlain over an aerial photo used as a base map on GIS. The red line represents the palisade walls. The Brailsford (1981) is most accurate in topography in close proximity with areas of archaeological interest: house sits and the terraces.
Figure 3: “Curtain of fire.” Remnants of a volcanic episode where basaltic magma rises through a fissure. Spattered scoria deposits can be identified.

Figure 4: Google SketchUp© model of the Pa Bay site. Dimensions of known rectangular house units have been derived from the Murray Thacker excavation (Brailsford, 1981). The Unit K drain depression slopes towards the cliff face allowing for gravity to dictate flow direction.
Figure 5: Hillside slope with garden terraces to on the west of the palisades and the home terraces to the east. Slopes of approximately 15° gradually steepen to 20°. Using the Lambert equation, a slope between 15-20° would provide sufficient amount of solar energy for successful kumara growth, assuming that the Kumara 5-month timetable involving >15°C temperatures is fulfilled (Bassett et al., 2004; Tang, 1997).

Figure 6: Ground view of the village site overlooking Pa Island across the bay.

Figure 7: Aerial view of the Pa Bay site with shadows and sunlight represented in close dates relative to equinoxes and solstices. The generally trend suggests that sunlight hits the pa site and village shortly after sunrise and hits the garden terraces after 10:00AM. Assuming a given day is not too overcast, the garden receives sunlight during the entire afternoon.
Figure 8: A graph displaying relative hours of sunlight each section of the Pa Bay site received each first day of every month. Hours were rounded to the nearest half hour in order to compensate with the variability in shadow shading within the Google SketchUp© shadow setting.
Table 1: A table comparing site Pa Bay site characteristics with pre-European and post-European trends.

<table>
<thead>
<tr>
<th>Site Location &amp; Type</th>
<th>Settlement Patterns</th>
<th>Fauna</th>
<th>Horticulture</th>
<th>Fortification</th>
<th>Terraces &amp; Houses</th>
<th>References</th>
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<tbody>
<tr>
<td>Pa Bay</td>
<td>- Village located on outskirts of fortified pa site&lt;br&gt;- Terrace gardens&lt;br&gt;- 105m away from House Site 13&lt;br&gt;- Village on slope overlooking Pa Island, palisades, garden, and pa site to the north&lt;br&gt;- Highest point: 67m&lt;br&gt;- Population: 250-350&lt;br&gt;- Stream mouth cuts into pa site and garden&lt;br&gt;- Archeological evidence suggests permanent settlement&lt;br&gt;- K unit for food storage&lt;br&gt;- Forest uphill from garden terraces</td>
<td>- Mudsnails&lt;br&gt;- Weka&lt;br&gt;- Seal&lt;br&gt;- Shellfish, especially paua</td>
<td>- Kumara&lt;br&gt;- Potato&lt;br&gt;- K storage unit for kumara storage and drainage</td>
<td>- House Site 13&lt;br&gt;- 136m from Te Puke-ki-waitaha palisades&lt;br&gt;- Village separated from pa site&lt;br&gt;- Fortification contained houses on terraces</td>
<td>- Rectangular buildings supported by terraces&lt;br&gt;- 60 recorded terraces&lt;br&gt;- Building dimensions: 5.8m x 3.4m&lt;br&gt;7.8m x 3.5m</td>
<td>Brailsford, 2009&lt;br&gt;*GIS, Google SketchUp, and Google Earth data</td>
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<tr>
<td>Pre-European Contact Sites</td>
<td>- Specialist activities sites&lt;br&gt;- River mouth location preferable; provided dry camping sites and adequate canoe landings&lt;br&gt;- Relied on seasons; moved around for food in coastal and inland territories&lt;br&gt;- Evidence of some permanent sites in archaeological record; repeated oven uses and sheltered local climate</td>
<td>- Moa most sought after&lt;br&gt;- Birds: pigeon, tui, kaka, kiwi, kakariki&lt;br&gt;- Dog&lt;br&gt;- Marine mammals&lt;br&gt;- Inland activities: fishing and birding</td>
<td>- Possibility of kumara growth during warmer climates of the 13th and 14th century&lt;br&gt;- Tree cropping: cabbage tree, karaka tree</td>
<td>- River mouth provided easy access to open sites; lack of fortification not of concern&lt;br&gt;- Fortification rare before 1769&lt;br&gt;- Palisades constructed adjacent to settlements, providing refuge</td>
<td>- Inland activities: stone quarrying for infrastructure and tools&lt;br&gt;- Round huts&lt;br&gt;- Houses constructed in pits</td>
<td>Anderson, 1986&lt;br&gt;Challis, 1985&lt;br&gt;Grant, 1994&lt;br&gt;Leach, 1969&lt;br&gt;Trotter, 1975</td>
</tr>
<tr>
<td>Post-European Contact Sites</td>
<td>- Small populations&lt;br&gt;- More scattered&lt;br&gt;- More focused in Kaapoi, Horomaka, and Taumutu&lt;br&gt;- Closer to marine fishing and shell fishing</td>
<td>- Shellfishing most prominent source of food&lt;br&gt;- Fish&lt;br&gt;- Seal&lt;br&gt;- Whales&lt;br&gt;- Shellfish&lt;br&gt;- Dolphin&lt;br&gt;- Dog</td>
<td>- First recorded kumara cultivation taking place in early 19th Century&lt;br&gt;- Kumara grown despite unsuitable conditions in Canterbury</td>
<td>- Fortification common in sites with or without geological or environmental barriers&lt;br&gt;- Permanent&lt;br&gt;- Semi-permanent</td>
<td>- Small rectangular infrastructure</td>
<td>Challis, 1985&lt;br&gt;Leach, 1969</td>
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