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The first accurate and precise calendar dating of New Zealand Māori Pā, using Otāhau Pā as a case study.

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ABSTRACT

This research investigates the potential of radiocarbon wiggle-match dating of palisade posts to provide precise and accurate calendar ages for Māori pā (forts), using Otāhau Pā in the inland Waikato region, New Zealand, as a case study. Even though pā are a dominant element of the pre-European North Island archaeological landscape, they are poorly understood archaeologically, with systematic investigations hampered by the relative lack of precision in radiocarbon dating within the context of New Zealand's comparatively short prehistory. Using the Southern Hemisphere calibration curve SHCal13, we determine wiggle-match calibrated ages for three palisade posts, using different sampling resolutions to determine the cost-effectiveness of the method. We also test the accuracy of the wiggle-match by obtaining new Southern Hemisphere calibration data from known calendar-age kauri.

KEYWORDS: Māori pā, radiocarbon dating, dendrochronology, calibration.

1. Introduction

The archipelago of New Zealand was the last significant landmass on Earth to be colonized when Polynesians voyaged from central-eastern Polynesia in the 13th century AD (Anderson, 2016a: 52-55). For centuries Polynesians had settled island archipelagos across the Pacific, their culture optimized for successful habitation of small, tropical islands supporting limited native and introduced foods compared to extensive marine sources. The initial settlers in New Zealand found very large

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islands with continental geology and abundant natural resources – large fauna (the flightless moa and pinnipeds) and plentiful fish stocks. But they were also confronted by a novel, temperate climate unsuited to their customary agricultural system. In many ways the history of Polynesian settlement of New Zealand is about the adaptation of a tropical culture to this temperate climate and comparatively massive landscape.

New Zealand's archaeological landscape is dominated by a class of fortified 'villages' known as *pā*. Approximately 7000 *pā* have been recorded (Fig. 1 inset) and they vary considerably in size and complexity, from a few hundred square metres with a simple enclosing earthwork to others of several hectares and multiple layers of defences. The distribution of these sites is distinctly graded from north to south with most found in and around the main horticultural districts in the northern half of the North Island. The association suggests that most *pā* fulfilled functions arising from horticulture, both directly by accommodating and protecting seed tubers and harvests, and indirectly as fortified villages required to defend tracts of cultivable lands in conditions of increasing population density after about AD 1500.

Understanding the development and chronology of *pā* is critical to understanding the evolution of Māori society out of its East Polynesian ancestry. The apparent relationship between intensifying horticulture and *pā* construction is part of a more complex set of changes that also encompassed changes in social organisation from family and clan based structures towards multi-clan polities. After about AD 1500 there was also a substantial re-ordering of territorial ownership involving numerous and often long internal migrations. Much of the evidence for these changes comes from chiefly genealogies and tribal histories although these have yet to be analysed comprehensively at regional or greater scales of analysis. As *pā* sites were often the loci of conflicts involved in the changing political landscape, the comparison of traditional with archaeological evidence depends upon robust chronologies (Anderson 2016b).

Yet, despite their dominance in the North Island archaeological landscape, surprisingly few *pā* have been studied spatially, diachronically or even with reference to their internal organisation. The earliest attempt at systematic examination was by Best (1927) in his ethnography *The Pā Māori*. Later archaeological research focussed upon the defensive structures of individual *pā*, but often the construction sequences derived could not be linked coherently by structural typology or radiocarbon dating into a diachronic framework (e.g. Kauri Point Pā – Ambrose, 1962; 1967; Green, 1978). Locational analyses of *pā* (Irwin, 1985, 2013; Sutton, 1993; Sutton et al., 2003) have also been constrained by relatively few radiocarbon dates; the inherent lack of precision limiting establishment of diachronic relationships between and within sites.

At a national scale, Groube (1970) used demographic models to hypothesize that *pā* building developed exponentially and that as much as half were constructed in the last 100 years of prehistory. However, dating *pā* as a national phenomenon has been confined to a single study by Schmidt (1996). This was focused upon determining the calendar age for initial *pā* construction using indirect ¹⁴C dating of associated middens. Schmidt accumulated a total of 317 published radiocarbon dates that were related to *pā*. He then applied a series of discard protocols aimed at establishing a high degree of chronological hygiene, which resulted in the discard of 81% of dates (cf Anderson and McGovern-Wilson, 1990; Anderson, 1991). Schmidt concluded that construction of *pā* had begun by 1550 AD or perhaps by 1500 AD.

A significant contributor to the uncertainty of Schmidt's conclusion is the

relative lack of precision in radiocarbon dating within the context of New Zealand's comparatively short prehistory, approximately 500 years between first settlement and European contact. The lack of precision is associated with variation in the concentration of atmospheric ^{14}C that occurs largely as the result of fluctuations in the solar wind and changes in the geomagnetic field strength, that modulate galactic cosmic ray fluxes reaching the Earth's atmosphere. The variations in atmospheric ^{14}C (known as 'wiggles') cause divergence between radiocarbon and calendar years, requiring radiocarbon ages to be corrected using a calibration curve (e.g., SHCal13 for correcting Southern Hemisphere (SH) ^{14}C dates, Hogg et al., 2013a) which for the last millennium is created by ^{14}C dating known-age SH tree rings. The calibration curves show extended periods of uniform atmospheric ^{14}C levels (^{14}C plateaus) e.g., at AD 1100, 1350, 1550, and 1750. Consequently, any high precision ^{14}C dates derived from archaeological material that coincide with a plateau are transformed into low precision calendar age ranges, inhibiting understanding of prehistoric events.

Here, we offer a solution to the lack of precision by using the wiggles in the radiocarbon calibration curve to establish accurate and precise calendar ages for pre-contact age cultural material. For the first time, we present high resolution wiggle-match calibrated ages, derived from accelerator mass spectrometry (AMS) radiocarbon analysis of three *in-situ* palisade posts, for a wetland archaeological site, Otāhau Pā in the inland Waikato region. We examine different sampling resolutions to determine the cost-effectiveness of the method. We also test the accuracy of the wiggle-matches, by measuring ^{14}C levels in known dendro-age New Zealand kauri, allowing comparison with the data composing SHCal13, used in the wiggle-match process.

1.1. High resolution calendar age dating by radiocarbon wiggle-matching

Radiocarbon wiggle-match dating refers to the fitting of several ^{14}C data points of unknown calendar age from a constrained sequence (e.g., tree-rings) to a ^{14}C calibration curve. Matching of the data to the wiggles in the curve not only significantly improves the precision of the calibration but also reduces the influence of minor offsets (Bronk Ramsey et al., 2001). Galimberti et al. (2004) showed that highly precise and accurate calendar ages could be obtained from archaeological timbers using ^{14}C wiggle-matching. Wiggle-match dating has not yet been applied directly in New Zealand archaeology but it has been used in calendar age dating of two important New Zealand eruptions (tephras): the Kaharoa eruption using a carbonized log (Hogg et al., 2003) and the Taupo eruption using trees felled by the eruption (Sparks et al., 1995; Hogg et al., 2012).

There are various requirements for a successful wiggle-match:

- Wiggle-matching works best with tree-rings that are formed reliably each year.
- Ideal species have clear ring patterns with minimal wedging.
- Ideally ring widths should be established from multiple trees and cross-checked to identify potentially missing or false rings in individual trees.
- Bark (or at least sapwood) must be present, or missing outer rings will make the calendar age too old.
- The samples need to have a sufficient number of growth rings (generally >40) to provide a distinctive ^{14}C signature recognizable in the calibration curve.
- The wood must be reasonably well preserved, to avoid modern contamination

- (percolating soluble humic and fulvic acids) making the ^{14}C ages too young.
- Context is critical. There needs to be a close association between the samples dated and the structure/event they are associated with.
 - Although the success of the wiggle-match can be judged by calibration software (e.g., OxCal; Bronk Ramsey et al., 2001) level of agreement indices (defined in Table 4) and the magnitude of the standard error, the accuracy of the wiggle-match may be compromised either by laboratory measurement biases or calibration curve errors. The accuracy of the wiggle-match can only be assessed by measurement of known-calendar age tree-rings, to check the alignment of the measuring laboratory with the official calibration curves.

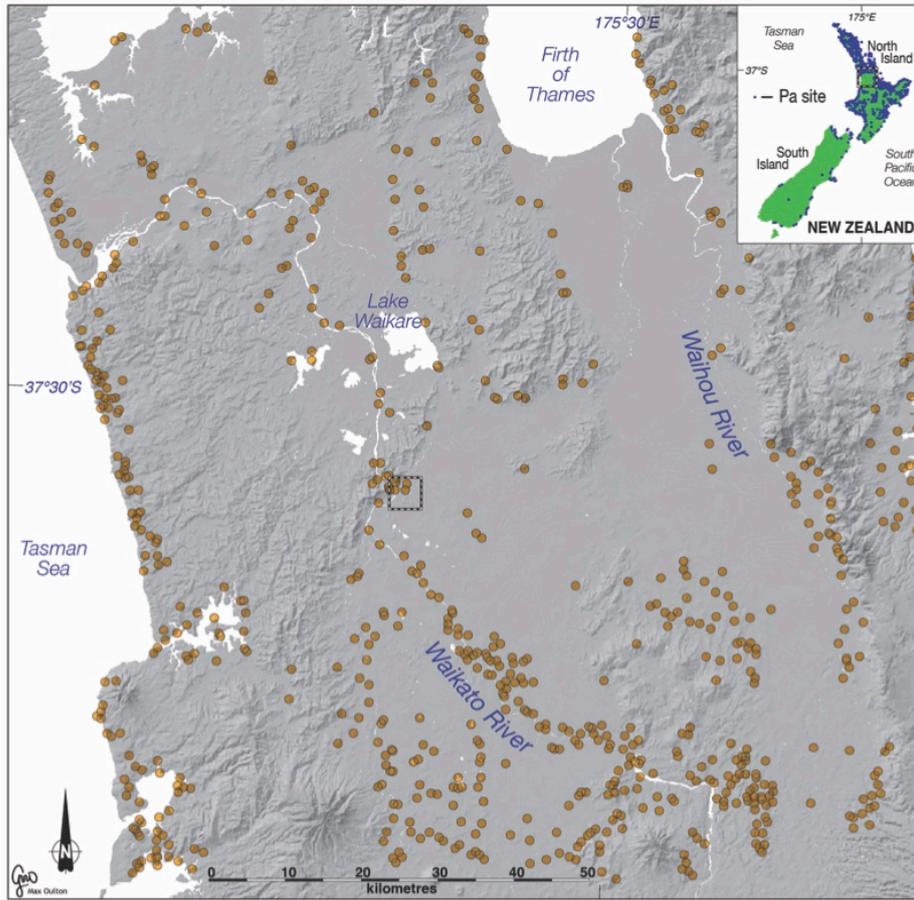
In the context of archaeological sites such as pā, suitable wooden items as characterized above need to be preserved. Bark-covered palisade posts derived from suitable species and preserved *in-situ* in adjacent swamps or backwaters are one possibility as these should provide reliable calendar ages for construction and/or occupation of a pā. If possible, more than one post should be dated in case palisades were periodically re-built. In contrast, carved wooden implements (e.g., wooden staffs) even having outermost rings, may not accurately date pā if the implements have been handed down between generations.

1.2 *Otāhau Pā in its Waikato context*

The Waikato contains many wetland or “swamp” pā (fortified villages found in swamps, lakes and on rivers, Fig. 1a) with access to numerous navigable waterways and resource-rich delta-like environments (Pick 1968). It was these wetland pā that first attracted archaeologists to the Waikato region, notably to palisaded pā at Lake Ngaroto (Shawcross, 1968) and Mangakaware (Bellwood, 1978). The focus of pā in the Waikato archaeological landscape is strongly toward lakes and waterways (Cassells, 1972a; 1972b) reflecting their value both for resources and transport.

Otāhau is one of five identified pā in the environs of Taupiri (Fig. 1b) which was a strategically important locality for Māori. It is on a large bend where the Waikato River passes through a gap between the Taupiri and Hakarimata Ranges, and is joined by the Mangawhara tributary which provided a strategically important link east to the Hauraki region. About 8 km upstream from Taupiri the Waipa River, the main tributary of the Waikato, facilitated access south into the King Country and harbours at Kawhia, Aotea and Raglan (Whaingaroa). Otāhau Pā and its neighbours, except Taupiri Kuau Pā, are located where navigable waterways merge and provide both riverine resources (eels were a major resource here until the last 50 years) and rich horticultural soils on the banks of the Waikato River and the Komakorau Stream (Fig. 1b).

A



B

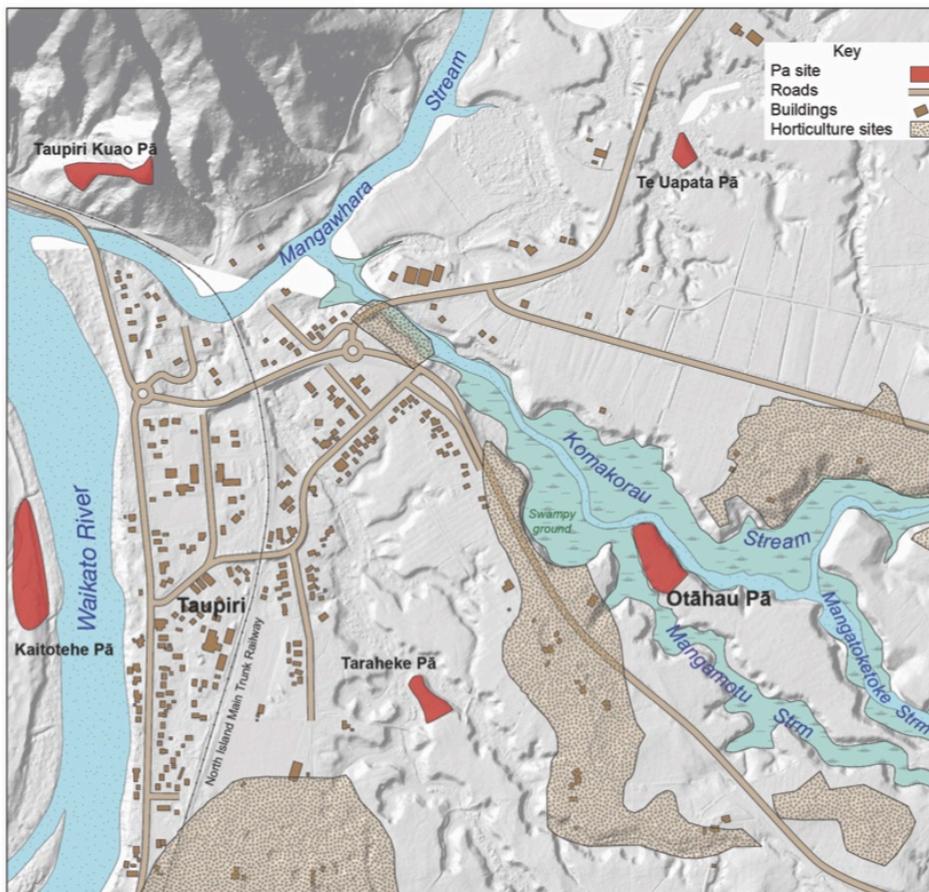


Fig. 1. (a). The distribution of pā sites in the Greater Waikato, North Island of New Zealand, (b) Pā sites in the Taupiri region, shown as a rectangle in Fig. 1a.

Otāhau is a typical Waikato river-edge pā. These are often situated on promontories at the junctions of waterways but also overlook stretches of the Waikato River. The sites are defended by earthworks varying from simple, single transverse ditches to pairs of ditches or a ditch in a broadly rectangular plan.

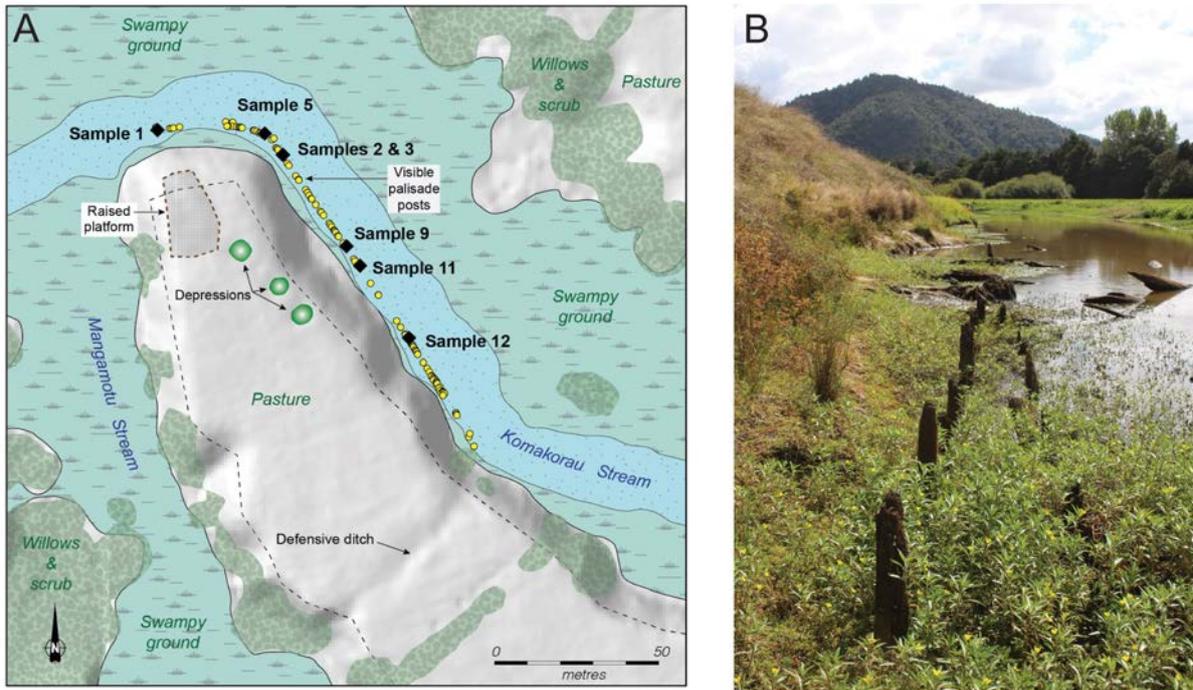


Fig. 2. (a). Otāhau Pā, Taupiri. Posts extracted for analysis shown in black (b) Section of double row palisading preserved in the Komakorau Stream, looking north-west towards Taupiri Mountain.

Otāhau Pā (Fig. 2a, b) is defended by a single transverse ditch that crosses the land dividing the Komakorau and Mangamotu streams. The pā is 150 m long, from the northern end of the promontory to the transverse ditch and is the largest of the local pā, with 6000 m² within its defences. The ditch is visible as a distinct linear depression approximately 1 m deep, 2 m wide and 51 m long. The interior of the pā is flat with a slight rise at the northern end. The edge of the pā descends steeply about 5 m to water-level. The only features visible within the level platform are two terrace-like areas on the slightly raised ground at the northern tip of the pā and three depressions interpreted as the visible remains of storage pits.

A series of palisade posts is visible from the north-western tip of the pā and along its north-eastern side as far as the transverse ditch (Fig. 2a, b). The posts are in the water about 1-2 m from the bank. They form a distinct linear feature that is visible as a single line but also becomes a double row in places. There are other items of wood visible in the river bed close to these and some appear to have been posts that have fallen over. The height of the posts is variable and they are more or less seasonally exposed above water level. There are 100-120 visible posts but others were encountered below water-level during sampling. The Mangamotu

Stream margin of Otāhau Pā is silted-up and has a dense cover of reeds and other vegetation. It was not possible to determine if posts were present there, but it is likely.

2. Methods

2.1. Sample collection

Seven palisade posts were extracted from the western edge of the Komakorau Stream (Table 1, Fig. 2a, Fig. 3) and sectioned. Prior to obtaining ring counts for each post and radiocarbon analyses of selected samples, the wood was frozen to limit degradation or growth of mould between collection and sampling. The transverse surface of each sample was prepared for further analysis by using a power hand-sander and wet-and-dry sandpaper to produce a polished surface.



Fig. 3. Palisade post 005, Otāhau Pā. This post (*Prumnopitys ferruginea*, miro) was ~1.6 m long and 165 mm wide with bark remaining, with a chiseled base.

Physical properties of the posts are given in Table 1.

Table 1

Details of sampled round-wood palisade posts from Otāhau Pā.

Notes: Miro round-wood posts in bold (003, 005, 009) chosen for tree-ring analysis and radiocarbon wiggle-match dating. Ring counts for 001, 002, 011 are best estimates due to ring anatomy. Rings were not clearly visible on 012.

Sample nr.	Species	Nr. of rings	Post diameter (cm)	Post length (cm)	Depth into sediment (cm)
001	<i>Weinmannia racemosa</i> (kamahi) or <i>Weinmannia silvicola</i> (towai)	~70	14	202	125
002	<i>Streblus heterophyllus</i> (turepo)	~80-100	11.2	75	57
003	<i>Prumnopitys ferruginea</i> (miro)	67	11.0	127	100
005	<i>Prumnopitys ferruginea</i> (miro)	62	16.5	163	110
009	<i>Prumnopitys ferruginea</i> (miro)	62	14.4	162	120
011	<i>Kunzea ericoides</i> (kanuka)	~70	11.5	161	115
012	<i>Melicytus ramiflorus</i> (mahoe)	-	14.2	122	70

2.2. Tree-ring analysis

Ring counts were obtained from each sample, except for 012 where the growth rings were poorly defined (Table 1). All samples retained bark or the bark-edge surface.

Of the five species, the miro samples met the criteria for radiocarbon wiggle-matching. Miro has clear, sharp annual rings (Dunwiddie, 1979), and each sample had >40 rings and retained the outermost ring below the bark. However, incomplete rings which narrowed and disappeared on part of the circumference were observed on all samples, and false rings were also noted. Therefore, to ensure accurate ring counts, the ring widths of three radii per sample were measured using a set-up comprised of a travelling stage and binocular microscope linked to a computer. Tree sequences were made for each sample by averaging the three radii after they had been reconciled (Table 2). The sequences were then compared against each other visually and statistically to cross-check the ring width patterns.

Table 2

Details of the Otāhau pā miro roundwood post samples

Sample nr.	Span (ring nrs)	Pith	Bark	Nr. of samples dated	Ring nrs of Samples dated
003	1 to 67	Y	Y	2	Rings 67 to 58 & 12 to 3
005	1 to 62	Y	Y	12 (contiguous)	Rings 62 to 3
009	1 to 62	Y	Y	2	Rings 62 to 53 & 12 to 3

2.3. Sampling for radiocarbon analysis and dating strategy

Because the miro posts have only ~60 rings, we used high-resolution 5-ring sampling to improve the likelihood of a successful wiggle-match by increasing the calendar interval between the innermost and outermost samples. Each block was sampled using a scalpel blade to cut or shave the rings and the wood chips placed in

a labelled plastic vial. Cutting was carried out under a low-power microscope to ensure that ring boundaries were not crossed between sections. Twelve contiguous 5-ring samples were obtained from the largest post, 005 (16.5 cm in diameter). Sampling for the miro posts 003 and 009 was restricted to the outermost (youngest) and innermost (oldest) pair of 5-ring blocks (Table 2). Differential sampling enables us to determine cost-effectiveness of the method, whilst wiggle-matching all three posts enables us to test the assumption that the three miro posts were contemporary and made from trees felled at the same time. It is quite possible that the assumption of a single phase is incorrect and that the palisade posts were from different phases, e.g., repairs or replacements, and therefore not overlapping in time.

Fine shavings (<0.5 mm thick) were subsampled from the 5-ring wood blocks, taking care that all five rings were sampled more or less equally, producing samples of 20–40 mg for AMS dating. The wooden shavings were pretreated to isolate α -cellulose, the fraction least susceptible to modern contamination by percolating humic or fulvic acids. The pretreatment sequence includes: solvent extraction using acetone, acid-base-acid (ABA) treatment, isolation of holo-cellulose using acidified NaClO_2 , and a final base-acid extraction.

The α -cellulose samples were combusted and graphitized in the University of Waikato AMS laboratory, with $^{14}\text{C}/^{12}\text{C}$ measurement by the University of California at Irvine (UCI) on a NEC compact (1.5SDH) AMS system (Southon et al., 2004). The pretreated samples were converted to CO_2 by combustion in sealed pre-baked quartz tubes, containing Cu and Ag wire. The CO_2 was then converted to graphite using H_2 and an Fe catalyst, and loaded into aluminum target holders for measurement at UCI.

2.4. Methodology for assessing the accuracy of the Otāhau Pā palisade post calendar age dating

To obtain a truly accurate wiggle-match calendar age, the measured ^{14}C concentrations from the miro posts and the known-age calibration curve ^{14}C data both need to reflect atmospheric ^{14}C levels identically during the time of growth. Bayliss et al., (2016) recently tested the accuracy of wiggle-matching known dendro-age Medieval oak timbers against the Northern Hemisphere (NH) calibration curve IntCal13 (Reimer et al., 2013). They found three of the five, long (120–207 years) wiggle-matches produced inaccurate results. Although they did not speculate about the causes of the inaccuracies, clearly the AMS laboratories doing the oak timber analyses are not accurately reproducing the ^{14}C dates composing the calibration curve. This may be due to offsets in either IntCal13 (NH geographic offsets or laboratory analytic offsets) or offsets in the laboratories undertaking the oak analyses.

The international calibration curves SHCal13 (Hogg et al., 2013a) and IntCal13 (Reimer et al., 2013) for the last millennium contain tree-ring ^{14}C data from different geographic locations within each hemisphere. SHCal13 for example, contains data from New Zealand, Chile, Tasmania and South Africa. A geographic offset (cf McCormac et al., 1995; Nakamura et al., 2013; Hong et al., 2013; Hogg et al. 2013c) within the SH is therefore possible.

Laboratory offsets, or inter-laboratory differences, have been commonly reported and can result from differences in pretreatment regimes extracting variable wood components, and/or in measurement processes. For example, Hogg et al., (2013b) in a study comprising 12 contiguous decadal kauri samples analyzed by five

carbon dating laboratories reported initial inter-laboratory offsets from weighted mean values of up to 41 ^{14}C years. Further investigations discovered inconsistencies in both pretreatment regimes and measurement processes which once rectified, resulted in negligible offsets.

Therefore, to determine if the Waikato AMS laboratory has an analytic offset compared with the SHCal13 calibration curve (which will influence the accuracy of the miro post wiggle-matching), we measured ^{14}C levels by AMS in known dendro-age 5-ring blocks of New Zealand kauri (see section 3.3 below for details).

3. Results

3.1. Tree-ring analysis

To the best of our knowledge, the dendrochronological potential of miro is largely untested, and there are no known tree ring chronologies for this species. It is expected that the growth patterns of each post would be similar and the ring sequences would overlap with a common end date. All posts were from the same structure, and known from radiocarbon evidence to be contemporary (see 3.2 below), with the trees felled at the same time. However, statistical and visual comparison of the tree ring sequences did not establish secure cross-dating. This could be a consequence of the young age of the trees (all <67 years) and/or an absence of a strong common signal between trees.

Despite the absence of secure crossmatching, the rings counts for each post are considered reliable based on intra-tree analysis. Two further observations were made from the tree-ring analysis. First, it was noted that the posts were made from different trees species but of a similar age. Second, the final ring at bark-edge on all three miro samples was relatively wide compared to the year prior. This may suggest felling late in the growing season, although additional work is required on the seasonal growth of miro to confirm this.

3.2 Radiocarbon dating and wiggle matching of the miro posts

The ^{14}C dating results for the 3 miro posts are given in Table 3.

Table 3.
Otāhau Pā miro round-post ¹⁴C dating

Sample nr.	Wk lab nr.	Ring nr. (first – last)	mid-ring nr.	¹⁴ C age (yrs BP ± 1σ)
003/7-3	43743	3 - 7	5.5	166 ± 14
003/12-8	43742	8 - 12	10.5	127 ± 16
003/62-58	43741	58 - 62	60.5	221 ± 20
003/67-63 (sapwood)	43740	63 - 67	65.5	201 ± 17
005/7-3	43759	3 - 7	5.5	142 ± 15
005/12-8	43758	8 - 12	10.5	139 ± 15
005/17-13	43757	13 - 17	15.5	152 ± 16
005/22-18	43756	18 - 22	20.5	165 ± 14
005/27-23	43755	23 - 27	25.5	183 ± 15
005/32-28	43754	28 - 32	30.5	193 ± 19
005/37-33	43753	33 - 37	35.5	246 ± 18
005/42-38	43752	38 - 42	40.5	238 ± 14
005/47-43	43751	43 - 47	45.5	225 ± 19
005/52-48	43750	48 - 52	50.5	204 ± 15
005/57-53	43749	53 - 57	55.5	193 ± 15
005/62-58 (sapwood)	43748	58 - 62	60.5	226 ± 15
009/7-3	43747	3 - 7	5.5	158 ± 14
009/12-8	43746	8 - 12	10.5	123 ± 14
009/57-53	43745	53 - 57	55.5	194 ± 16
009/62-58 (sapwood)	43744	58 - 62	60.5	211 ± 15

The miro post ¹⁴C results were wiggle-matched against SHCal13 (Hogg et al., 2013a) using a Bayesian approach which combines the ¹⁴C dates with the known calendar interval between the dated tree-rings (determined by tree-ring analysis). We used the calibration software OxCal 4.2 (Bronk Ramsey et al., 2001) and employed outlier analysis (Bronk Ramsey, 2009) using Outlier_Model ("SSimple", N(0,2), 0, "s") and {Outlier, 0.05} (which allows individual samples - roughly 1 in 20 - to be outliers) to down-weight outliers. Calibrated ages are reported here as calendar years AD. Results for the wiggle-matches using various combinations of samples are given in Table 4 and shown in Fig. 4.

Table 4
Summary of wiggle-matching the miro palisade post ¹⁴C data against SHCal13

Post nr	n*	Post mid-ring numbers*	Acomb% {An%, n}§	Calibrated mean age (cal AD ± 1σ)	Calibrated 95% prob. range (cal AD)
005	12	5.5 – 60.5	118.4 {20.4, 12}	1769 ± 2	1765 - 1775
003	4	5.5 & 10.5; 60.5 & 65.5	94.9 {35.4, 4}	1768 ± 11	1752 - 1785
005	4	5.5 & 10.5; 55.5 & 60.5	95.1 {35.4, 4}	1767 ± 9	1750 - 1781
009	4	5.5 & 10.5; 55.5 & 60.5	79.4 {35.4, 4}	1767 ± 14	1748 - 1780
003	2	5.5 & 65.5	85.5 {50, 2}	1778 ± 45	1737 (90.2%) 1803 1869 (2.4%) 1877 1933 (2.0%) 1940 1950 (0.8%) 1953
005	2	5.5 & 60.5	103.5 {50, 2}	1768 ± 15	1746 - 1786
009	2	5.5 & 60.5	105.0 {50, 2}	1766 ± 22	1738 - 1787

* See Table 3

§ The OxCal Acomb value is used as an indicator of the quality of the wiggle-match (higher value is better). Threshold is exceeded if Acomb > An. An = 1/√(2n).

The model for the 12-sample post 005 (Fig. 4c) has good overall agreement ($A_{\text{comb}} = 118.4\%$, $A_n = 20.4\%$, $n = 12$) and estimates the final ring of the sequence to have been formed in AD 1765-1775 (95% probability, miro post 005; Table 4). Fig. 5 shows the positioning, as determined by the wiggle-match, of each of the twelve ^{14}C dates for 005. The distribution of ^{14}C ages is unusual as the oldest ^{14}C dates are derived from the outside youngest rings (largest ring numbers), with the younger ^{14}C dates obtained from the center rings (smallest ring numbers), which represent the first growth of the trees. This is because the ^{14}C calibration curve has a reverse slope from ~AD 1715–1750. The strong and rapid changes of slope in the calibration curve for this time interval strengthen the wiggle-match and produce narrow calibrated age ranges. The wiggle-match for post 005 (Fig. 4c) used 12 contiguous 5-ring samples encompassing 60 of the 62 available rings. The high sample density has resulted in a precise calendar age, with a 68% probability error of only ± 2 years (Table 4).

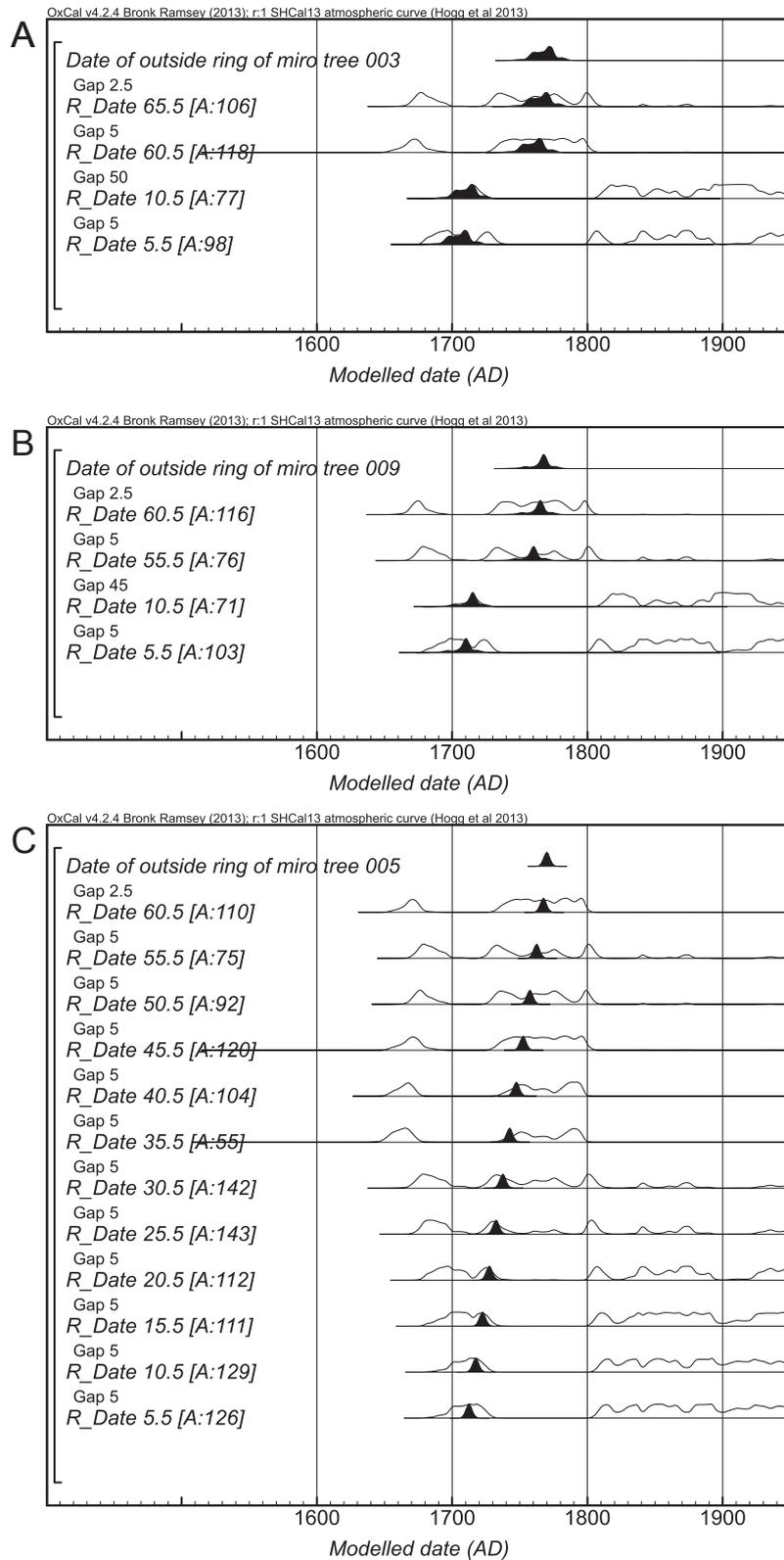


Fig. 4. Probability distributions of dates from miro posts (a) 003, (b) 009 and (c) 005. The distribution represents the relative probability that an event occurs at a particular time. For each of the dates, two

distributions have been plotted: one in outline, which is the result of simple ^{14}C calibration, and a solid one, based on the wiggle-match sequence. The distribution “Date of outside ring of miro tree x” is the estimated date when the tree was felled.

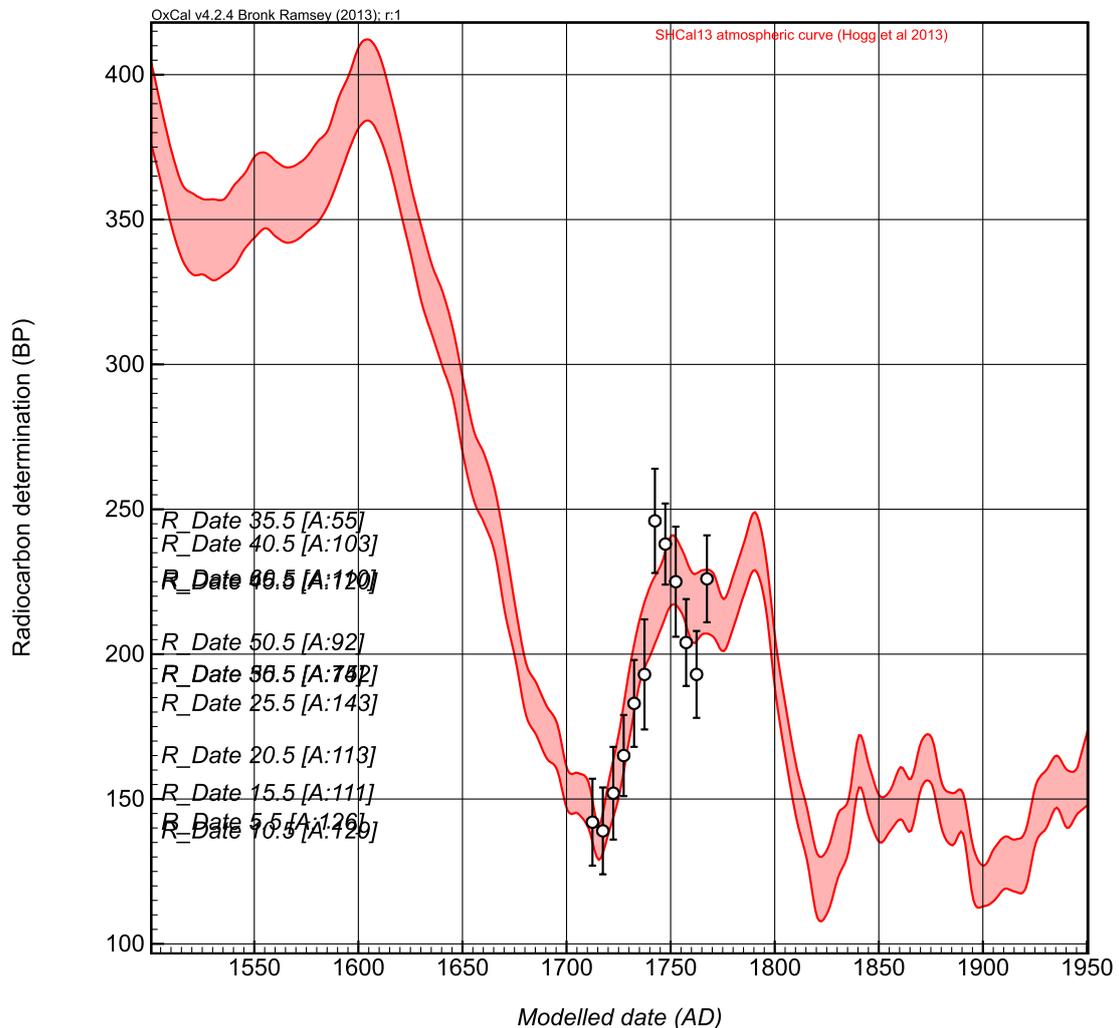


Fig. 5. Miro post 005 radiocarbon ages (1σ errors) as fitted onto the SH calibration curve SHCal13 by wiggle-matching.

Posts 009 and 003 (Fig. 4a, 4b) were dated to determine if the miro trees were felled at the same time and to investigate the levels of precision associated with employing lower, more cost-effective, sampling. Wiggle-match results comprising the two innermost 5-ring dates and two outermost 5-ring dates are given for all three posts in Table 4. Despite the restriction to four dates per post, for this time interval, the wiggle-matches are still accurate and reasonably precise, with 68% probability errors of 9–14 years. There is a significant reduction in precision when only two 5-ring samples are dated per post (Table 4) but even these errors, which range from 15–45 years (68% probability) can be significantly lower than those derived from single dates.

All three miro posts have the same calibrated ages indicating the trees were felled at approximately the same time.

3.3 The accuracy of the Otāhau Pā palisade posts calendar age dating

Radiocarbon levels in known dendro-age 5-ring blocks of the kauri sample SPC002 were measured in duplicate for the interval AD 1650–1829, which encompasses the calibrated age ranges determined by wiggle-matching the miro posts. Although the known dendro-age kauri ^{14}C data follow the shape of the SHCal13 curve closely (Fig. 6), the kauri data are slightly older, with a mean offset to SHCal13 of 12.7 ± 1.1 ^{14}C years. The reasons for this are unknown but are currently being investigated. Despite the offset, a wiggle-match of the 3 miro posts against the SPC002 kauri measurements instead of SHCal13, produces slightly younger but statistically indistinguishable calendar ages (Table 5). We consider the palisade post calendar ages derived from the SPC002 curve to be the more accurate, with all samples containing 5 annual rings and analyzed in the same laboratory.

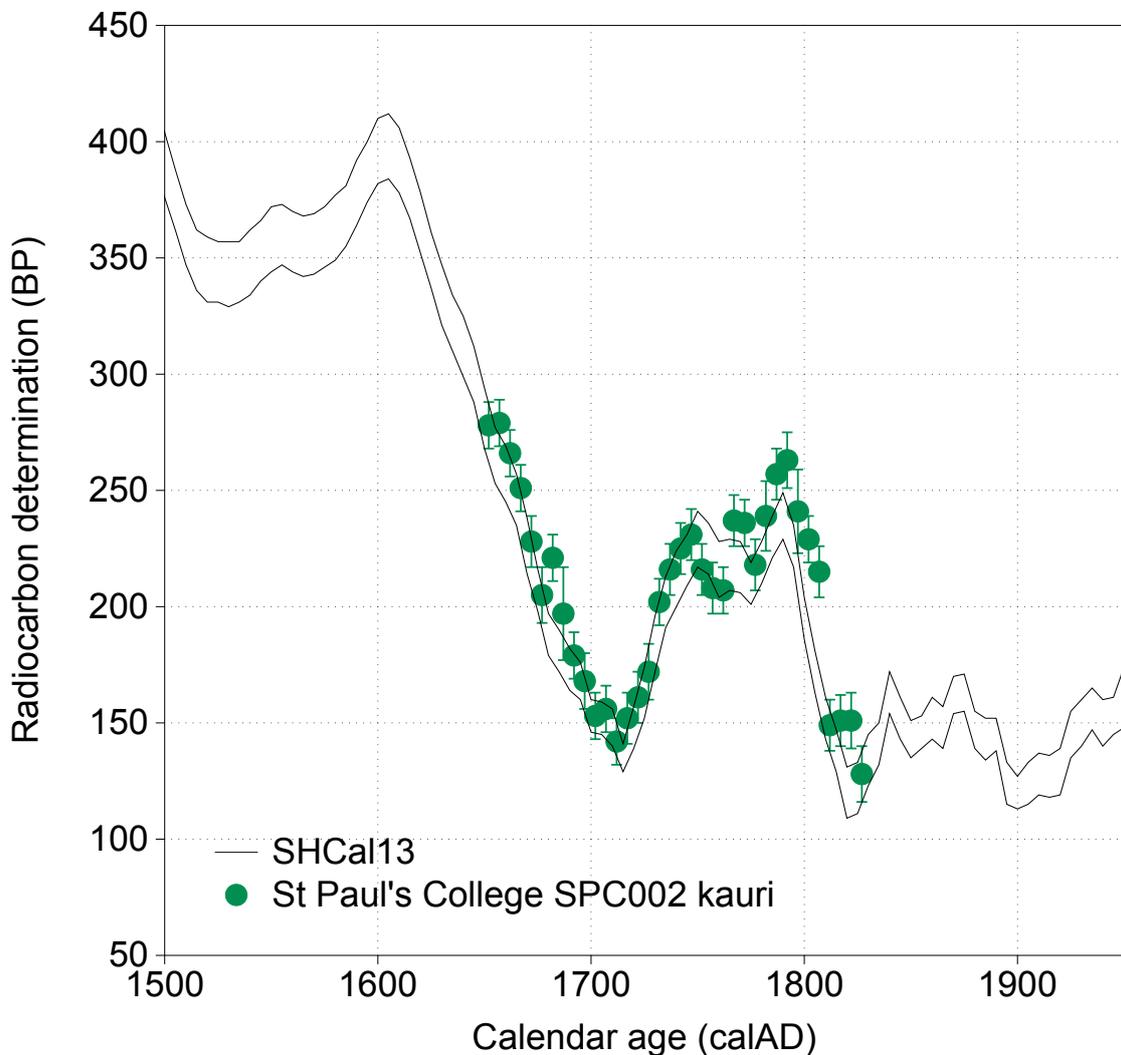


Fig. 6. Five-ring known dendro-age New Zealand kauri measurements from kauri SPC002 plotted against the 1σ SHCal13 envelope (Hogg et al., 2013a)

Table 5

Agreement data for comparison of unknown-age miro data against the known dendro-age kauri data ("SPC002")

Post nr	n *	Post mid-ring numbers	Acomb% {An%, n}§	Calibrated mean age (cal AD \pm 1 σ)	Calibrated 95% prob. range (cal AD)
003	4	5.5 & 10.5; 60.5 & 65.5	105.3 {35.4, 4}	1765 \pm 8	1754 (81.7%) 1774 1776 (13.7%) 1785
005	12	5.5 – 60.5	195.0 {20.4, 12}	1767 \pm 2	1763 (95.4%) 1771
009	4	5.5 & 10.5; 55.5 & 60.5	134.8 {35.4, 4}	1761 \pm 15	1682 (1.6%) 1687 1751 (93.8%) 1773

* See Table 2

§ The OxCal Acomb value is used as an indicator of the quality of the wiggle-match (higher value is better). Threshold is exceeded if Acomb > An. An = 1/√(2n).

The analysis enables us to determine a precise felling date for 005 of AD 1768 \pm 4 years (95% probability). Note that because the growing season in the Southern Hemisphere crosses the change of year, the calendar year for a tree-ring is considered as the year the new growth began (Schulman, 1956). Therefore, AD 1768 represents the AD 1768-69 growing season.

4. Discussion

The Otāhau pā case study presented here represents a significant advance for archaeological science in New Zealand and demonstrates the potential for radiocarbon wiggle-matching to producing accurate and precise calendar ages for Māori pā. It provides valuable insight into understanding this important class of site, in addition to outlining the prerequisites for successful wiggle-match dating; the type and size of material that can be used, pretreatment methods and wiggle-matching procedures.

The outcomes of the radiocarbon analysis demonstrate that 60-ring samples are sufficiently large for successful wiggle-matching of archaeological material, assuming prerequisites are met (see above). The higher-resolution 5-year sampling is an improvement over the 10-year decadal sampling commonly employed in SHCal13, by increasing the calendar interval known from tree ring counts between the innermost and outermost samples. This is especially important if objects such as palisade posts average 40-60 mm in diameter. The higher resolution sampling also provides more calibration curve structure, which is lost if integrating between decadal data points.

The parent trees used to make the posts were growing towards the end of the Little Ice Age, when increasing heliomagnetic shielding created periods of reverse slope in the ¹⁴C calibration curves. Because of the magnitude of the wiggles at this time, even the lower-resolution four-sample dating produced useful calendar ages, making this a cost-effective approach to establishing an accurate chronology. However, the ¹⁴C atmospheric record varies significantly between AD 1500 and 1850 and further investigation is required to determine the optimum number of dates needed for effective dating at other time intervals. The Galimberti et al. (2004) study referred to above used simulations to examine the variables of sequence length, sampling frequency and measurement precision, and calculated an efficiency

measure to determine the optimum number and precision of ^{14}C measurements for any given time range. A similar Southern Hemisphere study would also be useful, once inconsistencies in the Southern Hemisphere calibration curve SHCal13 as noted above have been resolved.

The ^{14}C dating of the palisade posts places the Otāhau Pā construction date at $\text{AD } 1768 \pm 4$ (95% probability). The three miro posts are amongst the largest of those remaining in position and although sampling of only three posts out of >100 could never be more than suggestive, the four-sample wiggle-matching of the other two miro posts show they are contemporary, suggesting that the palisade may have been erected in one phase. A variety of species were selected, with similar ages of trees suggesting that a local area of regrowth containing young trees was chosen as a source of posts. The palisade structure was clearly functional in nature, with no indication of ceremonial adornment. The more easily handled, smallish posts, with skillfully sharpened bases, may have been chosen to permit rapid construction with minimal effort.

Interestingly, the late 18th century date for the pā is younger than was expected by kaumatua (Māori elders) from Taupiri Marae, only 1.5 km from Otāhau Pā. They had no clear oral traditions about the period of site occupancy and, because of that, they expected that it would have been rather older. It is possible that a hapū (clan) from a different kinship group occupied the site 250 years ago or that details of the traditional history were lost as a result of European colonization in the 19th century. At any rate, a more detailed investigation into the oral history of Otāhau Pā will need to encompass the wider Waikato in any attempt to identify who built and occupied the pā.

At this stage, all that may be said is that Tainui tribal traditions as a whole speak of the Taupiri area as being involved in a long series of troubles that embroiled the region from about AD 1725 up to the great battle of Hingakaka in 1807, as the Ngati Raukawa iwi (tribe) pushed north up the Waikato River against the Waikato iwi (Jones and Biggs 1995: 294-301, 324-5, 348-57). Taupiri was a Waikato tribal stronghold and the radiocarbon age of the construction of palisades at Otāhau Pā sits at about the middle of this phase of warfare. If further traditional evidence is able to determine who built the pā, then the potential exists to link oral history with archaeological investigation and thereby to put names and events to major archaeological sites with some confidence. Ideally, this would be part of a larger project involving multiple sites with the objective of compiling parallel narratives of archaeological landscapes and their social and political histories. Clearly this would require much more historical research and a more extensive programme of Waikato-wide chronology than has been contemplated until now.

5. Conclusions

As a general statement, very little archaeological work has been done on pā in the Waikato and this parallels the situation in the rest of New Zealand. Pā, for all that they are a dominant element of the pre-European archaeological landscape, are poorly understood. In this sense any archaeological data relating to pā have the potential to enhance our understanding of this important class of sites.

This study shows that ^{14}C wiggle-matching can permit calendar-age dating of wetland pā sites, with unsurpassed accuracy and precision. If this example can be repeated on other sites in order to provide a precise chronological sequence of the construction of major pā sites, and if there is comparably detailed analysis of

relevant oral traditions then, for the first time in New Zealand, we might be able to write a rich material and social history of a region in the period before European observation. The Waikato district would be ideally suited for such a regional study, having both a relative abundance of wetland pā sites with preserved palisades, and extensive archives of oral history.

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