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The late Holocene kauri chronology: assessing the potential of a 4500-year record for palaeoclimate reconstruction

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ABSTRACT

Millennial and multi-millennial tree-ring chronologies can provide useful proxy records of past climate, giving insight into a more complete range of natural climate variability prior to the 20th century. Since the 1980s a multi-millennial tree-ring chronology has been developed from kauri (*Agathis australis*) from the upper North Island, New Zealand. Previous work has demonstrated the sensitivity of kauri to the El Niño-Southern Oscillation (ENSO). Here we present recent additions and extensions to the late Holocene kauri chronology (LHKC), and assess the potential of a composite master chronology, AGAUc13, for palaeoclimate reconstruction. The updated composite kauri chronology now spans 4491 years (2488 BCE −2002 CE) and includes data from 18 modern sites, 25 archaeological sites, and 18 sub-fossil (swamp) kauri sites. Consideration of the composition and statistical quality of AGAUc13 suggests the LHKC has utility for palaeoclimate reconstruction but there are caveats. These include: (a) differences in character between the three assemblages including growth rate and sensitivity; (b) low sample depth and low statistical quality in the 10th–13th century CE, when the record transitions from modern and archaeological material to the swamp kauri; (c) a potential difference in amplitude of the signal in the swamp kauri; (d) a westerly bias in site distribution prior to 911 CE; (e) variable statistical quality across the entire record associated with variable replication; and (f) complex changes in sample depth and tree age and size which may influence centennial scale trends in the data. Further tree ring data are required to improve statistical quality, particularly in the first half of the second millennium CE.
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1. Introduction

Long, high resolution proxy records of past climate provide essential context for contemporary variability in climate, and for investigating forcing mechanisms of climate change (Bradley et al., 2011). Tree rings are a natural climate archive that is abundant, widespread and relatively easy to collect (Hughes, 2011: 18) and numerous multi-centennial palaeoclimate reconstructions have been derived from tree-ring data, mostly from the mid- to high-latitudes in the Northern Hemisphere, but also in the Southern Hemisphere (see Boninsegna et al., 2009; Jones et al., 2009; Hughes et al., 2011; Neukom and Gergis, 2012). However, to be able to capture a more complete range of natural variability prior to the 20th century, millennial or multi-millennial tree ring chronologies are required (Cook et al., 2006). Globally, few tree ring based climate reconstructions are more than 1000 years in length and there is also a geographic bias in the distribution of these records towards western North America and the high latitudes of Eurasia, with more long chronologies needed from mid-latitude regions in the Northern Hemisphere and from the Southern Hemisphere (Jones et al., 2009).

The development of millennial and multi-millennial tree-ring chronologies for dendroclimatology depends on the availability of long-lived species and deposits of preserved wood that grew in similar ecological environments, which can be linked into continuous calendar dated records and are assumed to express a common

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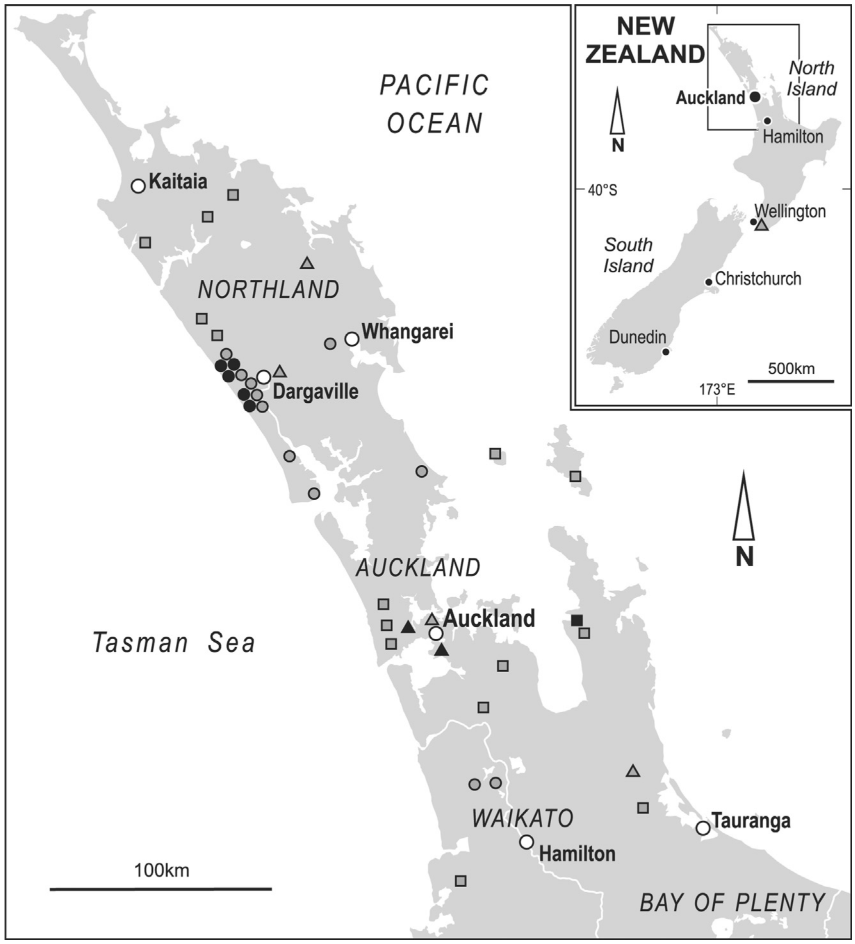

Fig. 1. Locations of modern (Mo), archaeological (Ar) and sub-fossil kauri sample sites (Sw). Only sites providing data used in the late Holocene kauri chronology are shown. Key: squares = modern; triangles = archaeological wood; circles = sub-fossil kauri. Note: some circles represent more than one site assemblage. Black symbols indicate new sites since 2008.

climate response (e.g. Cook et al., 2006: 694–696; Wilson et al., 2012; Cooper et al., 2013). In the Northern Hemisphere some multi-millennial chronologies have been built to address dendroclimatological questions (e.g. Linderholm et al., 2010; Büntgen et al., 2011) but many of the supra-long chronologies are composite records, constructed from living trees, wood from structures, and sub-fossil wood preserved in dry conditions at high altitudes or in wet situations, such as lakes, gravels or peatbogs. Chronology development was often driven by other questions, such as archaeological dating, radiocarbon calibration, or reconstructing landscape change, and there has been uncertainty about the utility of such records for dendroclimatology due to the changing sources of material. For example, the networks of bog oak chronologies from Ireland, Britain and Continental Europe have been applied to investigate broad scale patterns of environmental change, such as through exploration of signature years (Kelly et al., 2002) or germination and die-off events (Leuschner et al., 2002) but classic dendroclimatic reconstruction has been limited, presumably because of uncertainty concerning the climate response of trees that were growing on bogs compared to those in dryland situations.

In the Southern Hemisphere, multi-millennial composite chronologies have been built from tree species in South America, Tasmania and New Zealand. This includes the longest Southern Hemisphere chronology from the temperature-sensitive *Fitzroya cupressoides* (5666-years) from Northern Patagonia (Wolodarsky-Franke, 2002, cited in Lara et al., 2005), a 4136-year tree ring chronology from sub-alpine Huon Pine (*Lagarostrobos franklinii*), Tasmania, and 2327-year record from lowland Silver Pine (*Manoao colensoi*) from the South Island, New Zealand (Cook et al., 2006). The latter two species are also temperature sensitive and, although the chronologies incorporate living trees and dead wood, the material used in each record is from the same site or nearby locations.

A 3726-year kauri (*Agathis australis*) chronology has also been built for northern North Island, New Zealand (Boswijk et al., 2006). The late Holocene kauri chronology (LHKC) is a composite record based on data from multiple sites distributed mainly throughout the kauri region (Fig. 1). The data set comprises samples from: (a) dryland living trees (to 1269 CE) from predominantly lowland mixed forests of the upper part of the North Island (north of 38oS); (b) archaeological (= historical) timbers and logging relics (to 911 CE), and; (c) sub-fossil (swamp) kauri from low elevation sites in the Waikato Lowlands, Waikato, and Northern Wairoa region, Northland. Prior to 911 CE, the data set is wholly comprised of sub-fossil kauri. In addition, floating sub-fossil kauri chronologies have been constructed from preserved trees dating to the early Holocene (Hogg et al., 2013a) and from 'ancient kauri' for periods during MOIS 3 (e.g. Palmer et al., 2006; Turney et al., 2010).

Since the 1980s, considerable effort has gone into teasing out the climate signal contained in kauri tree rings. Statistical analyses of modern tree ring data have demonstrated: (a) strong regional scale forcing of kauri growth that is amplified in multi-site master chronologies; (b) that the El Niño-Southern Oscillation (ENSO) is a significant component of this forcing, and; (c) the reconstruction potential of kauri is confined to the ENSO state immediately prior to

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