Journal of Pacific Archaeology – Vol. 10 · No. 1 · 2019

– ARTICLE –

Dendroarchaeology in New Zealand: assessing potential to extend the suite of useful tree species beyond kauri (*Agathis australis*)

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ABSTRACT

Accurately establishing calendar dates for Māori wooden objects would place them in a secure temporal context and enable aspects of manufacturing and use to be explored within and between sites, and across time. Dendrochronology has the potential to produce accurate and precise calendar dates for wooden artefacts, but in New Zealand application of this technique to Māori cultural material is constrained by the limited overlap between wood species found in archaeological contexts and tree-species with proven suitability for tree-ring dating. Here we identify five conifer species – kahikatea (*Dacrycarpus dacrydioides*), matai (*Prumnopitys taxifolia*), miro (*Prumnopitys ferruginea*), rimu (*Dacrydium cupressinum*) and totara (*Podocarpus totara*) – found as culturally modified wood in archaeological contexts and assess their potential for dendrochronology. Of these, matai, miro and totara are identified as species that should be the subject of further comprehensive dendrochronological investigation.

Keywords: Dating; Dendroarchaeology; Dendrochronology; Kauri; Māori; Matai

INTRODUCTION

Māori used a wide range of broadleaf and conifer tree species to manufacture household goods, tools, hunting equipment and weapons, and carvings, and to construct structures such as palisades, buildings and basic shelters. Such wooden objects can survive in waterlogged conditions and have been recovered from wetland sites such as Kohika, a late 17th century lake village (pā) in the Bay of Plenty (Irwin, 2004), Otāhau Pā, Waikato, dated to the late 18th century (Hogg *et al.*, 2017), and from several pā sites in the Hauraki Plains, Waikato, as summarised by Phillips (2000). The archaeological remains of canoes (waka) made from kauri (*Agathis australis*), matai (*Prumnopitys taxifolia*) and totara (*Podocarpus totara*) have also been recovered from several locations in New Zealand, with the oldest radiocarbon dated to the 14th century and the youngest potentially dating to the 20th century (Irwin *et al.*, 2017).

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Submitted 3/8/18, accepted 19/1/19

Accurately establishing calendar dates for Māori wooden objects would place them in a secure temporal context and enable aspects of manufacturing and use to be explored within and between sites and across time. However, New Zealand has a short history of human occupation, c. 750 years, and the imprecision of archaeological dating techniques across this period presents particular challenges to investigating such technological change during the prehistoric and early historic period. Radiocarbon dating is the standard method for determining the calendar age of an object but variations in previous ambient atmospheric radiocarbon levels affect the precision of calibrated dates resulting in broad age ranges for artefacts. For example, a single conventional radiocarbon date of 123 ± 20 BP for a dugout canoe places it in a ~240 year window (1690–1930 CE) encompassing the pre- and post-European contact period (Boswijk and Johns, 2018). Such wide age ranges limits understanding of manufacturing and evolution of style, although Hogg *et al.* (2017) recently demonstrated that accurate and precise calendar dates can be obtained for archaeological wood using high-resolution wiggle-matching of carbon dates derived from miro (*Prumnopitys ferruginea*) palisade posts.

This paper focuses on the potential of using dendrochronological methods to calendar date Māori artefacts. Dendrochronology is widely used in the Northern Hemisphere as an archaeological dating method, providing independent calendar dates for in-ground and standing structures, as well as ships, boats and canoes, furniture, coffins, paintings, and other portable items (Čufar, 2007; Haneca *et al.*, 2009). In Europe, Oak (*Quercus* sp.) and conifers such as Scots pine (*Pinus sylvestris*) are commonly used for dendroarchaeology because they meet particular criteria for tree-ring analysis (described in subhead 'Dendrochronology' below) and, as timber, are found widely in archaeological contexts.

Since the mid-1950s, archaeologists and ecologists have suggested that dendrochronology could provide absolute dates for Aotearoa/New Zealand. An attempt made in the 1960s to apply tree-ring dating to wooden artefacts was unsuccessful, leading to a pessimistic view that the method would not work in New Zealand (Scott, 1964). But at that time, the suitability of different tree species – angiosperms and gymnosperms – for tree-ring analysis was not well understood. New Zealand has a variable climate, ranging from warm sub-tropical conditions in northern North Island to cool temperate conditions in the south. Temperatures are relatively mild and are moderated by the surrounding seas. Rainfall is evenly distributed throughout the year although late-summer and early autumn are typically drier and the winter wetter, and there are regional variations in annual rainfall amounts (Macara, 2018). Formative research was needed to identify which tree species met the requirements for dendrochronology, including assessment of ring morphology, seasonality of growth, and identification of a common response to an environmental factor, usually climate, limiting tree growth and on which crossdating and tree-ring chronology development depends.

Following initial investigative research in the 1970s (Dunwiddie, 1979; LaMarche, 1979), tree-ring analysis has been applied in ecology and climatology, using mainly modern (living-tree) chronologies from Silver beech (*Nothofagus menziesii*), Black beech (*Nothofagus solanderi*), and a suite of gymnosperm species, including kauri (described in subhead 'Native species' below). Calendar dating of wood from archaeological contexts has been undertaken since 2000, but has been confined to kauri timber collected mainly from historic-era structures. Little research has been done to establish whether tree-ring dating of Māori artefacts can be achieved. Recently, however, three studies have provided renewed stimulus to address this gap. The recovery of part of an early canoe made of matai from Anaweka, northwest Nelson (Johns *et al.*, 2014), and the carbon dating of three *in-situ* miro posts from Otāhau Pā, Waikato, by Hogg *et al.* (2017), prompted questions about the dendrochronological potential of these two species. Additionally, Boswijk and Johns (2018) attempted to tree-ring date two recently recovered kauri waka. Although they were unsuccessful in obtaining calendar dates, their work serves as a baseline for further investigation of accurate and precise dating of such artefacts using dendrochronology. These studies point to the need to expand the range of tree species useful for dendroarchaeology beyond kauri to encompass other wood types commonly used by Māori.

This paper represents a 'first step' towards achieving that goal. Norton and Ogden (1987) observed that '[e]mphasis should … be given to identifying the most commonly used woods and trying to develop modern chronologies with these species.' Following their suggestion, here we identify: 1) the current array of species used for dendrochronology in New Zealand; 2) the range of tree species found as culturally modified wood in archaeological contexts; and 3) assess which tree species used by Māori may also be suitable for tree-ring analysis. The current state of dendrochronological knowledge of these species is summarised and recommendations for further research regarding chronology development are presented.

It should be noted that this paper is concerned with 'suitability' of tree species from a dendrochronological perspective. The suitability of an artefact for tree-ring dating and the interpretation of any tree-ring dates are equally important aspects to consider with regard to dendroarchaeology. For example, artefact suitability is affected by species, as well as the function, size and condition of the object. These, in turn, are dependent on factors such as selection for wood qualities and tree-size by the maker, conversion processes, and the preservation environment. Conversion processes will affect the length of a tree-ring series available from a sample and the precision of tree-ring dates with regard to the event of interest. Additionally, the appropriateness of sampling Māori material culture for tree-ring analysis, and protocols for sample collection, previously raised by Boswijk and Johns (2018), have to be considered. These topics warrant detailed consideration and will be discussed in a separate paper currently in preparation.

IDENTIFYING SPECIES USEFUL FOR DENDROARCHAEOLOGY

Dendrochronology

Classic dendrochronology (*sensu* Heinrich and Allen [2013]) is underpinned by a set of principles and assumptions concerning tree-ring morphology, growth and registration of a common signal, assumed to be climate, by trees of the same species growing at the same time under similar conditions (Baillie, 1982; Fritts, 1976; Speer, 2010). Consequently, not all trees species are suitable for dendrochronology. Typically, a tree species should have well defined rings, with each ring representing one growth season in a year. The trees should be long lived, providing ring width sequences of sufficient length (ideally >100 years) to identify a pattern of wide and narrow rings unique in time, but common to different trees of the same species. The presence of this common signal permits crossdating and the construction of reference chronologies. Long calendar-dated tree-ring chronologies can be built by starting with tree-ring series derived from modern trees of known date, and overlapping series from successively older wood of the same species from archaeological contexts and natural deposits. Tree-ring series from wood of unknown age can then be compared to such reference chronologies and calendar dated based on matching growth patterns. Note that in the southern hemisphere, because the growing season crosses the change of year, the calendar date of a tree ring corresponds to the year growth started.

Native species currently used for New Zealand dendrochronology

In New Zealand, as indicated above, two angiosperm and seven gymnosperm species have proven suitable for dendrochronology (Table 1), and since the 1970s a nationwide network of tree-ring chronologies has been established. The chronologies are based predominantly on samples from long-lived, modern (living) trees. Most have temporal spans within the period of human occupation of New Zealand (~750 years; Anderson [1991]). The exceptions are kauri and Silver pine (*Manoao colensoi*) for which multi-millennial chronologies have been constructed using living trees and sub-fossil wood, and in the case of kauri, timber from 19th and early 20th century structures (Cook *et al.*, 2006; Boswijk *et al.*, 2014).

The species listed in Table 1 were selected, and are used, for dendrochronological research because they met specific criteria outline above, including: distinct growth rings enabling accurate measurement of each annual increment; sensitivity to a common limiting environmental factor; synchronous variations in the year-to-year growth pattern; demonstrable intra- and inter-tree crossmatching enabling construction of annually resolved tree-sequences and site chronologies for that species; species specific inter-site crossdating demonstrating replication of the tree-ring pattern over a wide region; and, a climate signal of interest. Although some species, such as kauri, present ring anomalies such as locally absent rings or false rings (see Box 1 and subhead 'Kauri' below) that can affect reliability of ring sequences, these can usually be resolved through intra- and inter-tree/site replication. Longevity is also key, enabling construction of reference chronologies spanning several centuries.

Tree species used by Māori

Table 2 presents a list of angiosperm and gymnosperm species used to manufacture artefacts (Wallace, 1989) and for structural elements identified at pā sites on the Waihou River (Phillips, 2000), recovered from Kohika (Irwin, 2004) and Otāhau Pā (Hogg *et al.*, 2017), and used

Table 1. *New Zealand Holocene tree-ring chronologies. Sources: International Tree Ring Data Bank (ITRDB) (sourced 2018); Norton and Ogden, 1987; Cook,* et al. *2006; Tree-Ring Laboratory, School of Environment, University of Auckland. The number of tree-ring chronologies may be underestimated as not all chronologies are lodged with the ITRDB.*

Family	Genus and Species	Common Name	No. of Chron.	Combined Temporal Span	General Location	Purpose	Researchers
Angiosperms							
Fagaceae	*Nothofagus menziesii*	Silver beech	5	1580–1980 CE	South Island	Climate	Norton
	Nothofagus solanderi	Black beech	25	1710–1980 CE	South Island	Climate	Aston; Norton
Gymnosperms							
Araucariaceae	*Agathis australis*	Kauri	61	2488 BCE–2002 CE (plus mid- and early-Holocene floating chronologies)	Upper North Island	Climate Radiocarbon Archaeology	Ahmed; Boswijk; Fowler; Lorrey; Ogden; Palmer; Turney
Cupressaceae	*Libocedrus bidwillii*	Kaikawaka	34	1064–2012 CE	North and South Island	Climate Radiocarbon	Cook; Dunwiddie; Fenwick; Norton; Palmer; Xiong
Podocarpaceae	*Halocarpus biformis* (formerly *Dacrydium biformis*)	Pink pine	3	1567–1995 CE	North and South Island	Climate	Dunwiddie; Xiong; Palmer; D'Arrigo
	Manoao colensoi (formerly *Lagarostrobos colensoi, Dacrydium colensoi*)	Silver pine	2	323 BCE–1998 CE	South Island	Climate	Cook; Dunwiddie; Palmer
	Phyllocladus alpinus	Mountain toatoa	1	1717–1976 CE	South Island	Climate	Dunwiddie
	Phyllocladus glaucus	Toatoa	4	1535–1986 CE	North Island	Climate	Dunwiddie; Palmer
	Phyllocladus trichomanoides	Tanekaha	6	1585–1986 CE	North and South Island	Climate	Dunwiddie; Palmer

Box 1. *Terminology, after Kaennel and Schweingruber (1995)*

Term	Definition
Density fluctuation	Layer of cells exhibiting a change in cell size and thickness within a tree ring. Identified by a diffuse boundary.
False ring	An additional growth zone that has well-marked boundaries, formed within one growing season. Can only be identified by crossmatching.
Lobate growth	Local suppression and acceleration of growth producing a non-concentric growth pattern around the stem circumference.
Locally absent ring or wedging ring	A ring that is incomplete around the whole circumference.
Missing ring	A ring absent around the whole circumference due to a failure of cambial activity. Missing rings can be located by crossdating.
Parenchyma	Storage cells, mostly rectangular, present in sapwood (alive), rays, xylem and phloem. Can form bands of one or more tangential lines within a tree ring.

to construct waka (Irwin *et al.*, 2017). Broadleaf species such as manuka (*Leptospermum scoparium*), kanuka (*Kunzea ericoides*), and maire (*Nestegis cunninghamii*) were used for domestic items such as hunting equipment, horticultural tools, and canoe accessories such as paddles because the wood is often hard, heavy, and tough (Wallace and Irwin, 2004). Conifers such as kahikatea (*Dacrycarpus dacrydioides*), kauri, matai, miro, rimu (*Dacrydium cupressinum*) and totara occurred as split dressed timber used in structures, as roundwood posts, and for canoe fittings, gunwales, and hulls. Resinous heart rimu and kauri branches were also favoured for items such as fern root beaters because of their weight and density (Wallace and Irwin, 2004).

Table 2. *Composite list of wooden artefacts and structural timbers found at New Zealand archaeological sites.*

Species	**Common name**	**Waihou River** (Prickett, 1990; Furey, 1996; Phillips, 2000)	**Kohika** (Wallace and Irwin, 2004)	**Otāhau Pa** (Hogg, *et al.* 2017)	**Canoes (Waka)** (Irwin, *et al.* 2017)
Angiosperms					
Beilschmiedia tawa	Tawa	*Structure:* stake (Whetukura Pā)	*Domestic items*: post *Canoe*: Canoe paddles; canoe seat		
Corynocarpus laevigatus	Karaka	*Structure:* stake (Whetukura Pā)			
Kunzea ericoides	Kanuka		*Domestic items:* Bird spear; digging tool; shaft knob*; fern root beater; chisel handle	*Structure*: Palisade post	
Laurelia novae-zelandiae	Pukatea		*Domestic items*: Post *Structure*: poupou (wall timber); dressed timber (fragments)		
Leptospermum scoparium	Manuka		*Domestic items*: Digging tool; javelin/darts; potaka (spinning tops); fibre working tool; sharpened sticks/stakes *Canoe*: canoe seat		
Melicytus ramiflorus	Mahoe		*Domestic items*: Digging tool; ladder; sharpened stick/stakes	*Structure*: Palisade post	
Metrosideros spp.	Rata / Pohutukawa		*Domestic items*: Digging tool; shaft knob; canoe bulkhead		
Nestegis cunninghamii	Maire		*Domestic items*: Bird spear; digging tool; fern root beater; wedge		
Sterblus heterophyllus	Turepo			*Structure*: Palisade post	
Vitex lucens	Puriri	*Structure:* stake (Whetukura Pā)	*Domestic items*: Shaft knob; chisel handle		
Weinmannia racemosa or *Weinmannia silvicola*	Kamahi or Towai			*Structure*: Palisade post	

Table 2. *Continued.*

Species	Common name	Waihou River (Prickett, 1990; Furey, 1996; Phillips, 2000)	Kohika (Wallace and Irwin, 2004)	Otāhau Pa (Hogg, *et al.* 2017)	Canoes (Waka) (Irwin, *et al.* 2017)
Gymnosperms					
Agathis australis	Kauri	*Structure*: Carved lintel; dressed timber; palisade posts (Oruarangi Pā); palisade posts; building posts (Raupa Pā)	*Domestic items*: Fern root beater *Canoe*: canoe gunwale *Structure*: dressed timber (fragments)		Waikato River Delta, Waikato, incomplete one-piece canoe; Muriwai, Auckland, one-piece dugout hull.
Dacrycarpus dacrydioides	Kahikatea	*Structure*: palisade posts (Raupa Pā)	*Structure*: dressed timber (fragments)		
Dacrydium cupressinum	Rimu	posts (Raupa Pā)	*Domestic items*: Bird spear; digging tool; hair comb; adze handle; flute; net gauge; post *Building*: dressed timber (fragments)		Mokomoko Inlet, two broken pieces of an unfinished dugout hull.
Podocarpus totara	Totara	*Structure*: Palisade posts (Oruarangi Pā); building posts; palisade posts (Raupa Pā)	*Domestic items*: Digging tool; bowl; potaka (spinning tops); net gauge; thread reel; fibre working tool; wakahui (treasure box) lid (?); bevelled strips (purpose unknown); post. *Canoe*: canoe hull piece; canoe gunwale; canoe seat; bailer *Buildings*: poupou (wall timber); poutahuhu (centre post); pare (door flashing) or korupe (window flashing); door sill; tumatahuki (vertical house wall battens); dressed timber (fragments)		Papanui Inlet, Otago Peninsula, main body of a dugout hull; Hutt River, Wellington, end section of a large canoe.
Prumnopitys taxifolia	Matai	*Structure:* building posts; palisade posts (Raupa Pā)	*Domestic items*: Shaft knobs; bowl; post *Canoe*: bailer *Structure*: dressed timber (fragments)		Anaweka, North west Nelson, complete plank; Doughboy Bay, Rakiura/Stewart Island, decking piece; Henley, Taieri Plain, Otago, small one-piece waka.
Prumnopitys ferruginea	Miro	*Structure*: palisade posts (Raupa Pā)		*Structure*: Palisade post	

*Shaft knobs are the end sections of broken shafts or handles that have a terminal knob.

Species useful for dendroarchaeology

Comparison of Table 1 and Table 2 (summarised in Figure 1) indicates that there is almost no overlap between those species for which tree-ring chronologies already exist and the wood species found at the selected archaeological sites – only kauri is common to both.

Of the angiosperm species listed in Table 2, some such as manuka and kanuka, are unsuited for tree-ring dating because their ring morphology precludes secure identification of seasonal growth bands, and/or relatively short lifespans limit the construction of reference chronologies. Other angiosperms were, however, assessed during the early phase of dendrochronological research. For example, Dunwiddie (1979: 262) observed rings 'of various degrees of clarity' in species such as *Beilschmiedia*, *Metrosideros* and *Weinmannia*. He noted that tawa (*Beilschmiedia tawa*) had ambiguous bands of parenchyma (cellular tissue) that could present as false ring boundaries (Figure 2a), as well as non-concentric (or lobate) growth. He also noted that indistinct ring boundaries were common in kamahi (*W. racemosa)* cores (Figure 2b). Such features can cause difficulties in discerning and accurately measuring annual rings. Therefore these species appear to have been subsequently discounted from chronology building efforts for dendroclimatology.

In contrast, research from Dunwiddie (1979) onwards has demonstrated the suitability of several native conifer species for dendrochronology, including kauri, and Podocarpaceae such as Pink pine (*Halocarpus biformis*), Silver

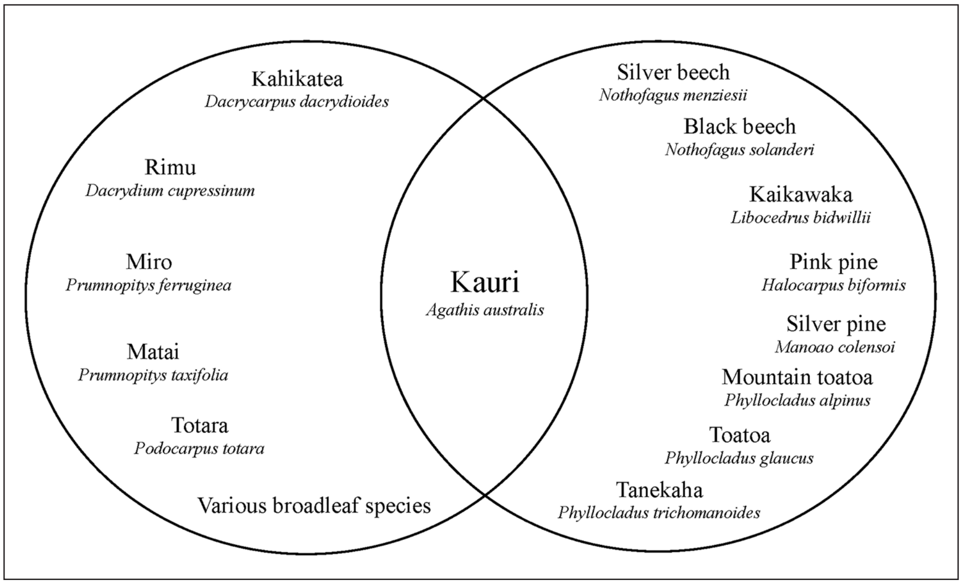

Figure 1. Overlap between coniferous species recorded in archaeological contexts (left) and species currently used for dendrochronology (right).

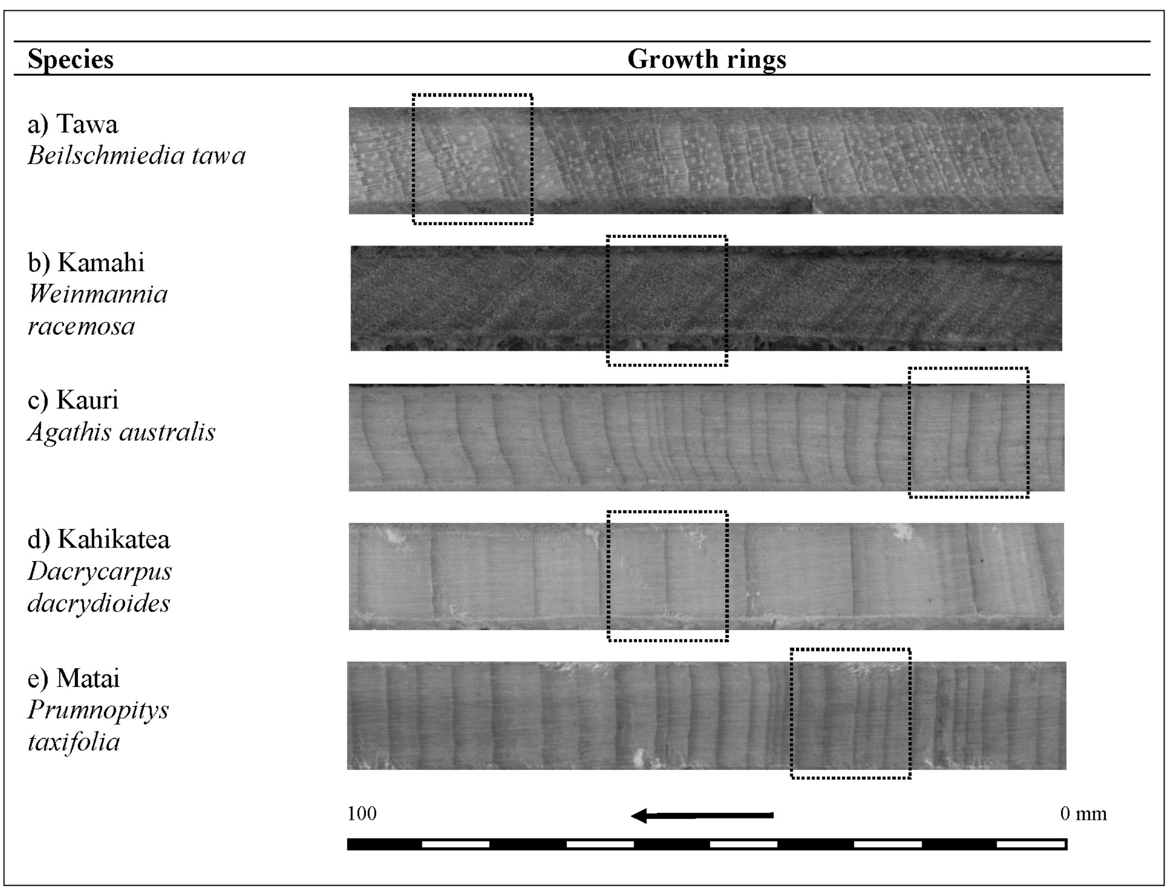

Figure 2. Growth rings of selected species. Particular characteristic features are highlighted (boxes): Tawa (*Beilschmiedia tawa*) can have ambiguous parenchyma bands forming apparent ring boundaries; Ring boundaries of kamahi (*Weinmannia racemosa*) are indistinct; Density fluctuations in kahikatea (*Dacrycarpus dacrydioides*), kauri (*Agathis australis*) and matai (*Prumnopitys taxifolia*) growth rings may be misinterpreted as true growth rings. The arrow indicates direction of growth from inner to outer rings.

pine (*Manoao colensoi*) and tanekaha (*Phyllocladus trichomanoides*). The use of other Podocarpaceae – kahikatea, matai, miro, rimu and totara – by Māori for construction of buildings and palisades, and for canoe hulls and components points to the potential importance of these five species for dendrochronology and archaeological dating.

ASSESSING DENDROCHRONOLOGICAL POTENTIAL

Identification of the potential of a species for dendrochronology is a necessary step towards development of tree ring chronologies which provide a framework for dendroarchaeological dating. This section presents current knowledge about the dendrochronological potential of kahikatea, matai, miro, rimu and totara, including a brief description of geographic distribution, ecology, cultural use and any previous tree ring related studies. Discussion of chronology development of kauri and its applications is also included as it is a benchmark for species useful for archaeological dating.

Kauri

Kauri is found in the upper North Island, northwards of 38°S, in mixed lowland forests up to 500 m and rarely to 800 m. The trees are large and long lived, commonly attaining ages in excess of 600 years. The dendroarchaeological utility of kauri was noted by Batley (1956). As a material, kauri was used in the pre-contact era for construction of waka, for house timbers and carvings, and for smaller items such as fern root beaters (Wallace and Irwin, 2004). From the early 1800s an extensive trade in kauri timber developed for masts and spars, and after the 1860s industrialised production of kauri timber supplied a domestic and international market with timber for construction and manufacturing (e.g. furniture, boats) until the 1930s.

The dendrochronological potential of kauri was assessed by Bell and Bell (1958), and investigated by LaMarche (1979) and Dunwiddie (1979). Dunwiddie observed that ring clarity was generally good but circuit uniformity was highly variable, and that kauri had three dendrochronological problems. The first of these was locally absent rings, where an annual ring is not formed completely around the circumference. The second problem was lobate growth – local suppression and acceleration of growth that migrate around the tree as it grows. The third problem was a lack of ring pattern consistency around the circumference such that a ring which was relatively narrow on one radius was unusually wide on another. These could cause problems with intra- and inter-tree crossmatching. However, Dunwiddie (1979) noted that under certain conditions these problems could be minimal and crossdating was excellent. A fourth issue is the formation of density bands within a ring that could be misinterpreted as a true ring (Figure 2d).

Further work from the 1980s demonstrated that these problems were not insurmountable. Seasonal growth studies confirmed that kauri add one annual growth ring with growth starting in late September and finishing by May (Wunder *et al.*, 2013). Careful crossmatching and intra-tree replication enabled resolution of ring issues. Tree ring chronologies were built from sites distributed throughout the natural range of kauri and the presence of a common signal in kauri was demonstrated by intra- and inter-site crossdating and correlation analyses (Ahmed and Ogden, 1985; Fowler *et al.*, 2000). Identification of sensitivity to the El Nino-Southern Oscillation (Fowler *et al.*, 2000) prompted a significant phase of wood collection and chronology development between 2002 and 2014. Several modern sites were revisited and updated, capturing tree growth from the mid-1980s to early 2000s, and sub-fossil kauri was collected from the Waikato Lowlands and north Kaipara district. Wood from 19th and early 20th century buildings was also analysed. This archaeological material was critical to linking modern and sub-fossil chronologies (Boswijk *et al.*, 2014). By 2014, over 50 reference chronologies had been developed from modern, archaeological and sub-fossil kauri, a 4500-year chronology had been built (Boswijk *et al.*, 2014) and a 700-year reconstruction of ENSO variability produced (Fowler *et al.*, 2012).

Kauri has proven suitability for archaeological dating. Outcomes from analysis of multiple assemblages from 19th and early 20th century structures has demonstrated that tree ring analysis can provide calendar dates, including felling dates, useful to aiding understanding of construction and phasing of standing structures (Boswijk and Jones, 2012; Furey, 2011) and in-ground sites (Adamson and Bader, 2013; Boswijk *et al.*, 2016).

Kahikatea

Kahikatea (*Dacrycarpus dacrydioides*, formerly *Podocarpus dacrydioides*) is an endemic, dioceous, evergreen tree that occurs throughout New Zealand, predominantly on lowland alluvial and swampy soils. It is New Zealand's tallest tree, reaching heights of 60 m (Poole and Adams, 1990). As indicated above, and in Table 2, kahikatea was used by Māori for items such as posts and dressed timber, however, it is not durable which may limit its use for dendrochronology. During the early 20th century, the extent of kahikatea forest was considerably reduced due to timber milling as the light, non-tainting timber was favoured for butter and cheese boxes, as well as other uses such as picture frames, kitchen utensils and scrubbing boards (Park, 1995).

The growth ring boundaries of kahikatea were described by Patel (1967) as indistinct. Dunwiddie (1979) recorded that the species had good ring clarity (Figure 2d) but was prone to lobate growth. Arlidge (1992) and Kennedy (2012) examined kahikatea growth ring formation. Both authors observed that growth starts in about September and ends in May, although Arlidge (1992) also noted possible winter increment on samples obtained for seasonal growth studies. They each reported that identification of true rings was affected by anomalous features within the rings, including false rings indicated by an apparent boundary during the growing season (Figure 2d) and locally absent or missing rings. Arlidge (1992) also identified a gender difference in the timing of maximum wood growth. For female trees the highest rate of wood growth occurred in spring prior to cone production, whereas on male trees spring production of male cones coincided with low growth.

Bell and Bell (1958) collected kahikatea samples but did not explore the dendrochronological potential of this species in detail. They noted that a single specimen crossdated with totara and suggested further study on this species should be done. As part of the 1970s LTRR collection program kahikatea samples were collected from a single site at Ngahinapouri, Waikato, but no site chronology was developed (LaMarche, 1979; Dunwiddie, 1979). Arlidge (1992) examined the dendrochronological potential of kahikatea. She observed that male trees had higher mean sensitivity and there was a slight (though not statistically significant) difference in ring width, with males tending to have wider rings than females. Trees from the same site had similar ring patterns but crossdating was difficult due to anomalous rings. Kennedy (2012) also showed that it was possible to crossmatch trees from the same site, demonstrating presence of a common signal. Inter-site crossdating was inconclusive, however, and crossdating in general was 'technically demanding' due to anomalous growth patterns (Kennedy 2012: 97). The outcomes of these projects suggest that kahikatea is likely to present a range of challenges to chronology development and that at this stage its utility for archaeological dating is limited.

Matai

Matai (*Prumnopitys taxifolia* formerly *Podocarpus spicatus*) is a large, endemic, evergreen tree, reaching heights up to 35 m (Poole and Adams, 1990) and ~125 cm diameter (Patel, 1967). It is usually dioecious with male cones and female ovules occurring on separate trees (McEwen, 1988). It is present throughout North and South Island and abundant in central North Island. Matai is potentially significant for dendroarchaeology due to its use for buildings, posts, palisading, and large objects, including waka fittings (Johns, 1996; Johns, 2000; Johns *et al.*, 2017) and three early waka hulls, prow and large waka fixtures (Irwin *et al.*, 2017). In the 19th and early to mid-20th century matai was used as a construction timber, particularly for flooring, resulting in considerable loss of mature matai forest.

The growth rings of matai were described by Patel (1967) as indistinct to slightly distinct. In contrast, Dunwiddie (1979) observed that matai had clear sharp rings (Figure 2e) with little individual wedging; however, lobate growth was pronounced in the samples examined. He considered that matai was a promising species for dendrochronology and ages of 800 to 1000 years were considered likely, but no tree-ring chronologies were produced at that time.

Modern samples have been collected for studies of matai ecology and forest dynamics from central and upper North Island (e.g. (Bellingham, 1982; Lusk and Ogden, 1992; Willems, 1999), to investigate the effects of earthquake-induced disturbance on South Island west coast forests (Wells *et al.*, 2001; Cullen *et al.*, 2003), for radiocarbon studies (Sparks *et al.*, 1995), and to produce stable isotope chronologies (oxygen and nitrogen) from a Westland petrel colony (Holdaway *et al.*, 2007). These studies used ring counts to determine tree age but rarely applied dendrochronological principals of crossdating to establish accurate ring sequences. Bellingham (1982) undertook a basic assessment of matai's suitability for dendrochronology, using material from Pureora Forest, Waikato. He observed that matai could be very slow growing, with ring widths as narrow as 0.03 mm. He also noted that blocks of locally absent rings could occur causing discrepancies in ring counts between radii from the same tree and recommended the use of whole cross-sections to reconstruct ring sequences rather than core samples. His attempts at intra-tree cross matching were not successful but his methods did not follow standard dendrochronological approaches. Lusk and Ogden (1992) also noted potential for intra-tree crossmatching in their analysis of matai samples from central North Island but did not develop this further. Therefore, it appears that despite a number of collection programmes from sites distributed throughout New Zealand no tree ring chronologies have been built for matai. Further research is required to determine the potential of this species for chronology development and archaeological dating, especially given the early use of matai by Māori for construction of a large, ocean-going canoe.

Miro

Like matai, miro (*Prumnopitys ferruginea* formerly *Podocarpus ferrugineus*) is a large tree, reaching heights of 40 m (Poole and Adams, 1990) and ~125 cm diameter (Patel, 1967). It is also usually dioecious (McEwen, 1988). Miro is found in lowland and montane forest throughout New Zealand (Poole and Adams, 1990). Young miro (~60 years old) were used in the palisade at Otāhau Pā (Hogg *et al.*, 2017). Miro was treated by Europeans as a timber tree and used for construction and joinery (Clifton, 1994).

Dunwiddie (1979) indicates that miro has clear sharp rings with little individual wedging but dendrochronological research on this species has been limited. Tree-ring samples were collected from two North Island sites by LaMarche (1979) but no chronologies were developed. However, miro samples have been collected for ecological studies on stand disturbance histories and population structures (e.g. Cullen *et al*, 2003; Duncan, 1993; Lusk and Ogden, 1992; Lusk and Smith, 1998). In these studies, age counts were obtained but no intra- and inter-tree crossmatching was undertaken. The three young miro posts from Otāhau Pā, Waikato, sampled by Hogg *et al.* (2017) had wide rings and were complete to the bark edge surface. They had complacent ring patterns (showing little year-to-year sensitivity) and intra-site comparison of ring series was inconclusive. However, the occurrence of miro roundwood in archaeological contexts makes it a candidate for further research to assess its suitability for chronology development and archaeological dating.

Rimu

Rimu (*Dacrydium cupressinum*) is an endemic, dioecious, evergreen tree that is found in lowland and montane forest throughout most of North Island and western and southern South Island (Franklin, 1968). It is tall, reaching heights to 35 m and occasionally up to 60 m, and long lived achieving ages of ~600 years and sometimes around 1000 years (Norton *et al.*, 1988). The timber was used by Māori for purposes such as waka planking (Irwin *et al.*, 2017). After European settlement rimu became an important timber species used for construction, joinery and plywood manufacture (Franklin, 1969).

Bell and Bell (1958) list rimu amongst species collected for tree-ring analysis but make no mention of the species potential in their paper. Early research has included investigation of whether the growth rings represent annual increments. Franklin (1969) identified common marker rings in different samples for the same years suggesting the rings are annual. There was also evidence of discontinuous (locally absent) rings and effects of fluting on growth ring formation. Dunwiddie (1979) noted the occurrence of lobate growth affecting circuit uniformity. Rimu samples from three North Island forest sites were collected by LaMarche (1979) but no site chronologies have been reported from these assemblages. In a tree-ring based study of rimu from the west coast of South Island, Stewart and White (1995) attempted to crossmatch ring width series but with only limited success. The inner 200 rings of their samples were 'relatively concentric and possible to crossmatch' (Stewart and White, 1995: 29) but intra-tree matching of outer rings was difficult. In general, accurate aging/measurement of samples was affected by poor circuit uniformity associated with asymmetric growth and wedging of growth rings. The findings from these studies suggest that rimu is likely to present a range of challenges to chronology development.

Totara

Totara (*Podocarpus totara*) and Halls totara (*Podocarpus cunninghamii* formerly *hallii*) are widely distributed in lowland forests throughout New Zealand, up to 600 m in North Island and to 500 m in South Island (Bergin and Kimberley, 1992). The trees can reach heights up to 30 m, with trunks up to 2 m in diameter, and can be long lived with larger trees estimated to be 1000 years or more (Bergin, 2000). They are dioecious with separate male and female trees (McEwen, 1988). Totara has high cultural and spiritual values to Māori, and the wood and bark was used for multiple purposes (Simpson, 2017: 109, 143). At Kohika, the majority of timbers associated with whare construction and canoe hull pieces and an ornamental carving were totara (Wallace and Irwin, 2004). In the 19th century, totara was favoured as a construction timber, and for fence posts, wharf piles and sleepers (Simpson, 2017: 165).

Batley (1956: 240) considered that totara would take 'pride of place' in any investigation of tree ring dating in New Zealand because the timber was 'fully employed by the Māori for the construction of canoes and for building and decorative purposes' and because of the durability of the wood, the presence of worked totara in collections in New Zealand and overseas, and the practice of bark removal by Māori which 'has left chronological signposts throughout the country'. In spite of his optimism, the dendrochronological potential of totara has not been fully realised. Wells (1972) identified that Hall's totara formed annual rings. Dunwiddie (1979) noted that ring clarity was generally good but the species had severe problems with ring wedging and lobate growth, and Bergin (2000) indicates that many researchers have experienced difficulties in counting totara rings due to poor definition, anomalous rings, and lack of circuit uniformity. Recently, Bergin and Kimberley (2012) investigated ring clarity of *Podocarpus totara* (totara) in planted stands. They observed that visibility of latewood bands, used in their study to indicate growth rings, was variable and affected by growth rate and seasonal climate. They suggest that fast growing trees may form more than one growth ring per year and that additional bands are difficult to discern particularly as during warm winters there may not be an abrupt cessation of growth. These findings suggest that totara may be a challenging species for dendrochronology but, given its significance to and widespread use by Māori, the dendrochronological potential of totara should be investigated further.

CONCLUSION

As Norton and Ogden (1987) pointed out, we need to assess the capacity of tree species found in cultural contexts for chronological dating as a first step towards using dendrochronology to date Māori wooden artefacts. Currently, we can use only kauri, with the first attempt at tree-ring dating waka already undertaken by Boswijk and Johns (2018). However, the range of kauri is restricted to the upper North Island and, as shown above, Māori used a wide variety of tree-species to make domestic items, structures and canoes. Many of the broadleaf species may be unsuitable for tree-ring analysis mainly because of ring morphology, and previous work suggests that the growth characteristics of kahikatea and rimu present particular challenges to tree-ring analysis. Consequently, it is recommended that they are not investigated further at this time. In contrast, the podocarps matai, miro and totara are all archaeologicallyimportant, and prior research suggests some potential warranting comprehensive investigation of these three species.

Such tree-ring based research requires going back to basics and addressing fundamental questions for each species concerning: the seasonality of growth rings; sensitivity to a common climate factor limiting tree-growth; the ability to crossmatch ring width patterns within and between trees, and the effect of any potential sex-based difference in the growth pattern. The next step is construction of site chronologies and examination of inter-site crossdating. The development of a network of modern reference chronologies from different regions would enable identification of the geographic extent of a common tree-ring signal. This informs our ability to crossmatch material of unknown provenance against reference chronologies, which has particular value for portable objects such as canoes which may be recovered from sites distant to their construction origin. The potential for inter-species crossdating, e.g. between the three podocarp species discussed here, could also be investigated as another approach to increase scope for tree-ring dating.

Alongside this work, the suitability of different types of artefacts for dendrochronological dating also needs to be assessed. As highlighted in the introduction, the species, function, size and condition of the object will affect whether tree-ring dating is appropriate and the potential for obtaining a useful dendro date. Many of the items listed in Table 2 would not be suitable for dendrochronology because of species type or size, but it is evident that larger items such as palisade posts, and timber elements from structures and canoes, have potential.

The benefit of this work for New Zealand is to further develop a scientific method that has potential to provide accurate and precise calendar dates for wood from archaeological contexts. For example, Otāhau Pā had preserved roundwood posts that still retained the final growth ring, potentially ideal for dendrochronological dating. In such situations, crossdating of ring series from multiple posts against a calendar-dated reference chronology could provide precise calendar dates for each object. If the date of terminal ring on each sampled post is known, the tree felling event (or events), and by extension, palisade construction or repair, would be accurately fixed in time. The provision of such dates can only benefit interpretation of the site's spatial and temporal history. Even in situations where conversion processes have removed outer rings, such as in the manufacture of canoes, a tree-ring date would provide a *terminus post quem* for construction of the craft. In conjunction with radiocarbon dating of short lived material such as fibre used in the vessel, it may be possible to refine the age of the object. Again, such information can only assist in improving understanding of aspects of manufacturing and use, and enable them to be explored spatially and temporally. The long term outcome would be to contribute to improving chronology for New Zealand's prehistory.

Acknowledgments

We thank two anonymous reviewers for their comments which have helped improve the paper.

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