– ARTICLE –

Tree-ring Dating of Colonial-era Buildings in New Zealand

Gretel Boswijk[1] and Martin J. Jones[2]

ABSTRACT

This paper describes recent research in dendroarchaeology in New Zealand. In the Northern Hemisphere, dendrochronology is routinely applied to assist with investigating the age and phasing of wooden structures, and is often carried out in conjunction with building recording and documentary research. In New Zealand, tree-ring analysis of building timbers has been undertaken since 2000, in some cases to assist with archaeological investigations of standing structures. The results of three such sites, Sinton Road (SINT), Arney Road (ARNY) and Westney Farmstead Barn (WSNY) are presented here, and the potential and limitations of dendroarchaeology are discussed. Key points are: the identification of fell dates for timber from two structures (SINT, ARNY) and the importance of secure context; the development of a 'use-date range' to assist interpretation of felling dates regarding construction and phasing; and recognition of other information from tree-ring analysis that could shed light on building construction as well as timber production and supply processes.

Keywords: archaeology, building, dendroarchaeology, kauri, tree-ring analysis

INTRODUCTION

Following a period of initial contact between Maori and Pakeha, New Zealand became a formal British colony in 1840 and remained so until granted Dominion status in 1907. As part of the major changes that occurred during this period, the country's built environment was substantially transformed as raupo whare and other structures of Maori design increasingly gave way to new types of buildings introduced by European and other migrants. These new structures often echoed familiar designs from overseas, but were also frequently modified to meet local needs and conditions (Stacpoole 1976: 8–9; Salmond 1986; Shaw 1991). Structures erected within Maori cultural frameworks similarly retained, modified or rejected traditional approaches according to circumstance as the colonial period progressed (Brown 2009; Sundt 2010).

Such buildings and standing structures are visible elements of a society's material culture. Because they reflect a variety of activities and changes occurring in society, including those of a social, cultural, technological and economic nature, the analysis and interpretation of buildings is significant to shedding light on historical issues (Newman *et al.* 2001; NZHPT 2006). In New Zealand, building recording and analysis is carried out to assist with assessments of cultural heritage significance, to inform the development of conservation projects, and as mitigation in the event of demolition or relocation. Despite early work by Coutts (Knight & Coutts 1975; Coutts 1977), and others such as Clunie (1989), the application of explicitly archaeological methods in the investigation of buildings has not widely been taken up until more recently to assess or retrieve evidence about the history of a structure (e.g. Best 1997; Jones 2001) and, in some cases, complement in-ground archaeological research (e.g. Campbell & Furey 2007).

A key component of recording is to accurately ascertain the developmental sequence and age of individual buildings (Grenville 1997: 2). Part of the importance of this process is that it allows information about the creation, modification and use of a structure to be more accurately assessed and interpreted within its historical context. Comparisons with material from other buildings can also be made using the same chronological reference points. This allows us to more accurately observe the trajectory of general patterns of activity occurring in the past, as well as to recognise notable variations of differences that permit an appreciation of the nature and extent of diversity (Jones 2000: 113). Establishing the age of colonial-era buildings has traditionally relied directly on documentary information such as written records, maps, plans and photographs, and on the application of stylistic typologies, themselves based on documentary evidence. Salmond (1986) describes creating a detailed record of the stylistic and formal development of ordinary New Zealand houses between 1800 and 1940 based on such research. While

1 Tree-Ring Laboratory, School of Environment, University of Auckland, Private Bag 92019, Auckland, 1142

2 New Zealand Historic Places Trust, Northern Regional Office, Premier Buildings, 2 Durham Street East, Private Box 105-291, Auckland 1143

Corresponding author: g.boswijk@auckland.ac.nz

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these approaches can be effective in determining the date and phasing of structures, they can also have limitations.

In particular, documentary information can be subject to inaccuracy or bias, and requires careful interpretation in relation to the purposes for which it was created. There may also be gaps in what is captured through documentary means regarding the history of a building's evolution. Certain types of structures, including those of a humble nature and those located away from major urban centres, are particularly prone to invisibility in the documentary record. Dating through the use of stylistic typologies such as those linked with overall architectural style or the design of individual features is also often chronologically imprecise, particularly within the comparatively short timeframes during which New Zealand's colonial history evolved. Until more extensive studies are carried out, applying dates from diagnostic features is itself usually subject to generalisation and may not adequately take into account chronological divergence in use created by regional, social or other differences (Jones 2000:114). As with gaps in documentary evidence, there can also be shortfalls in whether a place contains distinctive diagnostic features. For these and other reasons, supplementary dating methods, particularly those based on primary evidence from a place, can be considered desirable.

In the Northern Hemisphere dendrochronology (tree-ring analysis) is a scientific dating technique which is widely used to accurately establish the age, and phasing, of wooden structures and is often carried out in conjunction with building recording and, depending on the time period, documentary research. Typically, the technique is limited to analysis of those species that produce clearly defined annual rings such as oak (*Quercus* spp) and conifers, which were also most commonly used in structures (Hillam 1993, Towner 2002, Wrobel & Eckstien 1993). The fundamental principle underlying dendrochronology is the crossdating of tree-ring patterns (Bannister 1963:163). Tree growth is influenced by various factors including environmental and climatic conditions. Such conditions vary from year to year so that over time a ring-width pattern develops that is unique in time but which is common to trees that have experienced similar environmental and climatic conditions. Starting with living trees, where the calendar date of each ring is known, and overlapping successively older tree growth sequences, long calendar-dated tree-ring chronologies can be established (Bannister 1963; Baillie 1995). A key strength of dendrochronology is the intra- and inter-site replication of ring patterns that occurs as a routine part of chronology development, including replication of results generated by different workers, which ensures confidence in results (see Baillie 1995:27–28, English Heritage 2004:11).

Tree-ring dating is both accurate and precise, and tree-ring dates have no associated statistical uncertainty or standard error (Towner 2002:68). It is possible to compare tree-ring patterns of timbers of unknown date to dated reference chronologies, identify the exact position at which the series match and obtain calendar dates for the rings present on the samples. If a tree-ring series also extends to the terminal growth ring at the bark edge (also known as 'waney edge', Kaennel and Schweingruber 1995:380) it is possible to identify the precise year the tree was felled. Providing that there is good understanding of processes of wood supply and conversion, and the context of the dated sample, such felling dates can be used to determine a construction date for a building and/or subsequent phases of alteration. Importantly, the tree-ring dates are based solely on comparison of ring-width patterns and are completely independent of other types of dating evidence (e.g. style and documents), history, or theory (English Heritage 2004:5). In this light, *Guidelines on Dendrochronology* produced by English Heritage, the Government body in charge of heritage (including archaeological sites) in England, states that: "provided [the dates] are produced by an experienced dendrochronologist and are from a secure context, [they] should take precedence over those produced by any other means" (English Heritage 2004:5).

Nash (2002) provides a summary of archaeological applications of dendrochronology and cites numerous examples from New World and Old World archaeology. In North America, tree-ring analysis has been used to study a range of pre- and colonial period buildings (e.g. Douglass 1929; Towner 2002; Wight & Grissino-Mayer 2004) and Dean (2009) highlights the expansion of dendroarchaeology beyond dating to incorporate the analysis of human behaviour and past environmental conditions. In Britain, tree-ring analysis is one of the specialist techniques recommended for understanding the significance of historic assets (English Heritage 2008) and has been used to investigate the construction history of prestigious buildings such as Windsor Castle (Hillam & Groves 1996), as well as numerous vernacular structures.

In New Zealand, tree-ring analysis has been commonly used as a technique to study population dynamics in forest ecology (e.g. Ahmed & Ogden 1987) and to develop tree-ring chronologies for use in climate reconstruction (e.g. Buckley *et al.* 2000; Cook *et al*. 2002; Boswijk *et al.* 2006; Martin 2007). Native species suitable for dendrochronology include tanekaha (*Phyllocladus trichomanoides*), New Zealand cedar (*Libocedrus bidwillii*) and silver pine (*Lagarostrobos colensoi*) but one of the key species used for such research in New Zealand is kauri (*Agathis australis*). A multi-millennial calendar-dated tree-ring chronology has been constructed for this species using data from living trees, sub-fossil wood and kauri timbers salvaged from demolished buildings (Boswijk *et al.* 2006). This record has applications to investigation of past climate (e.g. Fowler *et al.* 2008), radiocarbon calibration, and archaeological dating.

The potential of dendroarchaeology in New Zealand has been discussed since the 1950s in the context of dating Maori artefacts (Golson 1955; Dunwiddie 1979; Norton &

Ogden 1987) but early attempts in the 1960s at crossdating archaeological material were discouraging (Scott 1964). Consequently no further work has (to the authors' knowledge) actually been undertaken in dendroarchaeology, and no-one had considered its application to investigating colonial period structures. Since 2000, kauri timber samples have been collected for tree-ring analysis from 13 buildings in the North Island (one from Kawakawa, 10 from Auckland, and two from Wellington City), which were being demolished or extensively altered. Collection from some demolished buildings was linked to development of the late-Holocene kauri chronology (e.g. Boswijk *et al.* 2006), but sampling at several sites was specifically undertaken in order to aid investigation of historic structures.

In this paper we describe the results from tree-ring analysis of kauri timbers from three of these building assemblages: 2–4 Sinton Road, Hobsonville (SINT); 139 Arney Road, Remuera, Auckland (ARNY); and Westney Farmstead Barn, Mangere (WSNY); and discuss the potential of dendrochronology to aid investigation of colonial-period buildings, particularly with regard to developing chronologies of construction and phasing. SINT, ARNY, and WSNY were located in the Auckland region (Figure 1). Details of each building are presented below with summary information of tree ring results in Table 1. Each site was the subject of archaeological investigation including building recording prior to demolition or relocation. Tree-ring analysis was carried out as part of, or alongside, these investigations to assist in refining a construction history for the building. Separate reports detailing tree-ring analysis of each site assemblage have been written (Boswijk 2001a; Boswijk 2007; Boswijk 2009) from which the following is derived.

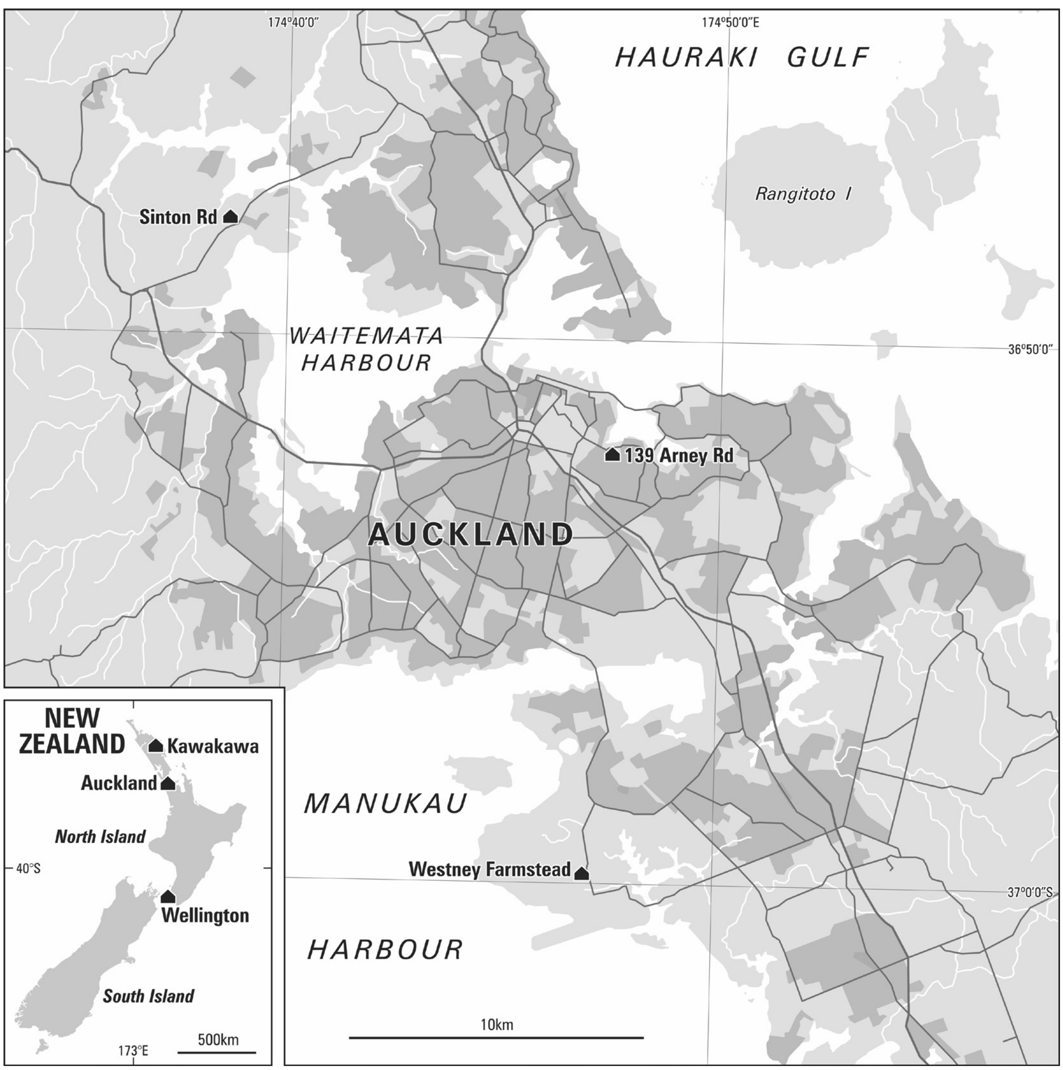

Figure 1: Location of ARNY, SINT and WSNY in Auckland, New Zealand. Dark grey indicates urban areas of the city. Light grey is parkland or rural land. The inset map shows the other locations in New Zealand where buildings have been sampled for dendrochronological analysis.

Table 1. *Summary details of SINT, ARNY and WSNY tree-ring assemblages. All sites were located in Auckland.*

Code	Site	Total # samples	Cross-dated series	Chronology (AD)	Fell dates	Comments	References
SINT	2–4 Sinton Road, Hobsonville	13	5	Sinton (1711–1903)	1903/4	Two samples with waney edge	Boswijk 2001a; Clough *et al.* 2001
ARNY	139 Arney Road, Remuera,	24	14	Arney1 (1547–1861)	1862/3	Two samples with waney edge	Boswijk 2009
WSNY	Westney Farmstead Barn, Mangere	140 (88 kauri)	46	Westney1 (1515–1861)	–		Boswijk 2007

METHODS

This section presents a general description of sample collection, preparation and measurement. Specific details of sample collection, chronology development and dating for each building are provided in the relevant section below.

Sample collection

The method of sample collection depended on the status of the building. SINT and WSNY were to be demolished or were being demolished enabling slices of timbers to be obtained from cladding and/or framing timber using a chainsaw (WSNY) or handsaw (SINT). The house at Arney Road was to be relocated. There, *in situ* rafters were sampled using a power drill and corer attachment. This produced a core approximately 9 mm wide and left a hole 11 mm wide in the timber. Each sample in a site assemblage was given a unique code and the original location of sampled timbers recorded on a plan, or sketch, if possible. Other information, such as evidence of reuse was also noted where possible.

Measurement and crossdating

Standard techniques were used to prepare the timber samples and measure ring widths (Baillie 1982; Stokes & Smiley 1968). Usually only samples with >50 rings are analysed, as sequences shorter than this are considered unreliable for crossmatching (English Heritage 2004). Very occasionally shorter series were measured if it was believed there was potential for a well replicated match within the site assemblage–for example, if it was thought timbers were derived from the same parent tree.

All series from a site were compared against each other to identify those that matched and site chronologies were constructed by averaging all crossmatched series. This reduces noise associated with individual series and enhances the common climate signal on which crossdating depends (Baillie 1982). Site chronologies were usually compared first to an unpublished composite kauri master chronology built from all available modern (living tree) and archaeological data to establish a calendar date, and then compared with independent modern site chronologies and other archaeological chronologies (as they became available) to check replication of the suggested match. For all the sites discussed here, intra-site crossmatching of series and crossdating of site chronologies and single series against reference chronologies was undertaken using a combination of computer programs (CROS (Baillie & Pilcher 1973), Cross84 (Munro 1984)) included in the 'Dendro for Windows' suite (Tyers 2004) and visual matching using line graphs. As described by Baillie (1982: 82–85 and summarised by English Heritage 2004: 10) the CROS program tests pairs of samples and calculates the product-moment correlation coefficient 'r' for every position of overlap. Because the value of r does not take into account the length of overlap between series, a Student's t value is calculated from r to provide a measure of the probability of the observed value of r having arisen by chance. For series with 100 or more rings, the 0.1 per cent significance level for t is 3.5, i.e. a value of this magnitude should occur by chance once in every 1,000 mismatches (Baillie 1982: 84). A value >3.5 indicates a potential match, but does not mean a suggested match has to be correct. As part of the process, matches are always verified visually using line graphs to ensure that the series are sync from start to finish.

Accuracy and precision of tree ring dates

Tree-ring analysis will provide accurate calendar dates for the growth rings present on a sample, although this may not necessarily indicate when the tree was felled or when the timber was used in a structure (English Heritage 2004). The precision of the tree-ring date with regard to dating the primary phase of a building and/or later additions will depend on the completeness of the sample. If the sample has heartwood rings only, or heartwood and some sapwood, this will provide a *terminus post quem*, after which time the event happened. If the sample is complete to the final growth ring, the exact year that the last ring was formed can be established. This will indicate the year of felling. The growing season for kauri crosses the

Table 2. *Crossdating of the site chronologies Sinton, Arney1 and Westney1 to independent modern tree-ring chronologies and each other. All Student's t-values from* CROS *(Baillie & Pilcher 1973). Note some modern chronologies have been revised to include new material since the* SINT *assemblage was analysed. Values in brackets indicate the value presented in the site report. Values in italics were not presented in the relevant site report but are included for comparative purposes.*

Site chronology	Date span	Sinton (1711–1903)	Arney1 (1547–1861)	Westney1 (1515–1861)	References
Cascades	AD 1559–1982	5.33	15.66	14.32	Fowler & Boswijk 2000
Hidvally	AD 1679–2002	8.34 (8.85)	8.11	*8.25*	Boswijk & Ogden 2005
Huapai	AD 1483–1997	4.47	10.34	14.29	Fowler & Boswijk 2001
Huia	AD 1720–1981	5.56	8.29	7.31	Boswijk 2001b
Manaia	AD 1269–1998	6.02	11.27	9.18	Boswijk *et al.* 2000
Pukloop	AD 1504–2002	8.91 (5.42)	8.11	9.63	Gergis *et al.* 2005a (Ahmed 1984)
Trounson	AD 1529–2002	*5.60*	6.95	9.13	Gergis *et al.* 2005b (Ahmed 1984)
Sinton	AD 1711–1903	*	5.84	6.59	Boswijk 2001a
Arney1	AD 1547–1861	5.84	*	10.55	Boswijk 2009
Westney1	AD 1515–1861	6.59	10.55	*	Boswijk 2007

change of year and seasonal growth studies of kauri by Fowler *et al.* (2005) indicate that kauri start putting on xylem cells in spring (October) and cell production ceases in late autumn/early winter (May/June). If the final growth ring appears incomplete, the tree would have been felled during the growing season, e.g. 1903/4. If there is clear indication that the final ring is complete, i.e. cell production has stopped, the tree was felled in winter, e.g. 1904.

Interpretation of felling dates

Felling dates are precise and independent of other physical or historical information associated with a structure. However, the interpretation of felling dates regarding construction of the structure can often be improved by other evidence (English Heritage 2004). In the first instance, the context of the timbers should be securely established; that is, it should be ascertained a) which construction phase they belong to, and b) whether the timbers are primary to the phase or if they have been reused or are associated with repairs. Second, interpretation of felling dates requires good understanding of timber production processes including seasoning and supply, and quantification of the time taken once a tree has been felled to be converted to timber and eventually used in a building (referred to here as a 'use-date range'). In New Zealand, a third consideration is whether the building was constructed on the site or has been relocated from elsewhere.

THE BUILDINGS

1) Sinton Road House

The duplex at 2–4 Sinton Road, Hobsonville (Figure 1), was a single-storey structure with lime-concrete walls, a simple hipped roof, central chimney and a verandah at the front (Jones 2001). It was on the route of the State Highway 18 realignment and has since been demolished. A report by Pearson (1999) suggested that the duplex was built in or about 1902 by the landowner, R.O. Clark Jnr, but an array of historical and other evidence cast doubt on this date (Clough *et al.* 2001). In 2000 a multi-disciplinary assessment of the heritage significance of 2–4 Sinton Road was undertaken by Clough *et al.* (2001), including documentary research, archaeological evaluation of the building and the site, forensic investigation of the concrete, and pollen analysis. Tree-ring analysis of roof timbers was also undertaken, the results of which are presented by Boswijk (2001a) and Clough *et al.* (2001).

The roof was described by Jones (2001) as having a simple design, and of being constructed from low quality kauri. There was extensive reuse of material; in particular some of the hip rafters and purlins had bolt holes and washer marks as well as concrete spatter consistent with the timber having been used as formwork and shuttering for the construction of concrete walls. He observed similarities between these roof elements and wall plates embedded in the tops of the walls indicating that either the roof was contemporary with the construction of the tops of the walls or that the timbers had been extensively re-used in subsequent modifications to the roof structure. Thirteen samples were obtained from the roof for tree-ring analysis. Six samples were obtained from *in situ* elements including a hip rafter, collar, purlins, and a strut, and seven samples were cut from sections of discarded timbers in the roof space (Boswijk 2001a; Clough *et al.* 2001). One of the *in situ* samples also had concrete spatter.

Although the sample from the concrete spattered timber could not be dated, five series crossmatched (Figure 2) and were averaged together to form a 193-year site chronology, *Sinton*. These series were from samples taken from a hip rafter, purlin, a collar and two discarded timbers.

The site chronology was compared to modern kauri chronologies and was calendar dated to AD 1711–1903 (Table 2; Boswijk 2001a; Clough *et al.* 2001). Two crossdated series from *in situ* timbers (a hip rafter and a collar) included the terminal growth ring at the bark edge, which appeared incomplete. This indicates that the timbers came from a tree or trees felled during the 1903/4 growing season. At the time Boswijk was cautious in interpreting the tree-ring dates, writing in the original report (2001a:4) that:

> It should be noted that the felling date of AD 1903/4 … does not necessarily date the construction of the building. Milling, seasoning and stockpiling may have delayed the use of the timber. Careful consideration should also be given to the possibility that the roof structure has been repaired or altered, or timber potentially reused.

Based on the wider range of evidence presented by the multi-disciplinary study, Clough *et al* (2001) suggested that the duplex was most likely constructed by 1885. The dendrochronological results were explained as relating to modifications to the roof occurring as late as the 1920s. However, an opportunity to re-examine the issue occurred when the building was dismantled and demolished in 2006. Observations by Jones and by Russell Foster & Associates (2006) at the time indicated that the main elements of the structure, including the concrete walls, formwork and most other timber in the roof were of a primary phase. All hip rafters were recorded as having concrete spatter on one side. Remnants of the sampled collar were also retrieved, and similarly appeared to have concrete spatter. This provides a secure context for the timbers with fell dates, which can be reinterpreted as indicating that construction of the walls and roof could not have occurred before 1904.

Further investigation of documentary evidence was also carried out by Holman (2004). This included location and inspection of the district valuation rolls for the Waitakere Riding (1905–1910) that begin at 1 April 1905, and which contains an entry for the Clark land stating 'one new dwelling'. On this basis, she determined that the duplex

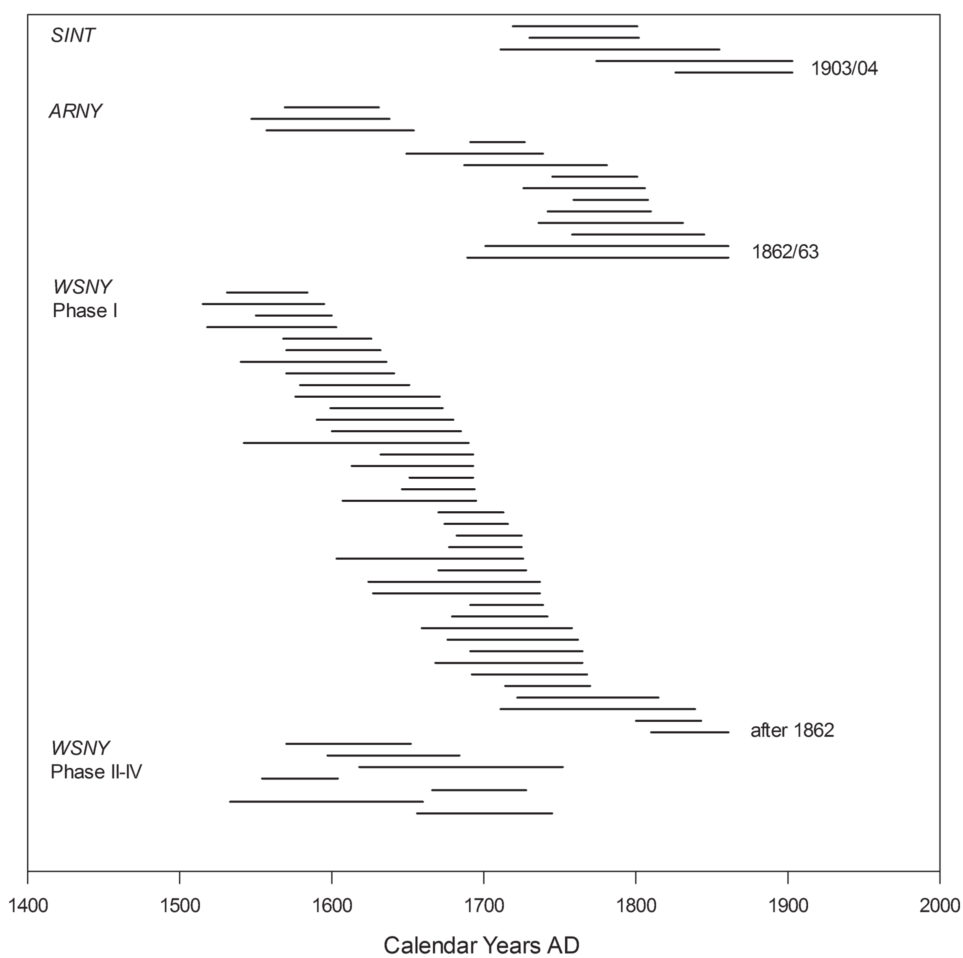

Figure 2: Temporal position of all calendar dated tree ring series from SINT, ARNY and WSNY. Each line represents one dated series from the site, aligned by end date. The dated WSNY series are also arranged by phase. Felling dates are identified for SINT and ARNY. The *terminus post quem* date for WSNY is also shown.

was built 'probably in the first half of 1905 (or just possibly in 1904) and certainly before 1 April 1905' (2004: 30). Therefore, in this case, the documentary information and the tree ring dates, now supported by secure context, provide independent but complementary evidence regarding the construction date of SINT. Additionally, the documentary evidence provided by Holman (2004) provides a starting point for quantification of the temporal delay between the felling of a tree and use of the timber (the 'use-date range'), critical to interpretation of felling dates.

2) 139 Arney Road

139 Arney Road was a large single storey Georgian-style house with a slate-clad hipped roof (Pearson 2005). The house was located in the suburb of Remuera, Auckland, overlooking Hobson Bay (Figure 1). The property was the subject of an archaeological survey in 2005 prior to the house being relocated to a new situation in the Kaipara district. It was thought that a house was built on the site in *c.* 1855 or 1856 by the landowner, S.A. Wood, and was subsequently enlarged within a short time period (Pearson 2005). In 1858 the property was described as 'the beautifully miniature estate of Woodville' with the house 'comprising every requisite for a respectable family' set in ten acres of grounds (*Daily Southern Cross*, 1858). In 1860, when the estate was put up for public auction by Wood, the house was reported as having nine rooms, with stables and all the necessary outhouses (*Daily Southern Cross*, 1860). Andrew Sinclair Esq (nephew of the Colonial Secretary, A. Sinclair) purchased *Woodville* in January 1861 (Pearson 2005). By 1950 the house had 14 rooms. In an assessment of cultural significance, Pearson (2005: 29) commented that the house had undergone 'a considerable number of changes during its lifetime, the exact sequence of which remains unclear'. It was suggested that the central part of the current structure formed the original 1850s house, which was extended through additions to the west, east and south, shortly after completion. However, he suggested that further investigation should be carried out to better understand the sequence of construction.

The archaeological survey undertaken provided an opportunity to carry out sampling for tree-ring analysis to assist in interpreting the phasing of the structure, prior to relocation. In the late 1950s a fire damaged a large area of the main roof structure and it had been reframed in imported pine (Bickler *et al* 2010). However, structural roof timbers over the west end (kitchen wing) and at the eastern end of the building were considered to be of the primary phase. Unfortunately, the timbers in the kitchen wing were too narrow for sampling with a power drill and corer and no samples were obtained from this area. The rafters in the eastern end had been smoke blackened, but were otherwise intact and did not appear to have been reused, reset or altered in any way. Three rafters were identified as having waney-edge, raising the possibility of obtaining felling dates for these timbers.

Twenty-four samples were obtained from 23 rafters (Figure 3). Fourteen series from the Arney Road House assemblage crossmatched (Figure 2) to form a 315-year site chronology, *Arney1*, which was calendar dated to AD 1547–1861 by reference to independent modern site chronologies and other building chronologies (Table 2; Boswijk 2009). Two samples were complete to the bark edge surface and both ring width series ended in 1861, with one unmeasured ring at the end. This provides a felling date of AD 1862/63. The outer few rings of a third sample were lost during coring but the end date of AD 1858 for this series indicates that the timber was derived from a tree felled

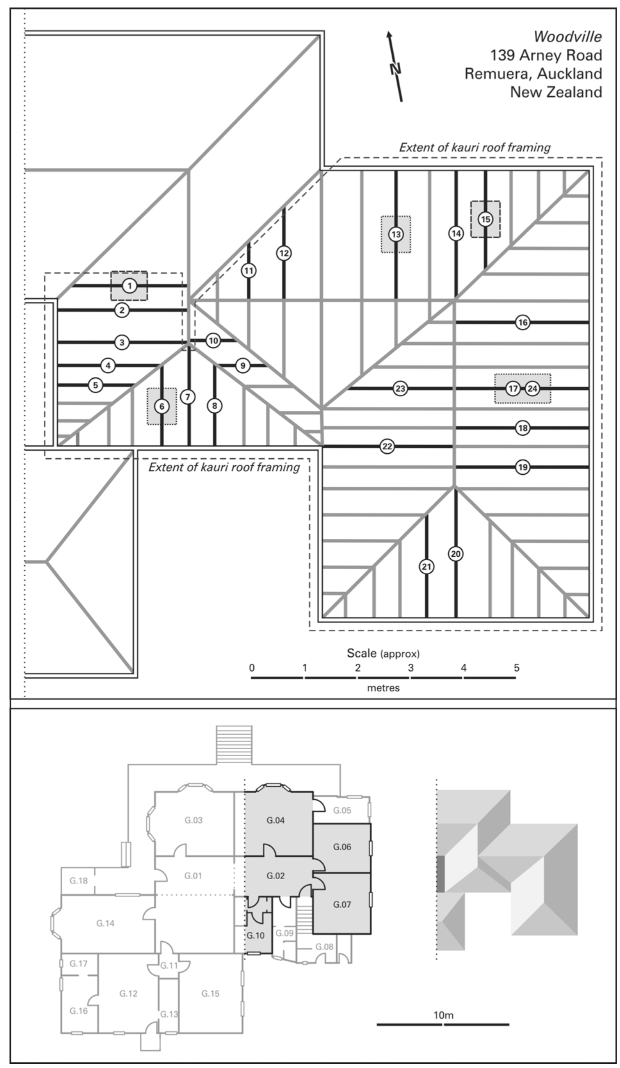

Figure 3: a) Sketch plan of the hipped-and-valley roof at ARNY showing the location of sampled rafters (numbered). Felling dates were obtained for rafters '1' and '15' (dashed boxes). Rafters '6', '13' and '17/24' appear to be from the same parent tree (dotted boxes). b) Floor plan, based on Pearson 2005, with shaded area indicating corresponding roof structure where tree ring samples were obtained. Reproduced from Boswijk 2009.

soon after this date. Furthermore, three series from two rafters have very similar growth patterns, strongly suggesting that the rafters were derived from the same parent tree (Figure 4a, Table 3a).

Application of a use-date range (discussed below) to the ARNY felling dates indicates construction of the roof in, or soon after, 1864 and probably by 1869. This is a decade later than the mid-1850s date for the original house, and is soon after the purchase of the property by Andrew Sinclair. Although no tree-ring data were available from elsewhere, careful consideration of a number of factors implies a substantial addition to the north and east side of the house. These factors include the location of the dated rafters over spaces G02, G04, G06 and G07 (Figure 3), use of 'same-tree' timbers in three different parts of the roof, the connection of this roof space to other parts of the structure, and no observed modification of the kauri roof structure. In this case, the dendrochronological results, arrived at independently of any other evidence, suggest that a reassessment of the phasing of the building is warranted.

3) Westney Farmstead Barn

The Westney Farmstead was located at Ihumatao, near Mangere (Figure 1). The site was the subject of an archaeological investigation prior to the land being redeveloped by Auckland Airport Ltd, which also included detailed recording of the farmstead house and barn, both complex multi-phase structures (Campbell & Furey 2007). The house, constructed in 1855 and subsequently modified, was to be relocated but the barn and adjoining structures were quite dilapidated and along with other outbuildings were to be demolished. This provided an opportunity to collect timber samples from the barn for tree-ring analysis.

The barn is described by Jones (2007). The earliest phase (Phase I) was a single crib-barn, probably built in the late 1870s or early 1880s. A flanking shed with a pentice roof was added to the northern side of the barn (Phase II), which was extended twice (Phase III, Phase IV) and modified. Further additions were made on the south side, including construction of a pole barn. Tree-ring analysis was carried out to assist in refining construction dates for the building and to improve understanding of the phasing of the structure. One hundred and forty timber samples were collected from weatherboards, studs, rafters, base plates and wall plates used in the barn and attached outbuildings. Samples were cut from the structural timbers and cladding using a chainsaw. The assemblage was diverse and included pine (*Pinus radiata*), totara (*Podocarpus* spp), and rimu (*Dacridium cupressinum*) timbers as well as kauri. Eighty-eight samples were kauri, but only 58 of these were suitable for tree ring analysis.

Forty-six samples from the barn and attached outbuildings were crossmatched and combined into a single 347-year tree-ring chronology, *Westney1*. The chronology was calendar dated to AD 1515–1861 by comparison to modern site chronologies and other building chronologies (Table 2; Boswijk 2007).

Although timbers with obvious sapwood and waney edge were noted in the structure and sampled, no crossdated series extended to the final growth ring at bark edge. Wood-worm damage to sapwood and possibly locally ab-

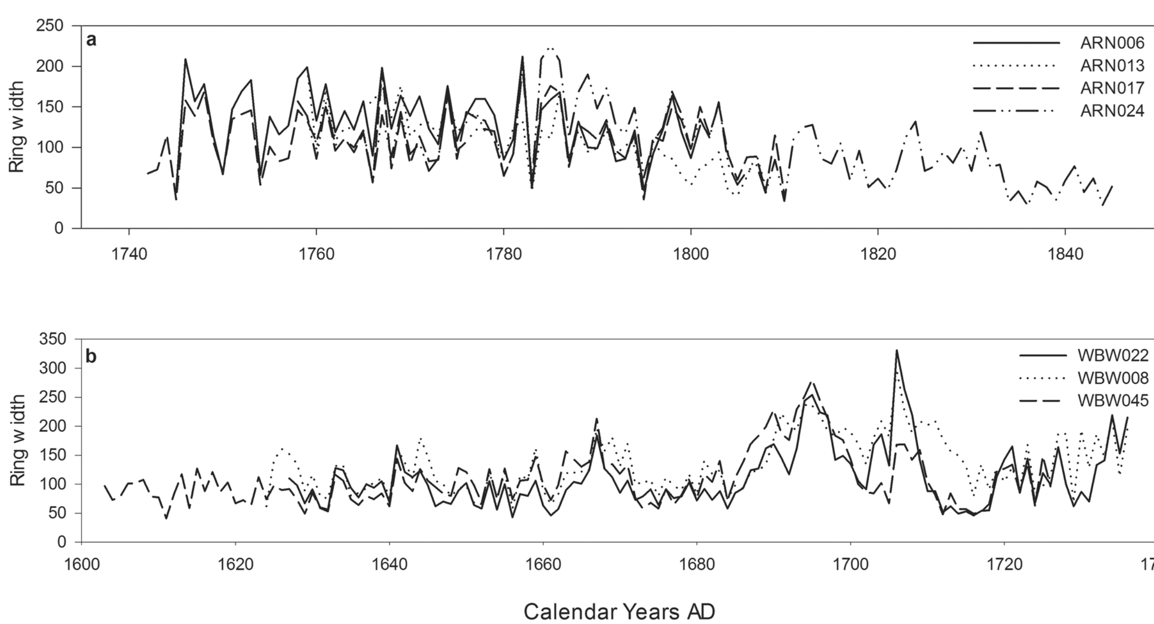

Figure 4: Line graphs (raw ring widths) of probable 'same-tree' series for a) a set of rafters from ARNY and b) a set of cladding boards (weatherboards) from WSNY. Statistics for the overlaps are presented in Table 3. Note there is no relationship between the two groups. 100 = 1 mm.

Table 3. *Crossmatching between probable 'same-tree' series for (a) ARNY and (b) WSNY. Identification of potential 'same-tree' series is based on careful consideration of statistical values, visual matches and comparison of the wood samples. Reported values are Student's t / correlation coefficient r derived from CROS (Baillie and Pilcher 1973).*

(a)

Series	ARN006 1745–1801	ARN013 1759–1808	ARN017^ 1742–1810	ARN024^ 1758–1845
ARN006	*	8.62 / 0.82	21.72 / 0.95	16.47 / 0.94
ARN013	8.62 / 0.82	*	8.98 / 0.80	8.16 / 0.78
ARN017^	21.72 / 0.95	8.98 / 0.80	*	17.75 / 0.93
ARN024^	16.47 / 0.94	8.16 / 0.78	17.75 / 0.93	*

^ ARN017 and ARN024 were from the same rafter and are included for comparative purposes

(b)

Series	WBW008 1624–1737	WBW022 1627–1737	WBW045 1603–1726
WBW008	*	13.32 / 0.79	12.17 / 0.78
WBW022	13.32 / 0.79	*	16.32 / 0.86
WBW045	12.17 / 0.78	16.32 / 0.86	*

sent rings affected the reliability of the outer sections of these series and they had to be truncated to include only that part of the sequence which could be reliably crossdated. Based on the array of tree-ring dates obtained from timbers, and accounting for unmeasured or excluded rings, the tree-ring results indicated that the crib barn (Phase I) was built after AD 1862. The later phases of outbuildings could not be differentiated based on the tree-ring dates. However, these structures contained a higher percentage of timber from different species, including pine, totara, and rimu.

Although it was not possible to determine felling dates for timbers from the structure, other information did emerge. The crossdated WSNY assemblage included subgroups of series that were highly correlated (statistically and visually). Near identical ring-width patterns strongly suggested that timbers were derived from the same parent tree, and possibly from the same long length of timber reduced to shorter lengths for use in the structure (example shown in Figure 4b, Table 3b). Usually series included in such sub-groups are from the same type of timber, e.g. weatherboard, but one sub-group included series from weatherboards and ridge pieces, suggesting conversion of a log, or logs from the same tree, into different types of timber. These findings give some insight into the use of timber in the structure, and into the production of timber for buildings.

DISCUSSION

The results of tree-ring analysis of building timbers from SINT, ARNY, and WSNY demonstrate the potential of dendrochronology to assist archaeological investigations of colonial-era (kauri) buildings and standing structures in New Zealand. Of significance is the occurrence of timbers with waney edge in each of the buildings discussed here and the identification of felling dates for two sites (SINT, ARNY). These can contribute to accurately establishing the age and chronology of development for the source structure and may be useful as a means to test theories about the development of a structure based on typological features or stratigraphic interpretations, especially when applied in conjunction with systematic recording of a structure. In addition, the occurrence of probable 'same-tree' material in each assemblage has potential to inform understanding of timber production and supply during the 19th and early 20th centuries, and in the use of timber in a structure.

The occurrence of framing timbers with waney edge, although not abundant, has not been as rare as expected across the suite of buildings analysed to date, particularly given the size of kauri trees, conversion processes and potentially, lower grade of such timber. It is possible that use of waney-edge timber was more acceptable for areas that were hidden from sight such as in the attic at SINT or ARNY, or for framing exposed in utilitarian spaces or structures such as a barn. Currently, waney-edge timber has been sampled at six sites, and felling dates have been determined for four sites from eight samples (Table 4). All of the wood samples were in suitable physical condition to enable measurement to the final complete growth ring. Wood worm, rot and degraded sapwood can all impact on the quality of a sample for tree-ring analysis and limit the potential for obtaining a felling date. Although the number of samples with felling dates is low overall, at ARNY and SINT the fell-dates are replicated by two series.

In the first instance, fell-dates from kauri timbers provide a *terminus post quem*; that is, indicating that the structure was built, or extended, or timber used, after a specific year. Interpretation is improved by knowledge of

Table 4. *Listing of all tree ring assemblages (up to 2010) that have produced felling dates. Felling dates have been obtained for timbers from four sites, but only three sites have sufficient supporting information to estimate a use-date range.*

Site	Building on site	Information Source	Waney edge	No. of Samples	Felling dates	Sample Context	Delay before use
Sinton Rd House	Late 1904/ early 1905	1905/6 rates roll (Holman 2004)	✓	2	1903/4	✓	Up to 1.5 years
26/28 Wynyard St	By 1908	1908 Map of city (Clough pers comm 2003)	✓	1 1	1905 1907	×	1–3 years
3 Alfred St	Wooden building by early 1878 Altered early 1900s	Lease documents and rates? (Clough pers comm 2003)	✓	1 1	1872/3 1895/6	×	Up to 5 years
139 Arney Rd	Mid 1850s and later additions	Pearson 2005	✓	2	1862/3	✓	?
St Paul's College reused tavern beams in 1930s bungalow	1865 (if from Harp of Erin / Rising Sun)	Primary sources: maps, land ownership; ACC building permit records; annual licensing meeting reports; photographs	✓	0	(after 1850)	×	×
Westney Barn	Late 1870s / early 1880s & later additions	Stylistic typology. Campbell & Furey 2007	✓	0	(after 1862)	✓	×

sample context and understanding of the likely temporal delay between the felling of a tree and its use as sawn timber in a structure. As shown by the reassessment of the dendrochronological results from SINT, knowledge of sample context is critical, whilst the availability of other evidence can assist in refining the interpretation of fell-dates. In such situations, the timing of construction or use could be constrained to within a year.

In the absence of comparative information for a structure, a use-date range of up to five years after felling is currently applied to the interpretation of felling dates. For ARNY, the fell dates were interpreted as indicating construction at the earliest by 1864 or up to 1869 (Boswijk, 2009). This range is derived from comparison of felling dates from three buildings, including SINT, with construction dates derived from documentary sources (Table 4). However, it is noted that in two cases evidence for construction was imprecise and interpretation is also hampered by a lack of context information for these assemblages. Therefore the use-date range will be refined as further sites are analysed. In particular, analysis of waney-edge timber from structures with accurately documented construction dates would significantly improve understanding of the time delay between felling and use.

Quantification of a use-date range will also be informed by greater understanding of the operation of the kauri timber industry, especially regarding processes of logging, milling and seasoning. We are aware that many factors, including changes in scale and rates of log extraction and timber production associated with industrialisation during the 19th century will introduce additional complexity to the calculation of a use-date range. For example, preliminary investigation of written sources indicates that factors such as mode of transport and weather conditions will regulate the rate at which logs reach the mill. There are also variations in the historical record to be clarified such as whether seasoning of sawn timber was routinely practised.

The tree-ring dates from SINT and ARNY also highlight the value of dendrochronological analysis in providing independent evidence that may confirm or challenge an existing hypothesis of chronology and phasing determined by other means. At SINT, the fell dates were only one year later than the construction date proposed by Pearson (1999) and fit with the rate rolls evidence of Holman (2004), thus providing independent supporting evidence for an early 1900s construction date. In contrast, the fell dates for the ARNY roof timbers considered to be primary to the structure were a decade later than anticipated for the original building. In such cases, the tree-ring results should act as a prompt to review or revise existing interpretations of the development of the structure.

Even in the absence of felling dates, tree-ring analysis may assist in developing a detailed picture of timber use within a structure through the identification of probable 'same-tree' timbers combined with secure context information, and aids such as mapping samples on drawn elevations. 'Same-tree' clusters are a common occurrence when analysing a large set of samples from buildings. Nine site assemblages analysed between 2000 and 2007, including ARNY and WSNY, have 'same-tree' clusters within the group of dated series. Currently, these clusters are identified on the basis of high correlation between ring patterns (statistical and visual) and similarity in the wood (colour and visual characteristics of the growth rings). Such 'same-tree' clusters may indicate that timber from a log/tree was stacked and sold as a unit. Where series and samples were near identical, they have been interpreted as indicating that lengths of timber were reduced to shorter sections before being used. This level of detail from the tree ring results could also assist with the interpretation of phasing in complex buildings and perhaps provide a mechanism to investigate timber production and supply.

As with any scientific technique, dendrochronology does have limitations that should be recognised. In the first instance, not all timber samples will be suitable for tree-ring analysis, and even apparently suitable samples sometimes cannot be crossdated. All three sites discussed above had timbers that fell into one or other of these categories. Samples that were unsuitable for measurement usually had insufficient rings reducing the potential for obtaining a reliable match, or had very narrow rings that could not be measured with confidence. Rot and extensive wood-worm damage to sapwood also impacted on the suitability of some samples from WSNY for tree-ring analysis.

In general terms, the crossdating potential of a wood sample may be affected if the parent tree experienced abnormal conditions (English Heritage 2004) producing an unusual growth pattern. With regard to kauri, periods of suppression (very narrow growth rings) or wedging (where rings flare out becoming wide) can mask the common signal on which crossmatching is dependant. In addition, kauri trees do not always put on a growth ring around the entire circumference of the trunk, so that a sequence may have locally absent rings which disrupts the growth pattern. Replication of the same time period by other samples from the same site can sometimes result in the location of the missing ring being identified, but where multiple absent rings occur crossdating is not possible.

It should also be recognised that whilst dendrochronology accurately dates the growth rings that are present on a sample, this is not necessarily indicative of the date when the tree was felled or the timber was used (English Heritage 2004). In New Zealand we have the additional complication of in-built age associated with long-lived trees. Kauri commonly attains ages of 600 to 1000 years and, because of its large size, framing and cladding elements typically represent only part of the growth sequence for the tree. Consequently, tree-ring analysis of a heartwood sample is likely to return a calendar date that is potentially several hundred years older than the actual structure. For example, rafters from ARNY had growth rings dating to the AD 1600s and series from WSNY were crossdated to the AD 1500s (Figure 2). Other assemblages have included series dating to the AD 1000s (Boswijk *et al.* 2006). In this case, the actual calendar dates have little value for dating construction or modification of a structure, but 'same-tree' relationships could be informative and the array of dates obtained will assist in understanding the age of trees that were being felled during the kauri logging era.

In order to make the best use of dendrochronology with regard to standing structures it is recommended that sampling of timbers is carried out in conjunction with the systematic recording and phasing of a structure. Any evidence of reuse of timber or modification to structures should be carefully recorded, and all relevant information should be made available to the dendrochronologist to aid interpretation of the tree-ring dates. The building assemblages discussed here varied in size from 13 samples (SINT) to 140 samples from WSNY. Larger samples sets (>20 samples from a site) improve potential for developing well-replicated site chronologies, but sampling should be targeted at framing timbers, especially those with waney edge, which will address the questions being asked.

At present our efforts have been focused on kauri as this was a common building material in the 19th and early 20th century, and the Tree-Ring Laboratory at the University of Auckland also holds an extensive databank of site chronologies from modern trees, sub-fossil kauri and (increasingly) buildings. However, modern tree-ring chronologies have also been constructed by several researchers from other native tree species including beech (*Nothofagus* spp; Norton 1983), tanekaha (*Phyllocladus trichomanoides;* Palmer 1989), New Zealand cedar (*Libocedrus bidwillii; e.g.* Martin 2007) and silver pine (*Lagarostrobos colensoi*; Cook *et al.* 2002) offering the potential to explore use of these species for dendrochronology should they occur in a standing structure or an in-ground archaeological context. Early investigations of totara (*Podocarpus totara*) and Halls totara (*Podocarpus hallii*) did not produce any chronologies (LaMarche *et al.* 1979) and matai (*Prumnopitys taxifolia*) is (to the authors' knowledge) untested. Because these species were also used in structures they may warrant (renewed) investigation for their dendrochronological potential, focussing initially on living trees in order to assess suitability for crossdating and to develop reference chronologies. Boswijk has observed that rimu (*Dacrydium cupressinum*) can have severe growth suppressions and is doubtful as to the suitability of this species for chronology development. Some imported species, such as Oregon pine from North America, may also be of dendrochronological interest and, alongside kauri, could provide a novel means to investigate the trans-Pacific timber trade.

CONCLUSION

This paper has described the results of tree-ring analysis of kauri timber assemblages from two 19th century buildings and one early 20th century building and discussed the potential for dendrochronology to aid the archaeological interpretation of colonial-era buildings. From the discussion above we can conclude that while tree-ring analysis of kauri from buildings has limitations, it is firmly established that we can obtain accurate calendar dates for timbers used in structures. Timbers with waney edge are not uncommon, enabling felling dates to be determined. As discussed above, the felling dates are independent of any documentary evidence or theory of when the building was constructed or altered. They indicate that the timber could not have been incorporated into a structure before that date, which may support or challenge interpretations based on stylistic or historical evidence alone.

Further research will continue into refining the gap between felling and use to ascertain an average value that can be applied to interpretation of fell-dates. Analysis of buildings from a wide temporal period will also assist in identifying whether this gap changes over time, as methods and technology of milling and construction changed. We wish to further understanding of both identification of 'same-tree' timber, and how information on the use of 'same-tree' timber within a structure can provide insight into aspects of timber production and supply, and the use of timber within a building. Work on dating typologies linked to manual and mechanised timber production, construction methods and associated materials such as nails may also be fruitful. An important area not addressed in this paper is provenancing of timber, which also has relevance to timber production and supply during the kauri logging era. Such research naturally extends into the environmental history of kauri forests and logging.

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