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Hidden histories: Tree-ring analysis of late Holocene swamp kauri, Waikato, New Zealand

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ABSTRACT: Three assemblages of sub-fossil (swamp) kauri (*Agathis australis* (D. Don.) Lindl) were collected from two sites, Pukekapia Road (PUKE) and Furniss Road (WHAN/FNSR) in the lower Waikato Lowlands, North Island, New Zealand. Three site-chronologies were produced and crossdated to form a 2593 year record of kauri growth, radiocarbon dated to ca. 3500 – 1300 BP. This precedes and is contemporary with a rise in kauri pollen observed at other sites in the Waikato lowlands. One generation of trees grew at PUKE between 3500 – 2800 BP, where recruitment and dieback of trees occurred over several hundred years. The WHAN/FNSR record spans ca. 3000 – 1700 BP, with a single tree extending the site record to ca. 1300 BP. The WHAN/FNSR chronologies have a more complex history than PUKE, with a hiatus in recruitment, two mortality events and a change in generation. Recruitment rates appear slower than those modeled for modern kauri forest, and tree ages may be lower, but this is probably a reflection of the environment the trees were growing in. Mortality patterns are, however, similar. There is no evidence for a single major catastrophic event which killed many trees at the same time, even at the time of the ca. 1850 BP Taupo eruption.

1 INTRODUCTION

The New Zealand conifer kauri (*Agathis australis* (D. Don). Lindl) is found in the forests of the upper North Island. Its sheer size and bulk, and high quality timber, make it one of New Zealand's most notable trees. During the 19^{th} and 20^{th} centuries logging and land-clearance drastically reduced the extent of kauri forest. Today, kauri is found mostly on steep ridges and slopes, and occasionally on boggy plateaus, such as on Mt Moehau, Coromandel Peninsula (Cranwell and Moore, 1936) and the Warawara Plateau, Northland (Ahmed 1984). In the past however, kauri appears to have occupied a wider range of situations including on, or adjacent to lowland peat swamps, in which buried kauri is often found (Cranwell 1939, Gudex 1963).

The history of these buried kauri stands is poorly understood. The date of various deposits has been established via radiocarbon dating, indicating that the kauri is either older than ca. 20,000 years BP or is of Holocene date (Ogden et al. 1992). However, little is known about the age and population structure of these kauri deposits, or how they relate to the swamps they were found in (Ogden et al. 1992). The exposure of sub-fossil (or swamp) kauri as a consequence of clearance and drainage, and through commercial extraction, has provided an opportunity to apply dendrochronological techniques to investigate the history of the buried trees.

Dendrochronology, or tree-ring analysis, is based on the measurement and comparison of patterns of tree-growth from which long annually-resolved tree-ring chronologies can be derived (Baillie 1982). Kauri is one of several species endemic to New Zealand which are suitable for dendrochronology, and tree-ring records have been obtained from living and recently dead trees which extend back to AD 911 (Fowler et al. 2004). In the past 25 years samples of Holocene-age swamp kauri have also been collected from 11 sites in the upper North Island, and tree-ring chronologies are now being developed for several locations by the Tree-Ring Laboratory at the University of Auckland. This paper presents results from tree-ring analysis of three assemblages collected from two sites at Huntly West, in the lower Waikato Lowlands (Figure 1), where the construction of tree-ring chronologies established relative relationships between trees and enabled age, germination, and mortality trends to be identified. We can use such information to extend understanding of kauri ecology during the late Holocene.

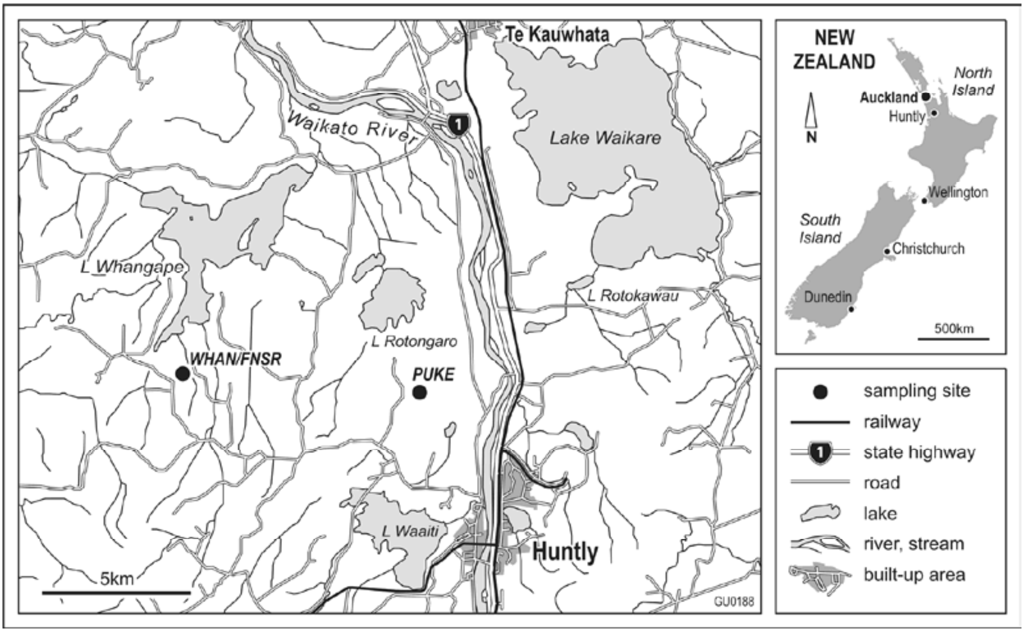

Figure 1. Location of PUKE and WHAN/FNSR swamp kauri sampling sites, Huntly West, lower Waikato lowlands, Waikato, New Zealand.

2 LOWER WAIKATO LOWLANDS

The sampling sites near Pukekapia Road (PUKE) and Furniss Road (WHAN/FNSR), Huntly West, are situated in the lower Waikato Lowlands, south of Auckland city (Figure 1). The lowlands are bounded by the Bombay Hills, Hapuakohe Range and the Taupiri Range. Locally, there are low rolling hills of Pleistocene age weathered sands, gravels and pumiceous silts of the Karapiro and Puketoka formations, and valley flats with Holocene age alluvium and peat below 20 m above sea level (Kear and Schofield 1968). The Waikato River flows northwest across the lowlands. Deposition of volcanic material alongside the Waikato River blocked tributaries, leading to the formation of shallow lakes and swamps (Lowe 1988), and, in some locations, oligotrophic raised bog (McGlone et al. 1984).

Ferdinand Hochstetter (1867: 294), an Austrian geologist who visited New Zealand during the 1850s described the lower Waikato Lowlands as having "a luxuriant vegetation of water and swamp plants" with kahikatea (*Dacrycarpus dacrydioides*) forest on the swamp edges and hardwood-podocarp forest on the hills. Almost all of the forest has since been cleared and 85% of the swamps drained and converted to agricultural use (Cromarty and Scott 1995).

3 MATERIALS AND METHODS

15 cross-sections were collected by Martin Bridge in 1983 from swamp kauri exposed on a paddock east of Pukekapia Road (PUKE), Huntly West (NZMS 260 S13 985075), south of Lake Rotongaro and west of the Waikato River (Bridge and Ogden 1986). The cross-sections were cut using a chainsaw from near the base of the trunks. A 491 year tree-ring chronology was developed by Bridge and Ogden (1986) from five samples, which was dated to ca. 3500 – 3000 BP.

Bridge also collected 15 cross-sections from swamp kauri trunks which had been recently extracted from farmland west of Furniss Road (FNSR), Huntly West (NZMS 260 S13 920070) south of Lake Whangape. The wood was archived, unanalyzed, at the University of Auckland. During the late 1990s 31 new samples (WHAN group) were collected by Jonathan Palmer and Alan Hogg from woodpiles in the same locality. An additional sample, FNS100, was collected in 2004 from a section of head log (the upper part of the tree where branches start to emerge) recently recovered from the same swamp system.

Details of sample preparation and analysis for each assemblage are provided in Boswijk et al. (2001), Fowler et al. (2001) and Boswijk and Palmer (2003). In brief, ring widths from up to six radii were measured from each sample. The radii were crossmatched and then averaged together into a tree-sequence, which was subsequently used for inter-tree crossmatching and chronology development. The programs CROS (Baillie and Pilcher 1973), included within the Dendro for Windows suite (Tyers 1999), and XMATCH (Fowler 1998) were used to aid crossmatching. All suggested matches were checked visually using line plots.

Line plots were also used to aid identification and resolution of ring problems. Kauri can produce 'false' rings, where the annual ring is divided by an apparent boundary, or locally absent rings, where the annual ring is not complete around the entire circumference. Occasionally clusters of locally absent rings can occur, affecting the suitability of the sample for crossmatching.

4 RESULTS

4.1 *Site Chronologies*

A new version of the PUKE site chronology (*Pukekapia*) was developed, incorporating five more trees and extending the record by 312 years compared to Bridge and Ogden's (1986) original chronology (Fowler et al. 2001). Two new site chronologies were developed for the FNSR and WHAN assemblages (Boswijk et al. 2001, Boswijk and Palmer 2003). Comparison of chronologies against each other identified a 258 year overlap between *Pukekapia* and *Whangape*, and a 185 year overlap between *Whangape* and *Furniss1*. In addition, a single sample from PUKE crossmatched with *Furniss1*. The combined chronologies spanned 2133 years[1]. All tree-sequences were assigned relative dates from 1 to 2133 years, according to their crossmatched position.

Radiocarbon dates had been previously obtained at different times for the PUKE assemblage (Bridge and Ogden 1986), and the FNSR and WHAN groups (Boswijk and Palmer 2003). To constrain the time period, decadal blocks were sampled for radiocarbon dating at 400 year intervals

[1] This differs by one year to the span published in Boswijk and Palmer (2003). A one year difference was identified when the Whangape chronology was crosschecked against other contemporary swamp kauri chronologies. Visual checking of the wood identified a false ring in the Whangape series, which has been corrected.

across the entire length of the combined record (Table 1). The chronologies were radiocarbon dated to ca. 3500 – 1700 BP (1740 cal BC – 390 cal AD).

Since then, the recent addition of the head-log sample, FNS100, has extended the WHAN/FNSR site record forward in time by 421 years, to end at ca. 1300 BP. Using the calibrated end date for *Furniss1* as a guide, the gap between the end of the head-log tree-sequence and the modern, calendar-dated record may be as little as ca. 100 years.

Table 1. Details of site chronologies and radiocarbon dates. The table lists the site code, number of trees and radii included in each chronology, and the chronology length (years). Two radiocarbon samples were obtained from each chronology. These were assigned a WK code by the Waikato Radiocarbon Dating Laboratory. Radiocarbon dates are conventional age based on the Libby half-life of 5568 years with correction for isotopic fractionation applied. ^{14}C dates were calibrated and wiggle-matched using OxCal v3.9 (Bronk Ramsey 1995, 2001, Bronk Ramsey et al. 2001), using atmospheric data from Stuiver et al. (1998) and southern hemisphere offset of 27±5 (McCormack et al. 1998)

Chronology	Site Code	No. Trees/Radii	Length (years)	^{14}C Sample	Waikato Code	^{14}C date (BP)	Calibrated date (2σ)
Pukekapia	PUKE	10/41	803	Waik001	WK13896	3441 ± 41	1740 – 1610 cal BC
				Waik002	WK13897	3119 ± 40	1340 – 1210 cal BC
Whangape	WHAN	27/65	1050	Waik003	WK13898	2738 ± 40	940 – 810 cal BC
				Waik004	WK13899	2443 ± 38	540 – 410 cal BC
Furniss1	FNSR	9/38	724	Waik005	WK13900	2073 ± 38	140 – 10 cal BC
				Waik006	WK13901	1707 ± 38	260 – 390 cal AD

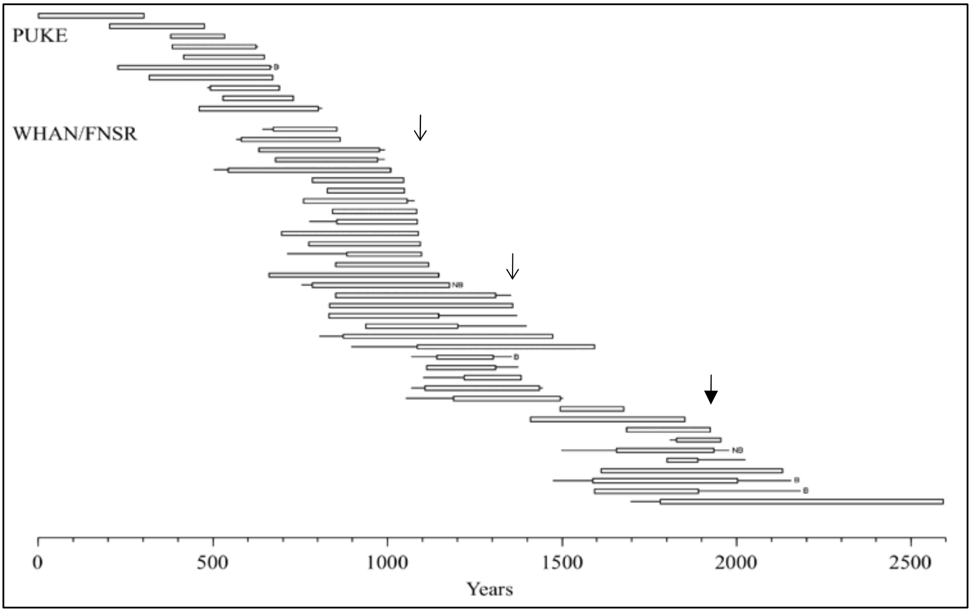

Figure 2. Relative positions of all tree-sequences included in *Pukekapia* (PUKE), *Whangape* and *Furniss1* (WHAN/FNSR), aligned by end-date. Each bar represents the dated span of a tree-sequence. Narrow lines indicate unmeasured rings. B = bark edge surface. NB = near bark edge surface. Open arrows indicate the Whangape mortality events. Closed arrow marks the approximate timing of the ca. 1850 BP Taupo Eruption.

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4.2 *Stand history*

Figure 2 illustrates the relative position of the tree-sequences included in each chronology. One PUKE sample and three WHAN/FNSR samples retained the final growth ring at the bark-edge surface, and two samples appear to end close to bark-edge. Survival of the final growth ring at the bark-edge surface enables the year, and sometimes season, of death to be identified. Unfortunately, suppressed and locally absent rings, or poor quality wood, prevented measurement or crossmatching of these sequences to bark-edge.

4.2.1 *Age*

Modern kauri commonly achieve ages upwards of 600 years, and trees >1000 years old are not uncommon (Ahmed and Ogden 1987). Figure 3 shows the number of crossmatched tree-sequences grouped by number of rings. The PUKE tree-sequences were all <500 years long. Of the WHAN/FNSR tree-sequences 32 (of 38) were <600 years long. The longest tree-sequence, from the head-log, had 898 rings. Most samples had lost outer rings as a consequence of pre-burial or, more likely, post-exposure decay. However, the survival of final outer ring on one PUKE tree and four WHAN/FNSR trees suggest that the PUKE kauri and the majority of WHAN/FNSR trees did not achieve ages similar to the oldest modern kauri.

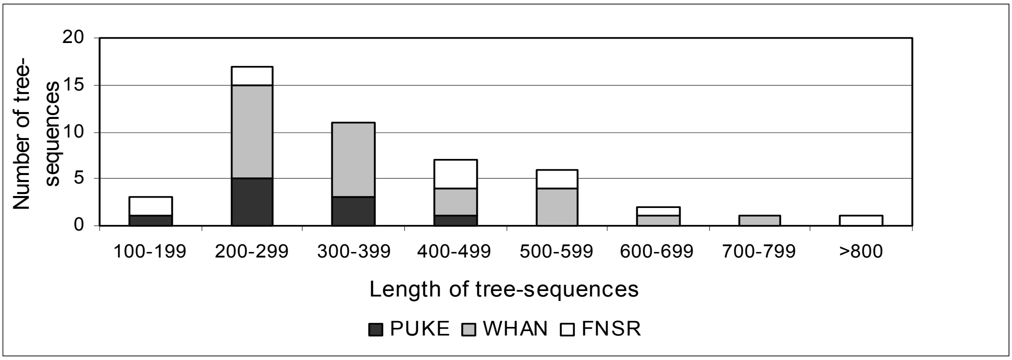

Figure 3. PUKE and WHAN/FNSR tree-sequences grouped by length.

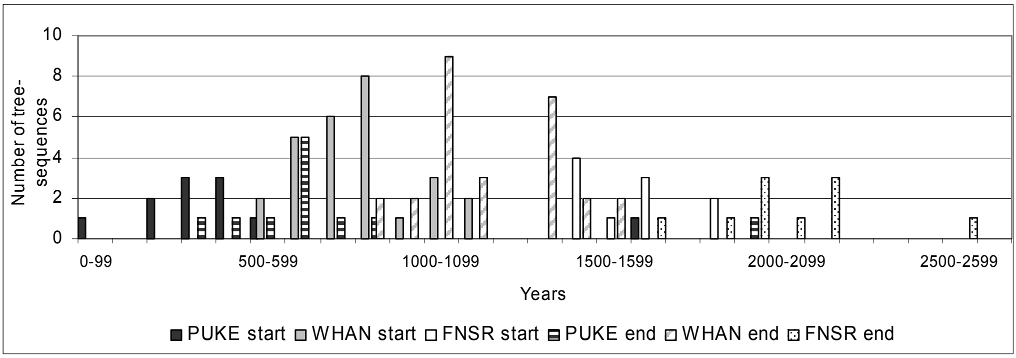

Figure 4. Recruitment and mortality trends for PUKE and WHAN/FNSR kauri, in 100 year blocks by start- and end date.

4.2.2 *Recruitment/mortality trends*

Recruitment and mortality trends can be inferred from start- and end-dates of tree-sequences (Fig 4). At PUKE, start-dates are spread over 600 years, with a similar distribution in end-dates. Five trees end between 600-699 years, one of which retained bark-edge (died in relative year 670). There is no evidence of regeneration at PUKE, although the crossdating of a single sample 884 years after the end of the Pukekapia chronology hints at a longer history of kauri at the site.

As the PUKE trees decline, kauri are increasing at WHAN/FNSR, peaking at eight trees between 800-899 years. Most noticeably there is a hiatus in start-dates of 297 years between the WHAN group and the start of the FNSR kauri, which is bracketed by two mortality events.

Both mortality events can also be seen clearly on Figure 2. The first event is signaled by the alignment of end-dates for 14 tree-sequences between 992 and 1178 relative years. In particular, eight tree-sequences have end-dates between 1048 – 1098 relative years. Although these samples have lost an unknown number of outer rings, the pattern strongly suggests that the trees were dying at around the same time. There is however, no evidence for, or against, a synchronous event.

Six tree-sequences extend through the first mortality event, although two had numerous locally absent rings or suppressed growth, which suggests that the growth of these trees was affected by some kind of disturbance. In addition, five tree-sequences start during this period, but the inner sections of four samples were unsuitable for crossmatching, due to narrow rings and/or locally absent rings.

The second mortality event occurs towards the end of the Whangape chronology. Seven trees, including both 'old' and 'young' trees, have closely aligned end-dates between 1355 – 1399 relative years. One tree-sequence retained the final growth ring (died at the end of, or after the growing season). Other tree-sequences end shortly after this date, implying that the trees died at around the same time, but not at the same time.

The second mortality event marks a change in generation, as the FNSR trees begin to be established after many of the WHAN trees end. Recruitment of the FNSR trees appears gradual, as does the decline in tree numbers. However, the outer rings of four samples were unsuitable for crossmatching, either due to suppressed growth or a high incidence of locally absent rings, indicating some kind of disturbance affecting the trees. One sample ended close to the bark-edge surface, and two had the final growth ring present. Of these two trees, one tree died during the growing season (the final ring was incomplete). The quality of outer wood on the other sample was poor, and it was not possible to determine how complete the final ring was. These two tree-sequences end (at least) 26 years apart.

5 DISCUSSION

The kauri were recovered from peat at both sites, emerging as the swamps were drained and peat shrank. The trunks were not in-situ when sampled, and unfortunately there is no associated environmental evidence from either site, such as a pollen/peat stratigraphic record, or basal peat dates, to aid setting the kauri chronologies in context with the swamps.

Elsewhere in the wider Waikato region, peat formation began after 7000 – 6000 BP, and palynological records suggest local expansion of kauri near lakes, and on, or adjacent to, swamp and raised bogs after 3000 BP as marginal ground became drier (McGlone et al. 1984, Newnham et al. 1989). The kauri chronologies discussed here precede and overlap with this period of kauri expansion. The location of the sampling sites and the preservation of trunks suggest that the chronologies represent kauri growth on the margins of, and possibly on, existing peat swamp; perhaps spreading out from the adjacent low hills.

Growth in such conditions may also account for the apparently shorter lifespans of the PUKE kauri and many of the WHAN/FNSR kauri, compared to modern dryland kauri. Kauri have fine lateral feeding roots in the upper 10-20 cm of the soil layer, as well as peg roots (Wardle 1991). Changes in waterlevel could adversely affect the stability of trees, or cause trees to become moribund. Trees growing on permanently wet, poorly oxygenated soils may have less well developed root systems, making them more vulnerable to fluctuations in waterlevels or windthrow (Koslowski 1984).

One generation of trees has been identified at the PUKE site, dated to ca. 3500 – 2800 BP and at WHAN/FNSR two generations of trees occurred between ca. 3000 – 1700 BP. The recent cross-matching of a single tree-sequence from the same site, which ends at ca. 1300 BP indicates that kauri were present in the locality until relatively recently.

The gradual, but persistent recruitment pattern at both sites implies sufficiently dry conditions to allow kauri to become established. This occurred between ca. 3500 – 3000 BP at PUKE, and between ca. 3000 – 2500 BP, and ca. 2300 – 1900 BP at WHAN/FNSR. The rate of recruitment is slower than that modeled for kauri in dryland forest (Ogden and Stewart 1995), but this may reflect the environment the trees were colonizing.

Between ca. 2500 – 2300 BP a hiatus in tree recruitment occurred at WHAN/FNSR. This, in itself, is not especially remarkable. Ogden and Stewart (1995) suggest that in kauri forest, and barring major disturbance, recruitment of new kauri may not occur until the existing cohort has become senescent, creating a 'regeneration gap'. The transition from *Whangape* to *Furniss1* could fit this model. However, the hiatus occurs in conjunction with two mortality events. The first period of die-back affected only some kauri, potentially released existing young trees but did not result in recruitment of new trees. Canopy gaps may have been filled by lateral growth of existing trees, preventing recruitment of new seedlings (Ogden and Stewart 1995). Fallen trees may also have impeded drainage, causing the environment to become too wet for new trees to become established; kauri are quite large and could act as effective dams. Cranwell (1953) notes that the best preservation of kauri occurred where there was rapid accumulation of acid peat, perhaps caused by ponding. Such a change in conditions may have contributed to the loss of trees in the second period of dieback, ca. 200 years later.

The WHAN mortality events contrast with the more gradual rate of dieback apparent in the PUKE and FNSR groups (Fig 2). This may be indicative of peat growth, with trees declining (and being preserved) as the swamps expanded upwards and outwards. Ogden et al. (1992) comment that waterlogging does not necessarily indicate wetter climatic conditions and suggest that tectonic lowering and/or sea-level rise may be more likely causes of increased wetness. Volcanic activity would also affect swamp hydrology, through deposition of ash and alluvium on terraces adjacent to the river.

Three eruptions from the Taupo Volcanic Zone occur during the span of the WHAN/FNSR chronologies: the Whakipo eruption at ca. 2685 BP, the Mapara eruption at ca. 2160 BP and the massive, well-dated, Taupo eruption at ca. 1850 BP (Froggart and Lowe 1990). The latter eruption occurred towards the end of the FNSR chronology. Palynological evidence suggests that there was no decline in forest pollen from the Waikato associated with the Taupo eruption and that forest was probably not damaged by a thin layer of ash (Wilmshurt and McGlone 1996). However, the eruption would probably have had a significant impact on the lake and swamp system, as the Waikato River was a major pathway for mudflows and flooding after the eruption (Wilson and Walker 1985). It is interesting to note that there is no evidence of sudden die-back of FNSR kauri around the time of the eruption, rather the pattern is of gradual loss of trees over the following ca. 200 years (Fig 2). The 'head-log' tree must have been in a suitable location, perhaps on the adjacent hills, as it continued growing until around ca. 1300 BP when the tree fell into the swamp.

6 CONCLUSION

Tree-ring analysis of swamp kauri from the Waikato Lowlands has built on the early work of Bridge and Ogden (1986), extending the sub-fossil kauri record from 491 years to over 2000 years. The tree-ring data complements palynological records from elsewhere in the Waikato lowlands, providing examples of kauri growth in potentially marginal locations at a time when kauri appeared to be expanding its range.

The age, recruitment and mortality patterns provide insight into the nature of the 'swamp' kauri forests of the late Holocene. Recruitment rates appear slower than those modeled for modern kauri forest, and ages may be lower, but this is probably a reflection of the environment the trees were growing in. Mortality patterns are similar to those suggested for modern kauri forests, with gradual dieback over time and occasional disturbance events, one of which promoted a change in generation. There is however, no evidence for a single major catastrophic event which killed many trees at the same time, even at the time of the ca. 1850 BP Taupo eruption. Instead, the assemblages represent the accumulation of trees which were established and declined over several hundred years at PUKE, and ca. 2000 years at WHAN/FNSR.

As other kauri assemblages, mainly from the Northland region, are analyzed it will be possible to determine if patterns observed in the Waikato Lowlands are replicated elsewhere, or if there are significant differences between regions.

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