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The scientific value and potential of New Zealand swamp kauri

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ABSTRACT

New Zealand swamp kauri (*Agathis australis*) are relic trees that have been buried and preserved in anoxic bog environments of northern New Zealand for centuries through to hundreds of millennia. Kauri are massive in proportion to other native New Zealand trees and they can attain ages greater than 1000 years. The export market for swamp (subfossil) kauri has recently been driven by demand for a high-value workable timber, but there are concerns about the sustainability of the remaining resource, a situation exacerbated in recent years by the rapid extraction of wood. Economic exploitation of swamp kauri presents several unique opportunities for Quaternary science, however the scientific value of this wood is not well understood by the wider research community and public. Here, we summarise the history of scientific research on swamp kauri, and explore the considerable potential of this unique resource. Swamp kauri tree-ring chronologies are temporally unique, and secondary analyses (such as radiocarbon and isotopic analyses) have value for improving our understanding of Earth's recent geologic history and pre-instrumental climate history. Swamp kauri deposits that span the last interglacial-glacial cycle show potential to yield “ultra-long” multi-millennia tree-ring chronologies, and composite records spanning large parts of MIS3 (and most of the Holocene) may be possible. High-precision radiocarbon dating of swamp kauri chronologies can improve the resolution of the global radiocarbon calibration curve, while testing age modelling and chronologic alignment of other independent long-term high-resolution proxy records. Swamp kauri also has the potential to facilitate absolute dating and verification of cosmogenic events found in long Northern Hemisphere tree-ring chronologies. Future efforts to conserve these identified values requires scientists to work closely with swamp kauri industry operators, resource consent authorities, and export regulators to mitigate potential losses to science as this precious material is progressively extracted from the ground and utilized.

1. Introduction

Kauri (*Agathis australis*) is an endemic conifer that occurs naturally in lowland forests of northern New Zealand (Ecroyd, 1982). They are iconic trees, achieving massive diameters (commonly over 1.5 m) with biological ages typically in the range of 600–1000 years (Ogden, 1983). The natural geographic range of kauri is constrained to the region north of 38°S, characterized by long, thin peninsulas, extensive coastlines, rugged topography, and river valleys with extensive wetlands (bog) locally referred to as ‘swamp’. These wetlands and former wetland environments can contain trunks and stumps of fallen kauri that may have been preserved for centuries through to hundreds of millennia. Preserved subfossil kauri (termed swamp kauri hereforth) is of interest to two parties: sawmillers, for economically valuable timber, and Quaternary scientists, for the chronological and environmental record that is preserved in the wood.

Swamp kauri has been excavated from northern New Zealand since at least the early 20th century. From the 1970s, swamp kauri has been collected by Quaternary scientists with interests in forest ecology, palaeoclimatology, and past environmental change (Dunwiddie, 1979; Bridge and Ogden, 1986; Ogden et al., 1993; Palmer et al., 2006; Boswijk et al., 2006, 2014; Lorrey, 2008; Lorrey et al., 2016a). Initial swamp kauri collections were

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salvaged from woodpiles after trees had been removed to improve lowland drainage. Often, the excavated wood was burnt or left to rot, but in the late 20th century recognition of the economic value of swamp kauri led to commercial extraction. In the 1990s, relationships were established between scientists and sawmillers who were engaged in extracting and milling swamp kauri timber. This enabled cross-sections (otherwise known as 'biscuits') to be obtained for scientific analyses when logs were removed from the ground. Outcomes of swamp kauri collections have included the multi-millennial calendar-dated late Holocene kauri chronology (Boswijk et al., 2006, 2014), floating tree-ring chronologies of early Holocene and late Pleistocene age (Boswijk et al., 2014; Lorrey, 2008; Palmer et al., 2016), and chronologies of atmospheric radiocarbon (^{14}C) for the late Holocene and late glacial (Palmer et al., 2006; Turney et al., 2010; Hogg et al., 2011, 2016a).

Since 2012, there has been a rapid increase in the commercial extraction and offshore export of swamp kauri wood (Lorrey and Boswijk, 2017). Recent estimates suggest 60,000 to 100,000 m^3 of un-milled material may be stockpiled at mill yards in northern New Zealand (Lorrey et al., 2016a). The accelerated rate of swamp kauri extraction and export overseas (MPI, 2016) presents something of a paradox for science: whilst new excavations can provide fresh material for Quaternary investigations, wood can also be lost from unknown excavations, partly due to a general lack of understanding about its scientific value. Here, we aim to address this issue by providing an overview of the scientific values of swamp kauri. To do this we present a review of the geography of swamp kauri, followed by the origins and applications of tree-ring and radiocarbon-based research on preserved wood. We then discuss the scientific values and benefits of swamp kauri. Our work incorporates recently acquired radiocarbon ages from archived kauri and new insight about the future prospects for the dendrochronology and palaeoclimatology potential of this subfossil wood resource.

2. The geography of swamp kauri

Kauri occur in Podocarp-broadleaf forests north of 38°S and are common up to 300 m altitude (Ecroyd, 1982), with some remnant forest patches reaching elevations of 600–700 m above sea level. Although now restricted in range due to the effects of deforestation, there is strong evidence that kauri thrived in lowland areas (Newnham, 1999) well before Polynesian arrival in the 13th century CE (Wilmshurst et al., 2011). Swamp kauri samples have been recovered from the Aupouri Peninsula in the far north of New Zealand (Ogden et al., 1992; Palmer et al., 2006) and as far south as the northern Waikato district (Fig. 1). The southernmost extent of recovered swamp kauri, which is dated to the late Holocene (Boswijk et al., 2006), is positioned slightly south of the modern limit for living kauri trees (Ecroyd, 1982; Steward and Beveridge, 2010; see Fig. 1). Skeet (1912) mentions the occurrence of buried kauri "a few feet below the surface" with large living trees growing over them. This observation indicates that into the early 1900s lowland forest systems may have contained both living and subfossil trees in juxtaposition, which is not currently observed (mainly as an artefact of deforestation and land use change). It is also highly likely that kauri formerly grew in close proximity or adjacent to wetlands and were able to occupy those sites when conditions suited (D'Costa et al., 2009a). Many former wetland systems in northern New Zealand have been extensively modified through drainage, kauri gum (copal) digging (Smith, 1952), and clearance for farming since the European colonization in the 19th Century CE. Spatial mapping of swamp kauri extraction sites by Lorrey et al. (2016a) indicates that the most recently excavated material originates from highly modified agricultural landscapes situated in valleys or in lowlands with slopes of less than five degrees. There is also a close association between sites where abundant kauri gum was unearthed (Smith, 1952) and some of the richest deposits of swamp kauri wood thus far excavated (Lorrey et al., 2016a).

Palaeoecological data indicate that during the late Quaternary kauri occurred across most of its modern latitudinal range, but its presence in lowland forest was spatiotemporally variable (see Fig. 2 references). Macrofossil and pollen evidence indicate kauri were most prolific during interglacial intervals and significantly diminished in extent during the last glacial maximum (LGM; ~26,000–19,000 cal y BP; Ogden et al., 1993; Elliot, 1998; Newnham, 1999; Newnham et al., 2017). These temporal changes in kauri prevalence through time imply environmental conditions for kauri were probably less suitable during full glacials and they were outcompeted (Ogden et al., 1992), and that kauri wood preservation may have been diminished when compared to warmer, wetter intervals that typified interglacial epochs and mild interstadials (Lorrey et al., 2009). Ogden et al. (1992) used spatial distributions of radiocarbon data to suggest that kauri may have expanded southward from a northern refugium after the end of the last glacial. However, the growing array of radiocarbon dates obtained since that study (Table 1), combined with palynological evidence, suggests instead that kauri was likely reduced in spatial extent within a mosaic pattern and/or represented in lesser proportion in northern New Zealand forests (Ogden, 1989) during glacial times, rather than simply confined to a restricted zone in the far north of the country (Fig. 2). It is currently thought that kauri is likely to have survived in small, favorable, microclimates where local conditions were more mild relative to generally harsher and colder (possibly drier and windier) mean climate state during the LGM (Newnham, 1999; Newnham et al., 2013, 2017; Lorrey and Bostock, 2017). Environmental niches that kauri may have occupied during the last glacial could include areas on the continental shelf that were exposed but are now submerged; however, only anectodal evidence of that situation exists at present.

In addition to the broad-scale climatic drivers creating conditions suitable for preservation through time, physical geography also influences spatial patterns of swamp kauri preservation. Lorrey et al. (2016a) used a combination of field survey, GIS-mapping, modern records of commercial extraction, and historical documents to understand the physical settings conducive to wood preservation. From this survey and review of other literature, it is evident that a range of geomorphic environments provided opportunities for kauri to be preserved, including: relic fluvial networks characterized by drowned, then in-filled former river valleys that are peripherally connected to modern meandering fluvial systems; relic coastal barriers that were formerly compartmentalized between rocky headlands and then abandoned during sea level regression; relic aeolian (parabolic and sand wave) dune systems inland of present coastlines that contain lakes or palaeolakes that formed as a result of migrating sand and/or abrupt drainage changes; and composite relic coastal barrier/aeolian dune complexes. Kauri has also been found in association with former volcanism sites (maars and in-filled eruption vents/craters; Hayward and Hayward, 1995), with tephras (Lorrey, 2008), and in former lake-proximal settings where ephemeral or aperiodic flooding may have occurred in the past (Boswijk et al., 2006, 2014).

Within the physical settings described above, swamp kauri most commonly occur within late Quaternary peaty sediments that are broadly described as mesic or humic organic soils (Lorrey et al., 2016a). In addition, podzol densipan, ultic-gley, brown sands, and acidic brown soil classification zones contain pockets of organic soils (dispersed across approximately 20% of their spatial extent) where swamp kauri has been recovered from small swales or hollows (Lorrey et al., 2016a). Reconstruction of tree-fall patterns and