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Understanding the scientific value of subfossil bog (swamp) kauri

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Contents

Executive summary

- A comprehensive literature review of national and international scientific research on subfossil bog (or swamp) kauri has enabled categorization of the main the scientific values of bog kauri.
- Published knowledge of subfossil bog kauri extends back into the early 20th century.
- There are three main locations where subfossil bog kauri are presently being archived for research in New Zealand; one tertiary institution, one Crown Research Institute and with one private scientist.
- There is one facility in New Zealand where we obtain high precision ages on subfossil bog kauri (University of Waikato Radiocarbon Laboratory).
- Subfossil bog kauri from Waikato through Northland range from several hundred years old to tens or even hundreds of millennia.
- Subfossil bog kauri tree ring samples are a globally unique resource to science. A similar resource is not likely to be found elsewhere.
- Subfossil bog kauri have widespread scientific value for improving our understanding of natural history of New Zealand, including the fields of palaeoecology, palaeoclimate, environmental change, geochronology (radiocarbon dating) and analysis of extreme events.
- There is a wide range of capability and capacity for collecting and studying subfossil bog kauri across a range of researchers involved in this project, who now form a subfossil kauri consortium. The national contact for this consortium is the lead author of this report.
- The greatest risks to subfossil bog kauri scientific values are connected to continued loss of wood in the absence of scientific evaluation.
- Inadequate knowledge of current and new subfossil bog kauri excavations (and ability to access those sites), stockpiles of wood previously excavated, loss of information within subfossil wood and associated stratigraphic and geomorphic settings that relate to the buried wood, an inability to curate and analyse subfossil wood in the present and future, and an inability to prevent wood deterioration are all risks that can be mitigated.
- Recommendations to mitigate risks for subfossil bog kauri scientific values are founded on involving scientists from the time a site is identified through the extraction consent application and milling statement approval process.
- Improving access to current and future wood excavation sites, setting baselines for submitting radiocarbon ages and a high proportion of wood samples to nationally-based archives, and undertaking palaeoenvironmental surveys at subfossil bog kauri sites that may be obtained in collaboration with scientists based in New Zealand who have expertise in the field. Continued support for subfossil kauri science at nationally-based institutions is critical to success.

1 Purpose of project

1.1 Background

The New Zealand Ministry for Primary Industries (MPI) has requested a study on the scientific value of subfossil bog kauri (also known as swamp kauri), in parallel with a request for a study of cultural and heritage values of subfossil bog kauri. Subfossil bog (or swamp) kauri refers to wood or trees that have been preserved on death in peaty waterlogged, anaerobic environments and which may have been buried for a few centuries to thousands of millennia.

MPI requires that information to better inform the discussion around management of the subfossil bog kauri resources of New Zealand. Of significance, the information from these studies will have bearing on how the values associated with subfossil bog kauri could be maintained for future New Zealanders. With respect to establishing the scientific values of subfossil bog kauri, and how they (and information about them) relate to cultural and heritage values, MPI wishes to understand what the greatest risks are to scientific values of subfossil bog kauri. The remit of the proposed work will also utilise information from relevant groups involved with subfossil bog kauri (e.g. industry, artists) and all available scientific literature.

The team (Lorrey, Boswijk, Hogg, Palmer, Turney) draws together the most active members of the subfossil bog kauri research community based in Australasia, with the recognition that many other supporting researchers are based overseas. Their perspectives were captured by the team and incorporated into this research project.

1.2 Requirements of the project

The scope for the project is to:

- Provide a broad understanding of the values that scientific groups associate with subfossil bog kauri;
- Demonstrate and/or determine how subfossil bog kauri scientific values relate to cultural and heritage values and what the risks to those values might be;
- Provide an indication of the steps that can be taken to maintain these values for future New Zealanders.

1.3 Deliverables

The key outcomes of the project are:

- A report outlining the methodology, details of research, and findings on the scientific values of subfossil bog kauri with recommendations about how to maintain those values for future New Zealanders;
- A final report and presentation to MPI, and provision of all information gathered during the course of research.

This report represents the final synthesis of our findings ahead of a presentation to MPI.

2 Establishing the scientific value of subfossil bog kauri

2.1 Methodology

The agreed methodology provided to MPI in the tender was to address the scientific value of subfossil bog kauri. To achieve that end, the team undertook to:

- Identify previous investigation outcomes related to subfossil bog kauri, and the scientific values associated with subfossil bog kauri research;
- Establish how the scientific values of subfossil bog kauri research tie into and/or enhance cultural and heritage values for New Zealand;
- Outline the current (and potential future) risks that exist that could impact on the scientific values of subfossil bog kauri (and subfossil bog kauri research);
- Highlight steps that can be enacted to maintain the scientific values for future New Zealanders (including New Zealand-based scientists and scientists abroad).

There were four work phases across the life of this project. They were:

1. Conduct a primary literature review, followed by a synthesis of the primary literature into a draft report that highlights the value attained from past subfossil bog kauri research (completed in September 2016);
2. Provide an augmented version of the draft report containing relevant interview results from industry and research colleagues (this report);
3. Hold a synthesis workshop (October 2016) on subfossil bog kauri scientific values, while working closely with the parallel project that is investigating the cultural and heritage values of subfossil bog kauri to reduce duplication and ensure the main elements of interest are treated holistically (contained in this report);
4. Deliver a final report and presentation to MPI (scheduled for late January 2017).

2.2 Design of literature review

A wide array of information from peer-reviewed national and international journals, grey literature, popular science and mainstream journalism was reviewed for this project. We gathered and summarized those sources with respect to their contribution to understanding the scientific value of subfossil bog kauri.

Grey literature includes formal working paper reports[1] published by the School of Environment (SENV) Tree-Ring Laboratory (TRL), University of Auckland (UOA) in a 'New Zealand Tree-ring Site Report' (NZTRSR) series. The reports summarize chronology development from site assemblages and are produced as part of the process of studying and archiving subfossil bog kauri. They act as stepping stones toward larger deliverables such as peer-reviewed papers. Since 2000, over 30 NZTRS reports have been produced by the SENV TRL, with almost half of these documenting subfossil bog

[1] The reports are formally published (ISBN, ISSN) in the SENV working paper series and are publically available via the National Library and UoA library.

kauri research. With the continuation of subfossil bog kauri research over the past decades, some of the wood collections described in these reports have also been augmented beyond their initial contribution to peer-reviewed publications.

3 Outline of scientific contributions toward understanding subfossil bog kauri

A framework was developed to guide identification of the scientific values of subfossil bog kauri. This included generating a bibliography of subfossil bog kauri literature categorised into research themes, and which also provided a comprehensive overview of the extent and impacts (both internal to and external to science) of previous scientific research efforts. We provided this bibliography broken down into three main categories to MPI in a draft update report in 2016, and include those references in major categories at the end of this report. This framework provided: (a) a structure for the Auckland workshop in October 2016 that included all members of our research team; (b) the structure for this report; and (c) an outline for a peer-reviewed paper (as an extra deliverable) that will be submitted at the end of this MPI-funded project.

4 Literature review and bibliography

This section presents a summary of key research themes identified from the literature review and workshop. The past and present spatial and temporal distribution of kauri, awareness of bog kauri as a landscape feature and resource, and origins of scientific research on bog kauri are identified. Key scientific research themes are presented. This provides a guideline for interested parties about the historic development of subfossil bog kauri research, and it helps to formulate the network of connections between kauri research elements. It forms the platform for identifying the scientific values of kauri, but also points out gaps in understanding subfossil bog kauri from a scientific perspective.

4.1 Geography of subfossil bog kauri

All subfossil bog kauri sites documented in SENV TRL Site Reports and details from historic excavations were covered as part of the MPI-supported project on the subfossil bog kauri resources of Northland (Lorrey et al., 2016. The spatial distribution map of subfossil bog kauri terrains generated in that study eventually will be extended to include Auckland and Waikato, the latter region including the southernmost subfossil bog kauri deposits in New Zealand. The subfossil wood coverage for kauri extends south of the current biogeographic boundary of the species (Ecroyd, 1982). Other quaternary studies have recovered peat and pollen from multiple sites across northern New Zealand, and some of those studies provide details about past kauri extent (Lorrey and Bostock, 2017). That information adds a layer of richness to the scientific analysis of changes in subfossil bog kauri distribution through previous ice age cycles. The summary of geographic information indicates:

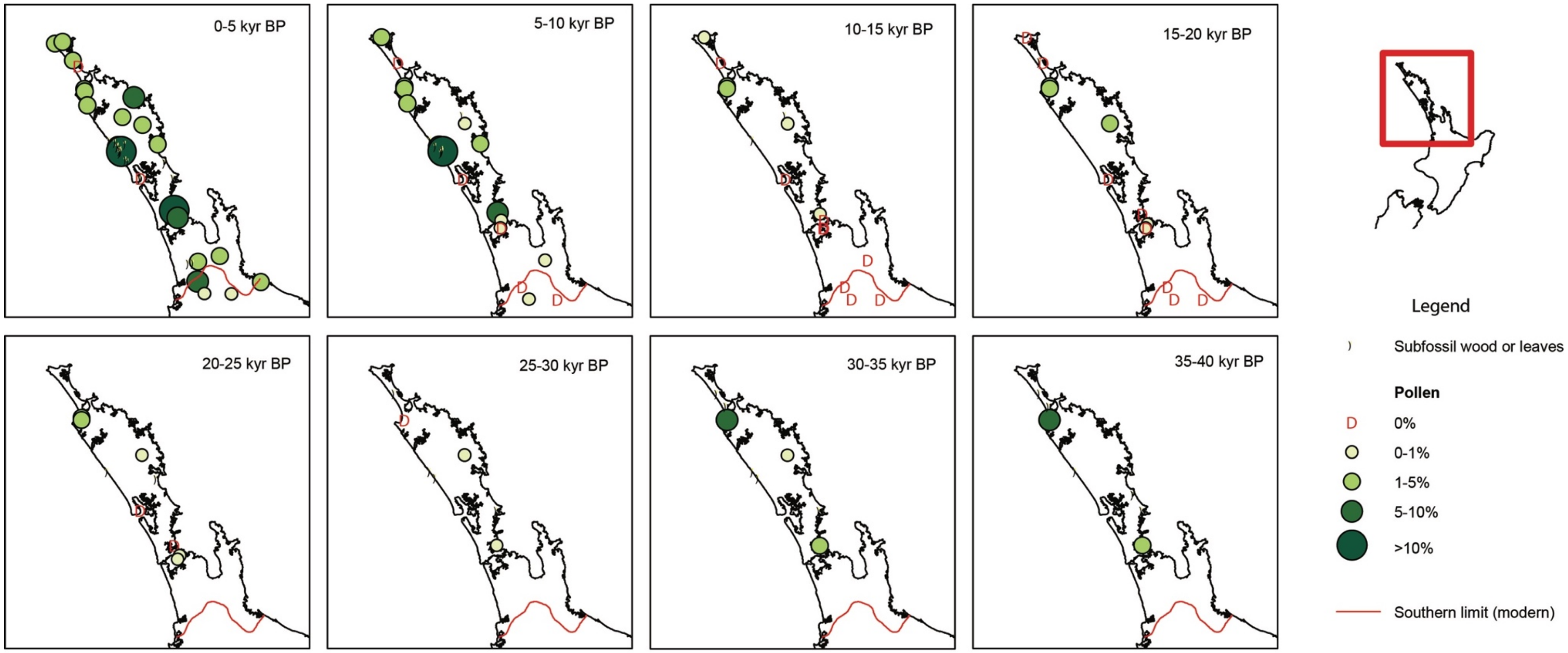

Figure 1. Pollen (palynology) evidence for changes in *Agathis australis* (kauri) distribution through the last 40,000 years of the late Quaternary (from Lorrey et al., 2016. It is recognized that sites with kauri pollen often underrepresent the relative proportion of that tree or pollen may even be absent where trees are present. As such, this series of maps is only broadly indicative of the waxing and waning concentration of kauri forest through the last ice age. Nevertheless, the pollen evidence suggests kauri are climatically-sensitive, and diminished along with other tall tree species during full glacial times when hydroclimatic conditions were different from today (colder, and possibly much drier and windier).

- Spatial and temporal distribution of kauri:

  - The preferred model for kauri distribution through the late Quaternary (the last 2.6 million years of Earth's history, encompassing the Pleistocene, Holocene, and Anthropocene Epochs) suggests it may have been more extensive prior to the last interglacial-glacial cycle and that it has persisted during that time across its modern range (Lorrey and Bostock, 2016). However, kauri were reduced number and survived at sites with favourable microclimates during colder harsher glacial intervals.

  - Dendrochronological and palynological studies (pollen) show kauri presence prior to, during and after the last glacial maximum (LGM, which ended about 19,000 years ago) and that kauri was spread across the northern part of the North Island. However, restriction of kauri to climatically-favourable sites may have occurred during the LGM (Figure 1) when temperatures were colder than present (Newnham, 1999; Newnham et al. 2013). Only one site with wood between 26,000 and 13,000 years old has been located so far, at Towai in Northland. *Any subfossil bog kauri wood found within this time interval would be of exceptional international scientific importance*.

  - There is strong evidence that kauri thrived in lowland forests well before (and upon) human arrival in the thirteenth century CE, including in wetland sites. An unpublished government report from the early 1900s refers to kauri in lowland locations, growing over buried trees.

- Sites of subfossil kauri preservation:

  - There are associations of subfossil bog kauri to organic and podzol soil types within discrete geomorphic settings in northern New Zealand (Figure 2; Lorrey, Martin and Palmer, 2016). Both Holocene (11,000 years ago to present) wood and wood that is older than ~25,000 years of age (also termed "ancient kauri") come from a wide range of different geomorphic settings in Northland, Auckland and Waikato.

  - In Northland, four basic geomorphic settings hold subfossil bog kauri within organic sediments and include relic fluvial systems, relic coastal barriers that were formerly compartmentalized between rocky headlands, relic aeolian (parabolic and sand wave) dune systems, and composite relic coastal barrier/dune complexes.

  - Few subfossil bog kauri sites are reported in Auckland, but a prominent site is located in the Manukau Harbour at Renton Road (Hayward and Hayward, 1995). At that location, trees that are approximately 200,000 years old (based on independent geochronology data) are contained in a volcanic setting. At that site, ash and tephra from an effusive local eruption buried and preserved trees that had been previously killed by a different event (origin yet to be determined).

  - Waikato subfossil bog kauri sites (see numerous references by Boswijk) have some similar geomorphic arrangements as Northland subfossil bog kauri, in addition to relic lacustrine margin settings where ephemeral lakes or ponding of backwaters may have occurred to form kauri-preserving environments. Near one Waikato site where subfossil bog kauri have been excavated near Whangape, the presence of a modern 'lake outlet delta' indicates that directional flow out of the lake to the Waikato River may have periodically reversed, changing the hydrology locally.

- Elsewhere in the Waikato region, abandoned, extensive "bird-foot" deltas can be seen in other lakes, suggesting that river aversion (course changes) to and from the main channel of the Waikato River occurred in the past. The causes of those changes have not been fully explained, but they could provide a range of settings and environments in catchments directly connected to the Waikato River which are conducive to preserving kauri.

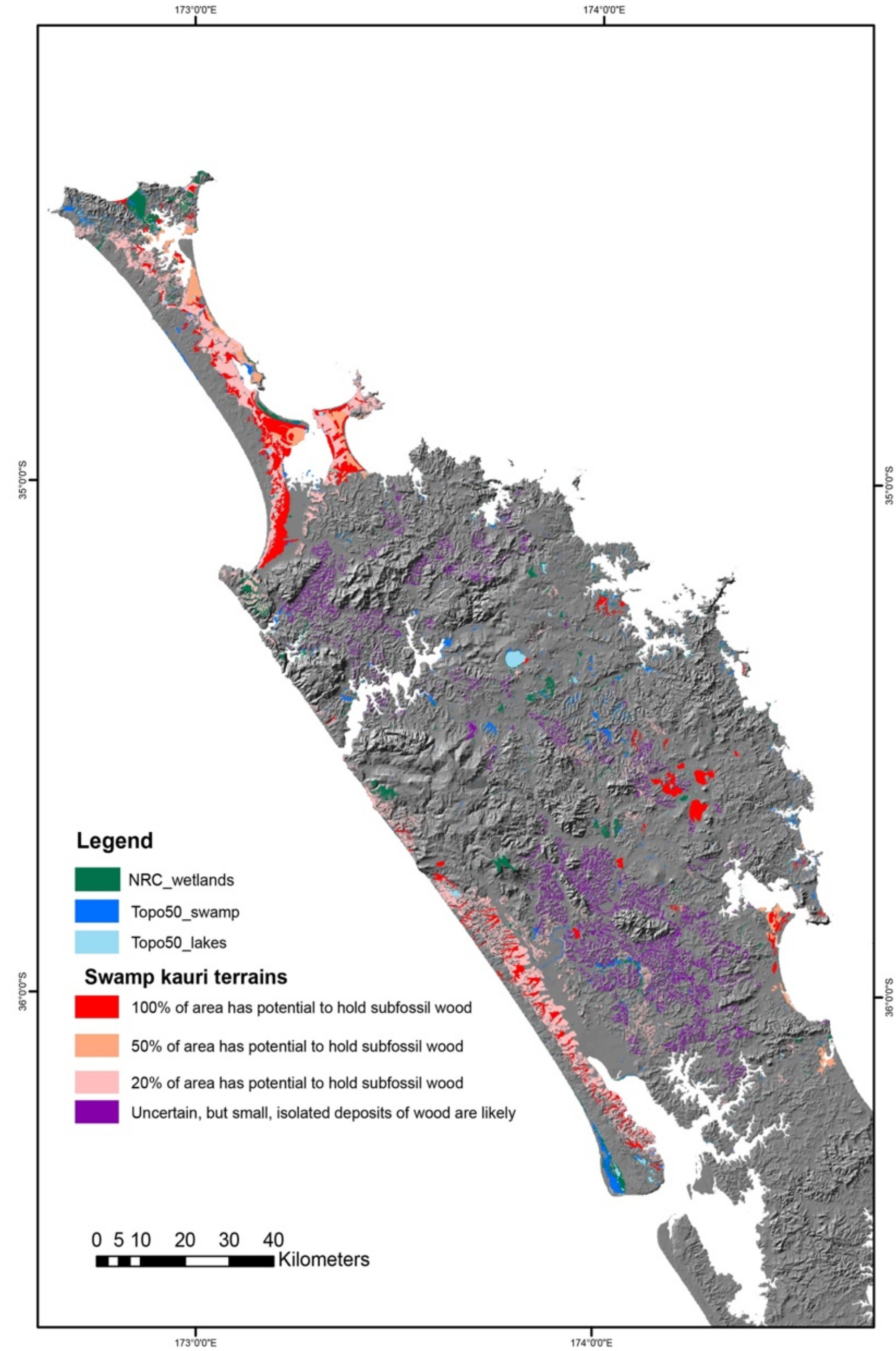

Figure 2. Subfossil kauri terrains of Northland determined from multivariate analysis of soil type and geomorphology validated by field excavations and tree ring research (Lorrey et al., 2016). All demarcated areas within the legend could hold subfossil bog kauri (including lakes). Regions demarcated as NRC wetlands have been excluded from any calculation of wood potentially remaining in Northland. Subfossil bog kauri terrain percentages are a guide as to how much areal extent of the ground surface may be underpinned by organic soils that contain subfossil kauri.

4.2 Awareness of subfossil bog kauri

Knowledge of subfossil bog kauri may extend from Māori settlement (e.g. Māori place names). The presence, recovery and sale of subfossil bog kauri timber and resin (gum) is documented in 19th and early 20th century publications and government reports, and has been the subject of historical research.

- During the early 20th century subfossil bog kauri was being extracted for timber milling and sale. There was some controversy over subfossil bog kauri being sold without being defined as such.
- Exploitation of kauri gum in gumlands showed an association of gum-bearing soils and subfossil wood.
- During the early 20th century subfossil bog kauri wood was tested for extraction of kauri resin. A significant operation was based on Babylon Coast Road north of Dargaville where buried wood was stockpiled for resin extraction, but this was abandoned soon after initiation because it was too expensive.
- In the late 20th century kauri environments were again tested for exploitation of kauri resin near Kaimaumau on the Aupouri Peninsula by Kaurex; after raising more than $20 million in capital for investment, the resin extraction operation did not significantly advance.

4.3 Origins of scientific research

There has been a long-term historical development of scientific research on subfossil bog kauri that spans multiple decades in New Zealand. There are also a significant number of international research relationships that have ties to studying subfossil wood, and motivations of research that are specific to subfossil bog kauri. Key points to date are:

- Research on kauri tree rings started with Robert and Virginia Bell, 1955, who undertook an assessment of the dendrochronological potential of NZ tree species.
- Scientific research on subfossil bog kauri started in 1973 with collection of wood by Prof. Alex Wilson and Dr Chris Hendy, and with radiocarbon (^{14}C) dating occurring from 1973 onwards. Historic correspondence between Alex Wilson and the Kauri Museum, Matakohe, specifically mentions an interest in finding and dating wood that was of last glacial age.
- The work of Hendy and Wilson may link to the Laboratory of Tree Ring Research (LTRR), University of Arizona, Southern Hemisphere (SH) collection programme carried out in the mid-1970s. This was undertaken in collaboration with a NZ researcher, Peter Dunwiddie, and included collection of subfossil bog kauri from sites in the Waikato lowlands (Dunwiddie, 1979).
- During the 1970s and early 1980s, two inter-connected strands of research were established which provide a foundation for current work on subfossil bog kauri:

1. *Radiocarbon dating:* In 1979, Alan Hogg began radiocarbon dating subfossil bog kauri wood supplied by Chris Hendy. Dates from that work were published in Ogden et al. (1992).
2. *Dendroclimatology*: In the early 1980s, John Ogden led research on kauri ecology and dendroclimatology, with graduate students Anthony Fowler, Jonathan Palmer, and Moinuddin Ahmed (Ahmed, 1984). That work demonstrated the ability and potential for long chronologies to be developed from kauri. Post-doctoral fellow Martin Bridge undertook a dendrochronological analysis of subfossil kauri from the Waikato lowlands and developed the first sub-fossil kauri tree-ring chronology.

- From the mid-1990s, kauri tree ring research focused on dendroclimatology (Villalba, 2000) and radiocarbon calibration. The value of the emerging chronologies for scientific dating and as a paleoclimate proxy was increasingly recognised, especially given the short length of the modern instrumental record in NZ and the wider Southern Hemisphere.

  1. *Dendroclimatology*: Chronology development and extension of Holocene records back in time has been driven as a result of finding a common climate signal between modern kauri tree ring sites. Development of a "master" chronology pooling available data and subsequent correlation analysis showed a statistically-significant relationship to the Southern Oscillation Index (SOI) component of El Nino-Southern Oscillation (ENSO) activity (Fowler et al. 2000; 2008). This finding elevated the status of a Holocene-era kauri long chronology (incorporating subfossil kauri samples) as having 'world-class potential' as a palaeoclimate record. In addition, application of modern relationships further back in time was integral to the development of ancient kauri chronologies. To date, a reconstruction of ENSO variability and possible ENSO teleconnection changes over the last 700 years has been published (Fowler et al., 2012), with extension back in time forthcoming (Fowler et al., 2016).

  2. *Radiocarbon calibration*: In 1997, further dating of subfossil bog kauri wood supplied by Jonathan Palmer began. Subsequent and ongoing radiocarbon studies on Holocene and ancient kauri have been conducted for improving ^{14}C methodology, radiocarbon calibration, and palaeoclimate reconstruction. Specifically, Late Holocene and early Holocene subfossil bog kauri has been applied in development of southern hemisphere (SH) and international (Int) calibration curves, reconstruction of climate from atmospheric ^{14}C, and investigation of abrupt events (Danisik et al., 2012) e.g. improved dating of the Taupo eruption (Hogg et al., 2012).

  Research from the mid-1990s was conducted in collaboration between the University of Auckland, Lincoln University, then Gondwana Tree-Ring Laboratory (GTRL), and the Radiocarbon Dating Laboratory, Waikato University. The NIWA ancient kauri research programme was initiated in 2007.

- Currently, NIWA, University of Auckland, University of Waikato, Gondwana Tree Ring Laboratory, and University of New South Wales are all actively involved in, and collaborate on, subfossil bog kauri research focused on dating and palaeoclimate reconstruction using Holocene, late-glacial and pre-LGM kauri.

- These parties are also involved in external collaborations with other national and internationally based organisations. Current research collaborations include:
  - investigations on alternate ways to date subfossil bog kauri using optically stimulated luminescence and Uranium-series, initiated by NIWA in conjunction with Victoria University Wellington since 2007 and University of Wollongong in 2011, respectively.
  - The supply of Holocene sub-fossil kauri samples by SENV TRL for high resolution chronology projects directed from ETH Zurich and LTRR, University of Arizona.
- Since the 1970s the key people involved in the collection and analysis of subfossil bog kauri have been: Alex Wilson, Chris Hendy, John Ogden, Martin Bridge, Alan Hogg, Jonathan Palmer, Chris Turney, Anthony Fowler, Gretel Boswijk, and Andrew Lorrey.

4.4 Scientific Research Themes

4.4.1 Chronology

Development of well replicated, robust kauri tree-ring chronologies underpins many of the time-dependent scientific interrogations from subfossil bog kauri. Therefore, collections of modern, archaeological and subfossil wood samples that are specifically devoted to scientific study of chronology are critical for kauri research, in addition to other studies based on passive and destructive analysis of the wood. Subfossil kauri collections are currently held in three main archives that are discussed below.

4.4.1.1 Dendrochronology

Dendrochronology is the scientific discipline concerned with building annually-resolved and absolutely dated (error = ± 0 years) records from tree rings (usually measurement of total ring width). Each year trees add a new growth increment that is defined as an annual ring by changes in ring anatomy separating one growth season from the next. The width of the annual ring is limited by climatic conditions, as well as local environmental factors, previous growth years and genetic make-up of the tree. Over time a pattern of wide and narrow rings accrues reflecting year to year variation in growth conditions. The pattern is unique in time but common to trees that have grown at the same time and experienced similar conditions. Therefore it is possible to compare the growth patterns of different trees and identify those which are contemporary via a procedure termed “cross-matching”. Cross-matched tree ring data series are normally combined into a ‘chronology’, a single record that presents an average pattern of tree growth across a specific time period. These periods can be calendar dated by starting with modern (living) trees where the date of the last ring formed is known and working back in time overlapping successively older wood. A calendar year then can be assigned to each growth ring on all crossdated samples. Material of unknown age, such as subfossil bog kauri, can be accurately and precisely dated by comparison of ring with patterns to an absolutely dated master chronology.

Development of robust kauri tree ring chronologies relies on analysis of at least two radii from a single tree and multiple trees from a single site. Cross-matching ring width series within and between trees enables inherent issues to be identified and corrected for, such as missing or locally absent rings (rings not present on a measured track) and false rings (where an apparent boundary is formed during the growth season). It ensures a high quality data set that can be applied to different scientific questions.

From the 1970s onwards scientific research on kauri has emphasised development of well replicated and robust calendar dated tree ring chronologies (Norton and Ogden, 1987; Norton and Palmer, 1992). This included production of a network of modern (living) tree chronologies, analysis of archaeological material derived mainly from buildings, and construction of sub-fossil bog kauri chronologies.

Key points regarding the history and use of subfossil bog kauri for dendrochronology are:

- The first floating bog kauri tree ring chronology was built in the 1980s from Waikato trees (Bridge and Ogden, 1986; Bridge 1987).
- Between 1999 and 2005 considerable effort went into collecting and analysing Holocene-age subfossil bog kauri, predominantly from sites in west Northland (Fowler et al., 2004). Assemblages collected in the 1980s from the Waikato were reanalysed (Boswijk et al., 2005). The resulting site records were linked to calendar-dated modern and archaeological chronologies producing a continuous 3722-year tree ring record for kauri. This work is documented and disseminated in Boswijk et al. (2006), Cook et al., (2006), Roig et al., (2010) various conference outputs, and in a series of NZTR Site Reports published between 2001 and 2005.
- Further collections of Holocene-age wood were made from 2008 to 2012 from sites in Northland. These extended the calendar-dated kauri tree ring chronology to cover the last 4500 years and improved the quality of the data set by increased sample depth (replication by different trees). This is one of the longest Southern Hemisphere calendar dated tree ring chronologies, and is provides valuable ENSO proxy record from the data sparse south west Pacific. Chronology development is documented and disseminated in Boswijk et al. (2014), conference outputs and a series of NZTR Site Reports published in 2012.
- The array of Holocene site chronologies demonstrated that trees >1000 years old at time of death were being preserved, and that multiple cohorts of trees, preserved over hundreds or thousands of years, could be recovered from single sites. These two factors enabled long periods of time to be covered by the tree ring records.
- Recently, early Holocene sub-fossil kauri spanning the Younger Dryas chronozone (approximately 12,900-11,500 calendar years ago) was recovered from Towai, Northland. A well replicated floating tree ring chronology was built from this material (Hogg et al., 2013; 2016; Palmer et al., 2016). The approximate calendar age of this chronology was established by high-resolution radiocarbon dating and 'wigglematching' to the international calibration curve (see below).

- Subfossil bog kauri had been collected in the early 1980s from Mangawhai but was not analysed at that time. Between 2003 and 2006 these assemblages were investigated along with new collections from Omaha (Lorrey and Ogden, 2005; Lorrey et al., 2005; 2007; Lorrey, 2008) and several tree-ring chronologies produced. This work showed tree ring chronology coverage at individual sites could be discontinuously spread across tens of thousands of years (summarized in Palmer et al. (2006)). Specifically, the multi-millennial kauri chronologies from Omaha cover approximately ~6,000 years of time in the pre-Last Glacial Maximum (LGM) interval (Lorrey, 2008).

4.4.1.2 Radiocarbon

Radiocarbon is a branch of science that is concerned with measuring radiometric decay of the unstable isotope 14-Carbon (^{14}C) that is inherent to all organic material on Earth. The techniques in ^{14}C dating are founded on knowledge of an established ^{14}C half-life of 5,730y; after that amount of time elapses, half of the existing ^{14}C in any organic remains will have decayed. The successive losses of ^{14}C for each half-life time step forms an exponentially-shaped decay curve. This means there is a 'finite' limit to the effectiveness of dating very old organic material at approximately 60,000 years before present (Hogg et al., 1994; 2006; 2007). Nevertheless, ^{14}C remains the most widely used geochronology method in the Quaternary sciences. ^{14}C may be measured via accelerator mass spectrometry (AMS), gas proportional counting (GPC) or liquid scintillation spectroscopy (LSC; Hogg, 2004; Hogg et al., 2006; Hogg et al., 2007) to determine the amount of remnant ^{14}C that forms the basis for an age estimate of the time when organic material, like subfossil kauri, died.

Radiocarbon content in the atmosphere varies through time and therefore radiocarbon years do not equate directly to calendar years. Therefore radiocarbon measurements need to be calibrated against an absolutely dated timescale in order to be converted to calendar years before present (cal BP). This conversion is undertaken is via a calibration curve, which is typically based on established measurements of atmospheric radiocarbon contained in known age tree rings. At present, calendar dated subfossil kauri has contributed to the development of a SH specific and international (global) radiocarbon calibration curve (Hogg et al., 2013). It remains the lone tree ring resource for wood that could be used to define the radiocarbon calibration curve older than the LGM.

Key points regarding the history and use of subfossil bog kauri for radiocarbon based research are:

- Radiocarbon dating of subfossil kauri timber began in 1973 with work by Alex Wilson and Chris Hendy.
- The array of radiocarbon dates obtained by the early 1990s improved understanding of the temporal and spatial distribution of kauri during the last glaciation and the Holocene (Hogg et al., 1987).
- Development of the late Holocene kauri chronology by 2006 facilitated extension of the Southern Hemisphere (SH) radiocarbon calibration curve from 950 CE to cover the last two millennia.

- Radiocarbon analysis of calendar-dated kauri tree rings has provided new knowledge of variation in inter-hemispheric radiocarbon offsets during the late Holocene, which is critical to construction and use of ^{14}C calibration curves (Hogg et al., 2009; 2013; Palmer et al., 2015; Turney et al., 2010)). That work has provided new insights into ocean-atmosphere interactions because of the link between ^{14}C variability and changes in oceanic upwelling (which serves to make the atmospheric radiocarbon pool in the SH older than it should be via release of old carbon to the atmosphere).

- Recovery of the Younger Dryas age wood from Towai has provided a significant SH record of atmospheric radiocarbon variability which could be linked to the Northern Hemisphere (NH) radiocarbon chronologies. This work demonstrated that there was an error in the NH radiocarbon calibration data set (which had been derived by splicing ^{14}C measurements from different species of trees).

- Recovery and analysis of ancient kauri has resulted in improved methods for processing and ^{14}C dating old wood material, especially at the limits of the ^{14}C method (Southon and Magana, 2010; Santos and Ormsby, 2013; see previous references by Hogg et al.).

- New updates of radiocarbon analyses on ancient kauri collections held by NIWA and Gondwana TRL (Palmer et al., 2006) suggest a tree ring and radiocarbon chronology covering approximately 30,000 years of time from the early LGM back to the outer limit of radiocarbon dating is possible. This opportunity is not available anywhere else on Earth (Figure 3).

- The application of current and future kauri-based late glacial and Marine Oxygen Isotope Stage 3[2] (MOIS3 or OIS3) radiocarbon chronologies show the potential to link subfossil kauri records directly to high latitude ice core records via co-variation of ^{14}C and ^{10}Be time series (Turney et al., 2010; 2016). This means subfossil kauri not only provides improved detail for radiocarbon calibration (something that could be used by almost all Quaternary researchers worldwide) but because the NZ radiocarbon data can double as an oceanic upwelling proxy, issues related to inter-hemispheric climate responses and connectivity can be tested. These applications confirm the “world-class” status of subfossil kauri.

[2] MOIS: a subdivision of geologic time based on long term isotopic variability in marine sediment cores. MOIS3 occurred between 57,000 and 27,000 years ago.

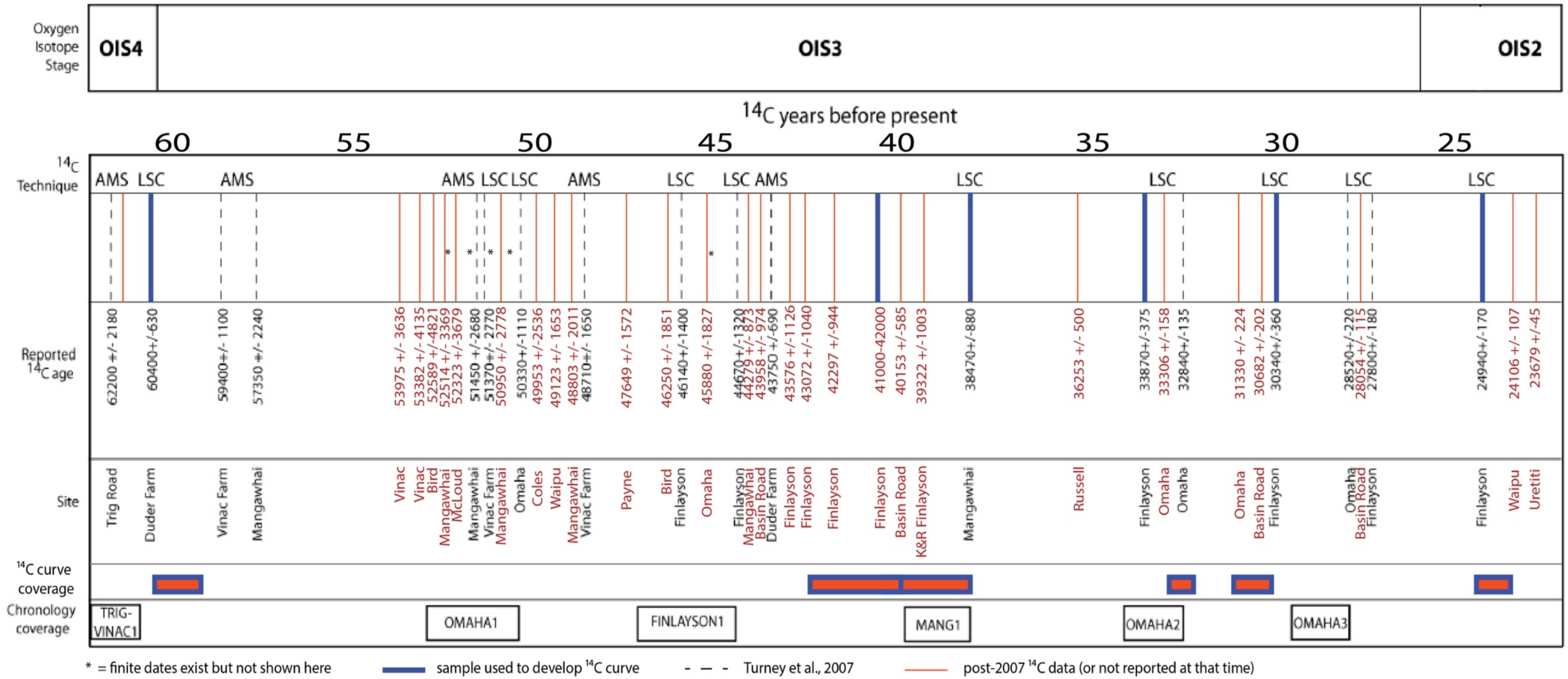

Figure 3a. Radiocarbon results for pre LGM subfossil bog kauri using high-precision liquid scintillation spectroscopy (LSC) and accelerator mass spectrometry (AMS) dating. Time scale at the top of the figure is in tens of thousands of years. Red labels denote conventional radiocarbon dates acquired since 2007. Wiggle-matched kauri sequences to extant radiocarbon calibration curves and to ice core beryllium variability (red boxes circumscribed by blue) allows precise synchronization of kauri-based climate reconstructions to globally-significant palaeoarchives.

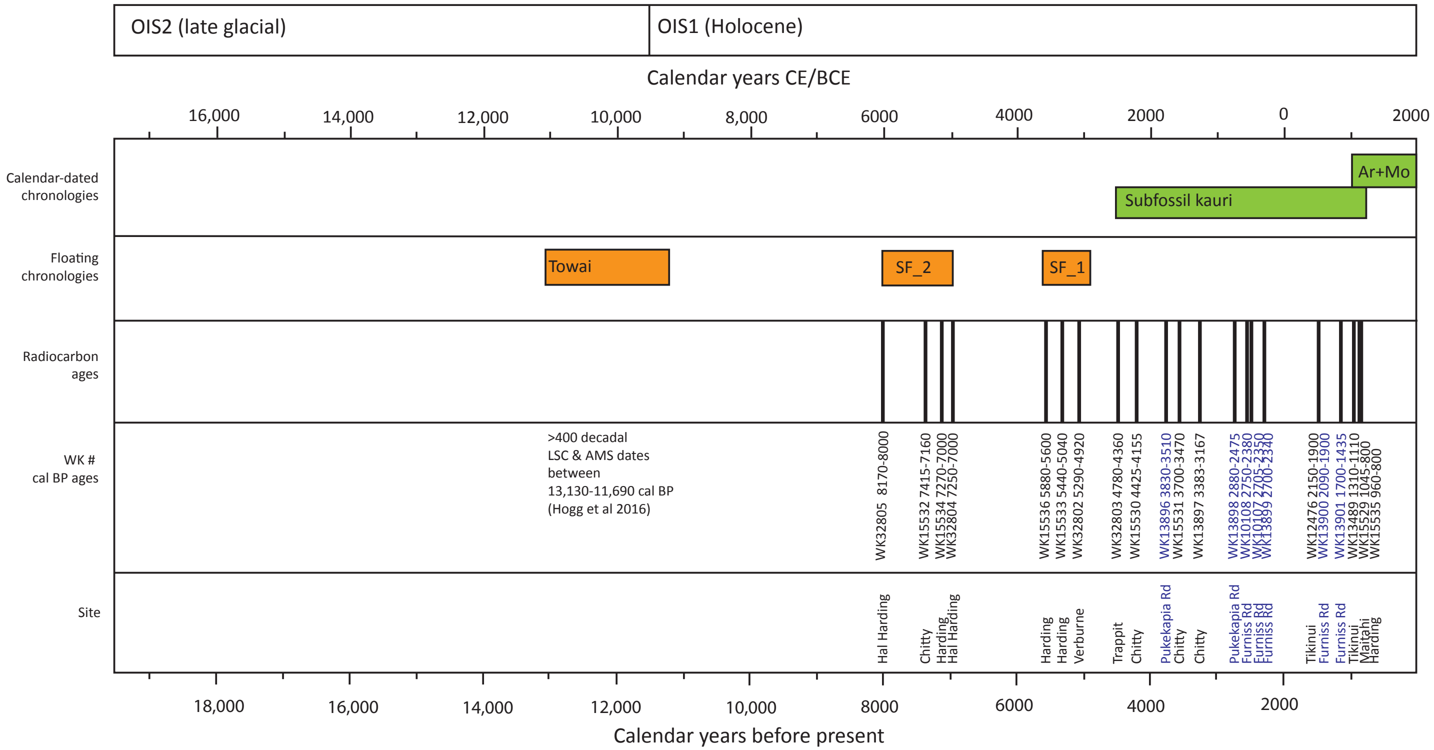

Figure 3b. Distribuion of radiocarbon dates for subfossil bog kauri analysed using LSC and AMS for the late glacial and Holocene. Mo = modern living kauri, Ar = archaeological kauri building timbers (drawn from across the range of living trees). The green boxes show the extent of the calendar-dated kauri tree ring record that extends back ~4500 years before present. The orange boxes show positions of temporally 'floating' chronologies anchored in time using radiocarbon. WK numbers are the laboratory identifier for University of Waikato Radiocarbon Laboratory, which is followed by an age span for the calibrated conventional radiocarbon age (CRA; 2 standard deviation range). Blue labeled CRAs come from the Waikato region, while black ones come from north Kaipara. Towai is located in central Northland, and is a globally unique site, containing wood that has been preserved from the late glacial.

4.4.2 Palaeoclimatology

Palaeoclimatology is a scientific discipline that uses a variety of natural archives to reconstruct past climate beyond the temporal coverage of instrumental observations. Typically, palaeoclimate archives overlap modern instrumental climate data and they may therefore provide a 'proxy' record of some physical aspect of the environment. In many cases, a proxy record can be calibrated against modern day climate variability and change. Reconstructions from many palaeoclimate archives are often statistically-based, and those reconstructions have associated errors that relate to the climate-proxy relationship and to chronologic uncertainty. Alternatively, some natural palaeoclimate archives might not be calibrated against a modern instrumental data series, but they may contain information that could be interpreted as reflecting past climate on the basis of physics.

For New Zealand, palaeoclimatology is highly relevant for contextualising current variability and recent changes because instrumental data of weather and climate only extend back to the mid-19th Century. Most work using subfossil kauri for palaeoclimatology has occurred since the start of the 1990s.

Key points regarding the scientific value of subfossil kauri for palaeoclimatology are:

- The temporal and spatial distribution of subfossil kauri identified by dendrochronological and radiocarbon data studies informs our understanding of changes in environmental and climatic conditions through the late Quaternary, particularly during the Holocene. The distribution of ^{14}C ages of all known subfossil kauri wood that has been radiocarbon dated suggests that kauri was significantly diminished in spatial extent during glacial times relative to interglacial epochs.

- Subfossil kauri has potential to provide insight into the El Niño-Southern Oscillation (ENSO) phenomenon or ENSO-like conditions and their impact on New Zealand's climate at different time periods (Fowler et al., 2000; Fowler et al., 2008; Fowler, 2008; Lorrey, 2008).

    - Mid to late Holocene: Analysis of modern tree ring chronologies (using total ring width) identified a significant statistical relationship between the tree-ring width variations and ENSO. It suggests our ability to match kauri ring width series is enhanced because of a variable regional climate, which relates to how ENSO changes prevailing wind patterns across kauri's natural growth range. Currently published insight into ENSO activity based on kauri tree rings for the late Holocene has been restricted to the last 700 years (Fowler et al., 2012); however there is a planned reconstruction to 4500 BCE using the newly extended tree ring record that includes subfossil wood (Fowler et al., 2016).

    - Younger Dryas/Late glacial: Collection and analysis of late glacial bog kauri has provided valuable insight into palaeoclimate forcing mechanisms at that time, suggesting an active ENSO during the late glacial and atmospheric teleconnections to the NH may have impacted on New Zealand's climate (Palmer et al., 2016).

- Pre-LGM/MOIS 3: Lack of multi-site replication in the ancient kauri record currently prohibits meaningful ENSO reconstructions from subfossil kauri ring width records older than Holocene age. However, spectral analysis of robust (by sample depth) ancient kauri site chronologies from Omaha dating to 56,000 years ago and 32,000 years ago suggest variable climate and possible ENSO-like signals (Lorrey, 2008). New statistical approaches (Palmer et al., 2016) also suggest some indications of past ENSO activity may be gained by further analyses of single site chronologies based on subfossil kauri.

- Sub-fossil kauri is a source of atmospheric radiocarbon which can be applied to investigate changes in ocean-atmosphere interactions across different time periods in the last ~60,000 years. For example, recent reconstruction of atmospheric ^{14}C records derived from Younger Dryas age subfossil bog kauri has provided insight into variability in climatic conditions at ~12,000 years ago. The approach of 'wiggle-matching' the variations of ^{14}C with 10-Beryllium (^{10}Be) facilitates inter-hemispheric comparison between ice cores and SW Pacific natural climate archive data (Hogg et al., 2016).

- Recent work on modern kauri suggests the oxygen and carbon isotopic signatures in subfossil kauri could be useful for reconstructing past hydroclimatic conditions (Lorrey et al. 2016b). One sample of ancient kauri from Trig Road was analysed for stable isotopes in 2004 (Poussart, 2004), but no modern calibration study had yet been undertaken, hindering the interpretation of that record. Replication of modern studies using from multiple trees at individual subfossil bog kauri sites is critical to progressing this science.

4.4.3 Abrupt/extreme meteorological and geological events

Abrupt events and extremes of past climate and environmental change may be able to be reconstructed using subfossil kauri trees. In addition, the signatures of past severe weather events might also be recorded in kauri tree rings. The field of research where reconstruction of past weather extremes is undertaken using natural archives is termed palaeotempestology.

Key points regarding the scientific value of subfossil bog kauri for palaeotempestology and investigating extreme events are:

- Tree ring chronologies from subfossil bog kauri, combined with metadata such as tree fall patterns and site stratigraphy, may enable investigation and precise dating, including to season, of abrupt and extreme events (e.g. Lorrey and Martin, 2005).
  - Changes in the composition of tree ring chronologies, such as the death of an individual or several trees during one single year, may help to reveal the timing of past mortality and point to possible causes of death related to an extreme event (ie. drought, flood, catastrophic windthrow, earthquake, etc).

  - Analysis of tree rings that are fully or partially formed just under the bark of extracted subfossil kauri can reveal the timing of tree mortality within a growth year (for kauri, the growing year starts in September and continues to the following June). This enables seasonality of events to be identified

- Episodic extreme winds are postulated as the most likely factor in subfossil kauri mortality in Northland (Lorrey and Martin, 2005). Conditions for episodic wind throw of trees could result from strong atmospheric pressure gradients that northern New Zealand are subjected to seasonally. Kauri are shallowly rooted and often found in peaty substrates which when wet, would lend to trees being uprooted. In many cases, only part of a kauri may preserved in former bog sediment, so in some cases determination of the exact timing of death (with reference to other trees at a site) may be limited.

- Tree mortality from Waikato subfossil kauri chronologies growing in the first millennium AD has been examined (Boswijk et al., 2005). There is no conclusive evidence that the Taupo eruption abruptly killed the late Holocene Waikato trees. Analysis of the mortality patterns at all subfossil kauri sites is ongoing.

- To date, analysis of abrupt events using tree ring isotopes has focused on investigation of short term solar variability (Murphy and Palmer, 1992), refined dating of the Taupo eruption (via a cross-calibration of trees buried at Pureora to the SH curve constructed using kauri), and inter-hemispheric identification of abrupt radiocarbon excursions (e.g. 775 CE event which registers as a beryllium and ^{14}C spike in ice cores and tree rings, respectively; Guttler et al., 2015).

- Detailed mapping of subfossil kauri at Renton Road, Manukau was completed in 2013, complementing earlier work that documented preserved kauri there (Hayward and Hayward, 1995). Relic kauri trees exposed on the tidal flat in the Manukau Harbour were not killed by an eruption of a nearby volcano, but were buried and preserved by it.

4.4.4 Palaeoecology and environmental change (non-climatic)

Palaeoecology is the scientific discipline of reconstructing past vegetative ecosystems (including dynamics, succession processes, disturbance impacts and influences of climate variability and environmental changes on the vegetative structure) using remains of plants trapped in sedimentary archives. Modelling is a crucial component of palaeoecology, and as a discipline it often provides some of the strongest evidence for past climate changes.

Most information about the palaeoecology of kauri has expanded since the late 1990s; in addition, it is only in the most recent decade that kauri tree ring analyses and palynology studies (use of pollen to reconstruct past vegetation) have been merged.

Key points regarding the scientific value of subfossil bog kauri for paleoecology and environmental change are:

- Analysis of subfossil bog kauri gives insight into the palaeoecology of kauri for the pre-human era in New Zealand (prior to ~1280 CE) and natural processes that occurred at different spatial and temporal scales prior to cultural modification of the forest environment.

- Use of kauri macrofossils, microfossil, and stratigraphical recording has provided increased understanding of temperate subtropical rainforest population structure and dynamics, mortality events, and landscape changes over interglacial-glacial cycles (D'Costa et al., 2009a; 2009b; Lorrey and Bostock, 2016).
  - Recent work has demonstrated great potential for this type of multiproxy analysis in the future. At Towai, sampling undisturbed peat stratigraphy in conjunction with collecting wood considerably enhanced the story that can be told from tree rings (Palmer et al., 2016).
- Meta-analysis of kauri ^{14}C data and extant pollen has been used to put forward two hypotheses about Pleistocene migration and ecosystem responses in northern New Zealand (Ogden et al, 1993).
- One hypothesis put forward is that subfossil kauri are preserved better during warmer and wetter intervals (which are categorized as either interglacial or interstadial; Lorrey and Bostock, 2016).

4.4.5 Prospecting for wood recovery and kauri environments

To date, wood collection has relied on relationships with sawmillers and landowners, with limited control of sampling and often reduced or no associated environmental metadata. Sedimentary material is often not able to be collected because kauri excavation sites may be highly modified during extraction of wood. We have observed one technique of digging 'long test trenches' to determine where wood may or may not be, and this results in destroyed stratigraphy.

Identification and understanding of the variation in geomorphic conditions promoting preservation, enhanced technology for geolocating wood ahead of commercial recovery, and capture of site-specific metadata are significant to improving the quality of scientific information that can be recovered alongside or in conjunction with commercial wood recovery.

Key points regarding scientific-based prospecting for subfossil kauri are:

- Enhanced understanding of likely locations of wood preservation. Excavation and recovery of bog kauri has relied on informal and field acquired first-hand knowledge of an association between organic/peat soils and buried wood, as many former lowland bog environments with organic soils have been found to contain preserved kauri logs and stumps. There are, however, some exceptions to where subfossil wood may be preserved and a recently completed subfossil kauri mapping exercise for Northland suggests geomorphology plays a role in preserving subfossil wood. A map of Northland subfossil kauri terrains has already been provided to MPI. Expansion of this work to encompass the wider range of kauri (including Auckland and the Waikato) is in progress at NIWA ahead a planned publication on New Zealand subfossil bog kauri (undertaken in parallel with this report).

- Improved knowledge of the extent and orientation of buried wood using aerial photography and/or remote sensing.
  - Historical aerial photos have been used to locate subfossil bog kauri deposits and provide knowledge of aspects such as tree fall patterns. During dry years (and because of landscape modification) former lowland bogs containing kauri often show buried trees emerging at the ground surface due to reduced hydrostatic pressure in surrounding organic soil pore spaces.
  - Ground penetrating radar (GPR) has been applied with limited success toward finding buried wood, but application of this technique is in its infancy. NIWA has acquired a new low-frequency radar antenna that may help clarify subsurface wood in some environments. Radar can, however, successfully be used to identify depth of organic soils, groundwater table level, subsurface features (like hidden sand ridges or tephra layers) and soil-hardpan interface depth at subfossil bog kauri sites. This provides useful metadata for interpretation of environmental conditions.
  - LIDAR and false colour infrared spectrum imagery use is in its infancy for locating buried kauri and need to be further tested at a range of sites to evaluate their efficacy.
- Enhanced understanding of environmental context at time of tree growth, mortality and post-preservation environmental change. Stratigraphic profiles and controlled sampling for micro-fossil provides an environmental context for subfossil kauri samples.

4.5 Dissemination (non-academic) and Outreach

Dissemination of research findings to public have been made by all members of the research team through presentations, media interviews (written, broadcast), popular science publications, and websites. These are summarised in the references, and demonstrate most of the regular outreach to the public has occurred since 2000.

5 Scientific values of subfossil bog kauri

Subfossil bog kauri has multiple scientific values. These are:

- *Uniqueness:* Internationally, Holocene wood is preserved in bogs and river gravels in Ireland, Britain, Europe and North America. However, because these regions were buried or impacted by glaciation, preservation of post-glacial and pre-LGM wood is very rare. New Zealand is the only place where wood from Holocene, post-glacial and pre-LGM periods have been preserved in-situ, and often in close proximity. This is a resource for the Quaternary Sciences that is not found anywhere else on Earth.
- *Temporal coverage*: Many subfossil bog kauri sites contain preserved wood from more than one cohort of trees, and many samples have >1000 rings. Collectively deposits may

span tens of thousands of years, inclusive of samples from discrete intervals for the last interglacial interval (~125,000 years ago) through to the late Holocene. Consequently, supra-long tree ring and radiocarbon chronologies for the pre-LGM and the Holocene may be possible. Globally, nowhere else can offer equivalent temporal coverage from tree rings for quaternary science research.

- *Irreplacable*: The subfossil bog kauri assemblages held in institutional and private archives are an irreplaceable resource for science because the material, once milled, is lost to science. We often cannot re-collect material we currently hold in archive because the source wood has all been utilized and the substrates the wood came from have been disturbed or disrupted. Changes to natural environmental processes also mean that subfossil kauri are not being preserved at rates that are equivalent to what they were in the distant past.
- *Enhanced knowledge of past global environmental change*: Sub-fossil kauri is an international significant environmental archive contributing multiple forms of long, high resolution proxy records (e.g. tree rings, ^{14}C, stable isotopes) from the data sparse south west Pacific to studies of global environmental variability and change.
- *Enhanced knowledge of environmental change in New Zealand*: subfossil bog kauri tree rings have direct use for establishing environmental change history for Northland, including ecology, landscape change, and climate, at different temporal and spatial timescales and prior to human arrival. This provides insight into natural processes, abrupt and extreme events occurring in pristine environments prior to cultural modification from the 13th century onwards, including those such as preservation processes that have been disrupted by human-induced landscape change.
- *Insight into local scale change*: Sedimentary archives found in close association with subfossil bog kauri provide evidence of past environmental history and change, which is complementary to the records contained in the subfossil wood. As such, the sites that subfossil kauri are excavated from, including their stratigraphy and geomorphology, also have significant scientific value. When these sedimentary archives can be appropriately assessed, they can add value to the analyses that are possible from subfossil kauri.

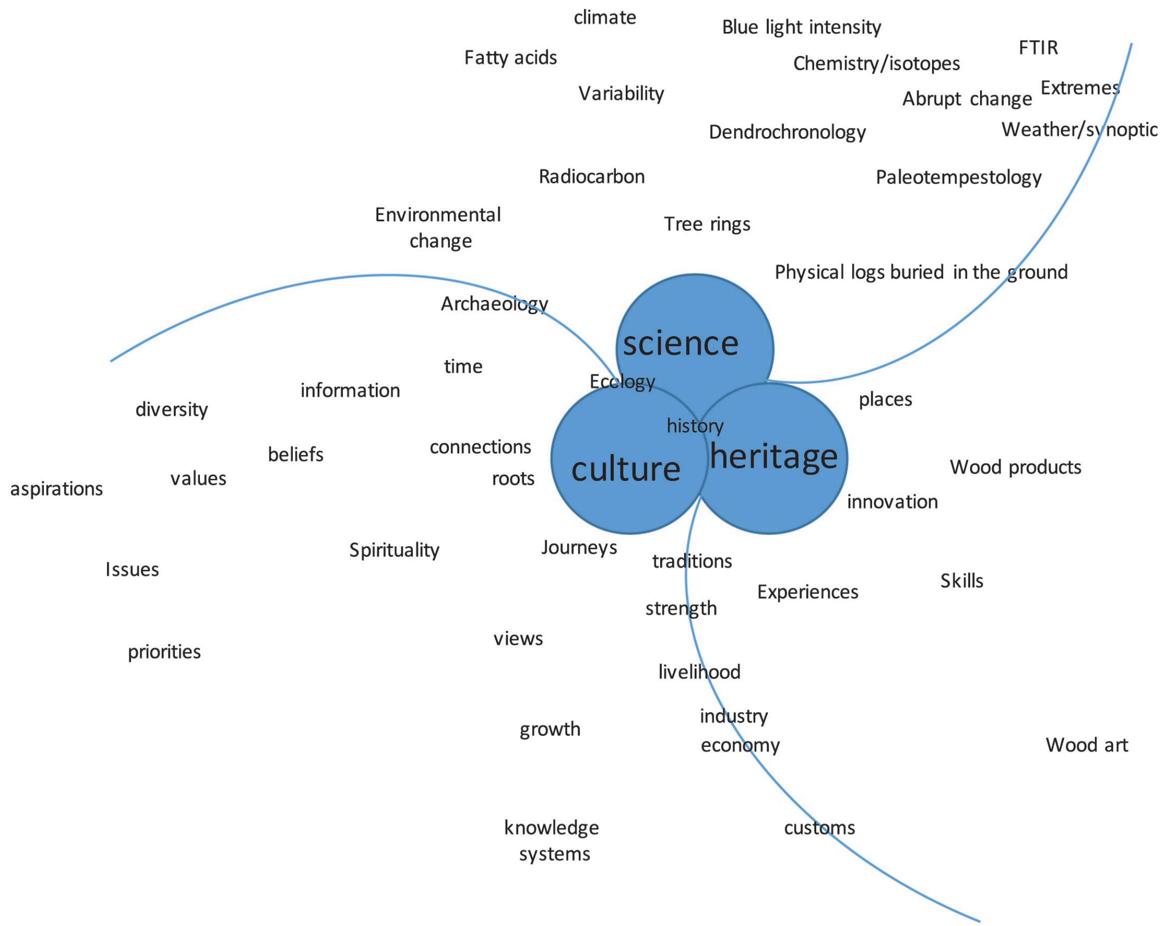

Figure 4. Pseudo-venn diagram showing the interconnectivity of several scientific elements to which subfossil bog kauri are connected. Closeness to middle of diagram indicates the proximity of primary elements for the value sphere, and other elements that build off of them. In particular, progression outward from the core of each sphere may be interpreted metaphorically as increasing outward reach, complexity of components and distant application of fundamental knowledge. In the case of science, this relates to subfossil wood with ever more specialised branches of technical analysis and/or fields within science that are mentioned in this report. We remark on two other value 'spheres' – culture and heritage – that are acknowledged from a scientific perspective and include possible (but not exhaustive) elements relating to those value domains.

6 Perceived benefits

The benefits of subfossil kauri to current and future science efforts, taking into account the contributions listed above (and interconnectivity of science elements; Figure 4), are manifold:

- Subfossil kauri is, and continues to have the potential to be, a world-class palaeoarchive. If a full extension of subfossil kauri chronologies (tree ring, ^{14}C, stable isotopes) eventuates from the Holocene through to the limit of radiocarbon dating (and beyond), it would be held in equivalent esteem as some of the best Greenland or Antarctic ice cores.
- Subfossil kauri can help to elevate New Zealand's status on the scientific stage because it is a globally-unique resource; our attention to, and reverence of, it as a special scientific archive is of benefit to the reputation of New Zealand science.
- Subfossil kauri wood covers time periods in the past that are not covered by other tree ring records. The benefit of having this information is a more complete Earth Science history.
- Subfossil kauri provides climate researchers with detailed data from the sparsely represented Southern mid latitudes, which is of benefit for validating interpretations about past global and regional climate variability and change (and checking the veracity of global climate model results).
- Subfossil kauri can provide detailed information about New Zealand on a resolution not offered by other archives in the country. The benefit of this archive is that it gives us opportunities to contextualise New Zealand's past climate and environmental history on the highest resolution possible and in a global framework by way of high-precision radiocarbon dating.
- The radiocarbon calibration curves that can be developed from subfossil kauri can be used by the global science community, not just in New Zealand. The radiocarbon curves that can be developed from subfossil kauri will have internal resolution that is not offered by other archives that presently make up the INTCAL13 radiocarbon calibration time series.
- Subfossil kauri radiocarbon records are beneficial not only for calibration and alignment of all palaeodata on a common time scale (via development of radiocarbon calibration curves, allowing cause and effect to be determined), but they also provide an independent measure of ocean upwelling (and wind stress) and timing of changes in the New Zealand region that are difficult to establish from marine records alone.
- The detailed past climate information contained in subfossil kauri is highly relevant for the most populated regions of New Zealand. It has the capability of extending current climate records well into the past. Therefore, it has the potential to improve our current knowledge base that could benefit planning for our future because it, along with other information, outlines the range of natural variations that are possible for Northland, Auckland and the Waikato. The fact that kauri ring widths and isotopes reflect climate (including impacts from ENSO) and hydroclimate variability are highly relevant for New Zealand agribusinesses. In addition, kauri tree rings are globally significant because of the extent of ENSO's teleconnections (global reach outside the Pacific basin, affecting billions of people worldwide) and it has been demonstrated to be an excellent ENSO proxy (Fowler et al., 2012).
- There are positive benefits from influx of grant funding and technological capabilities for analysing subfossil kauri wood, which include development of new scientific ideas and application of innovative techniques and technologies not presently used in New Zealand.

7 Current capability, capacity and future directions

Topics that were discussed in depth at the workshop on subfossil bog kauri values 26-28 October 2016 at NIWA in Auckland included:

- Building capability – dendrochronological, analytical, capacity, end user relationships
- Future research directions (known, unknown)
- Storage of samples; primary radii for measurements and offcuts
- Storage of sample photos and metadata
- Storage of chronology data
- Minimum sample storage and replicate samples
- Research efforts internationally and nationally
- Analytical facilities

A summary of the discussion indicates the following:

- Current archives of subfossil bog kauri are held at three locations. Each laboratory has facilities for processing, analysis and storage, although the research focus and capabilities of these nationally-based operators differ.
- NIWA:
  - NIWA's palaeoclimate research laboratory in Auckland is designed to contribute to tree ring chronology building and stable isotope/chemical analysis of kauri wood.
  - The NIWA laboratory has dedicated facilities for rapid processing of cross-sections of subfossil bog kauri wood samples (otherwise known as 'biscuits') for scientific analysis.
  - NIWA has a dedicated NewWave micromill specifically for sampling microscopic wood samples for geochemistry.
  - The NIWA wood archive is built for long-term storage of subfossil bog kauri. It is currently at 20% capacity with approximately 560 unique ancient kauri (older than 23,000 years age) samples currently in storage.
  - There are opportunities to add to the long-term storage, processing, and science capabilities at NIWA by utilising additional space at the Bream Bay NIWA facility, if expansion is needed in the future.
- Gondwana Tree Ring Laboratory:
  - Gondwana Tree Ring Laboratory has facilities for tree ring chronology building and sampling at high resolution for radiocarbon dating.

- Gondwana Tree Ring Laboratory retains collections of New Zealand and international tree ring samples. It has received support from a number of national and international grants to study subfossil bog kauri. It has approximately 350 unique subfossil kauri samples that are late glacial, Holocene and pre-Last Glacial Maximum age. This facility is space-limited, so only selected samples are brought there (based on research funding).

- SENV Tree Ring Laboratory at UOA:
  - The SENV TRL has dedicated laboratory space for analysis and processing of tree ring samples for chronology building, climate analyses, and sampling for other analyses, including radiocarbon.
  - The SENV TRL has a dedicated wood storage space, with several hundred kauri specimens. It also holds a nationally significant collection of living and archaeological kauri specimens, as well as samples from other wood species that have been collected since the 1980s.
  - UOA has a micromill similar to that at NIWA, facilitating future geochemical analyses.
  - UOA has an ITRAX facility that can be used in the future for non-destructive analysis of subfossil bog kauri tree rings. This is expected to be an area of research focus in years ahead.
  - The UOA is currently the only tertiary institution that provides extensive/formal teaching and training in kauri dendrochronology in New Zealand.
- Commonalities between the laboratories
  - NIWA, Gondwana Tree Ring Laboratory and SENV TRL have field gear and transport capabilities that allow their research scientists and technicians to identify, select and capture samples rapidly
  - Being based in northern New Zealand, NIWA and SENV TRL personnel are able to mobilize rapidly to assess new subfossil kauri sites across Northland, Auckland, and the Waikato, as required.
- The University of Waikato Radiocarbon Laboratory (WRL):
  - The WRL lab has been actively involved in collection of wood and sampling for ^{14}C, but does not have a wood archive.
  - It has generated most of the radiocarbon data on subfossil bog kauri and they are the world-leader in sample pre-treatment for kauri to attain the best and most reliable and precise radiometric ages using two methods.
  - The liquid scintillation spectroscopy (LSC) method of radiometric dating, while older technology, is world-class in terms of the results that can be produced for subfossil kauri and is highly appropriate for wood of old ages

like subfossil bog kauri. Finite ages on subfossil bog kauri have been issued from the Waikato Radiocarbon Lab out to 62,000 years before present.

– There is a role for AMS dating of subfossil bog kauri, and there are national and international partners who are current collaborators in that effort. University of Waikato provide expert nationally-based capability to convert subfossil kauri wood to graphite targets that are used for AMS radiocarbon dating.

8 Risks to the scientific value of subfossil kauri

8.1 Identification of risks to subfossil kauri wood

Identification of several risks to the scientific value of subfossil bog kauri were made via a situation assessment at the Auckland workshop. The research team contextualised the main risk profiles for subfossil kauri in a discussion that was underpinned by the research elements that are presented in sections 4-7 of this report. Four main risk categories for subfossil kauri scientific values formed a framework for the workshop discussion. The categories relate to wood currently in archive, wood yet to be collected (in addition to sites yet to be assessed), and site-based materials associated with subfossil kauri (eg. sediments, stratigraphy, geomorphology) that can help to improve on how the wood can be analysed and interrogated as a palaeoarchive. All of the risks relate to the current and future scientific knowledge that can be attained from analyses of subfossil kauri. The risks were classified as:

a) Loss of knowledge of current and new subfossil kauri excavation sites

   i. The activity creating this type of risk could come from unauthorized and/or not notified excavations of subfossil wood to scientists.

   ii. The impacts of this risk to science may result in the exclusion of important knowledge about subfossil kauri by:

      1. Limiting additional validation data that would help to determine where and how much subfossil wood (density/volume per area) exists in northern New Zealand,

      2. Diminishing the opportunity to capture wood from potentially important/unique time intervals not covered by wood in scientific archives (eg. the LGM, last termination or late glacial),

      3. Eliminating opportunities to assess and collect undisturbed stratigraphic records (including those that may be captured using GPR) that are associated with buried wood and that can complement subfossil kauri analyses (and/or stand alone from them).

b) Loss of internationally-significant scientific information that only New Zealand subfossil kauri wood or subfossil kauri sites can provide

   i. The activity creating this type of risk may come from rapid exploitation of subfossil kauri sites in the absence of evaluations by trained scientific experts who study kauri. This situation, while presenting significant opportunities to collect large amounts of wood for science, could also limit, diminish and or prohibit some aspects of scientific study of subfossil kauri.

   ii. The impacts of this type of risk to scientific values could result in loss of scientific potential for subfossil kauri (or subfossil kauri environments) via:

      1. Removal of wood, or utilisation of wood and/or destruction of the environmental/sedimentary context related to excavated wood (or the wood itself) before it can be adequately documented, sampled, preserved and/or archived.

2. Loss of wood spanning vastly different ages (lack of sample depth hinders dendrochronology) because not enough of it at individual site levels are made available for sampling.

3. Loss of wood that has already been extracted, but has not been documented or evaluated for scientific study.

4. Deletion of yet unknown information about New Zealand's natural history (wood, sediments, macrofossils, landforms, etc) which could retain significant details about the past that are not captured in other areas or by other records, which provide enhanced intepretation of subfossil kauri tree ring records from the same site.

5. Limitation on information at the scale of individual subfossil trees that may be acquired only prior to excavations, including metadata about stem orientation, whether crown/rootplate material is attached or not, whether bark edge is preserved or not, and what relationships exist between individual subfossil trees (stratigraphic layering, relationships to woody debris, volcanic ash layers, etc)

iii. The potential for this type of risk may become exacerbated further due to lack of knowledge of subfossil kauri sites (see above) and/or become amplified by the inability to mobilize a scientific party that is capable of evaluating subfossil kauri sites (possibly also because of a lack of funding rather than availability of personnel).

iv. In addition, a significant amount of subfossil kauri already resides at holding facilities owned by several timber merchants. Processing and shipment of that material offshore, or sale of it into the national market, without scientific evaluation presents a significant risk to the scientific value of subfossil kauri (see reasons listed above).

c) Loss (or reduced) stewardship capability and capacity for subfossil kauri collection and analyses

i. This type of risk may develop, in part, from a lack of support for (or loss of) nationally-based personnel who are experts in evaluating, analysing, reporting on and curating subfossil kauri wood samples.

ii. The impacts of this risk to science could result in diminished scientific potential of subfossil kauri via:

1. Loss of the institutional knowledge foundation within New Zealand where the resource is based. Loss or reduction of key personnel would likely mean abundant 'know-how' about subfossil kauri would become absent.

2. Loss of the response capacity that allows regular collection, preparation and analysis of excavated wood would mean portions of the scientific resource could disappear without any knowledge of existence. This could prohibit or limit future scientific evaluations of subfossil kauri.

3. Loss of the ability to collect new wood also means future analyses would be limited to present-day collections currently in archive, and therefore this would support only an incomplete perspective and understanding of subfossil kauri. It could also limit the future scientific potential of subfossil kauri (eg. generating a continuous 50,000 year long calendar-dated record might not occur because yet-to-be-identified glacial age sites are lost and/or not notified).

4. Losing the capability to conduct world-class kauri research within New Zealand would reduce, limit, and/or diminish the nationally-based expertise that is able to return expert information about subfossil kauri to industry, the Quaternary science community and the wider public

5. In addition, the profile for this type of risk may increase via a lack of support for development and management of data and metadata related to subfossil kauri analyses (tree ring measurements, archive photos, etc).

6. The profile for this risk could become exacerbated via further limitations on either the capability or capacity for collecting, curating, and/or maintaining archives of subfossil wood. If the specific locations where wood is currently archived were lost or removed, the wood in archive could deteriorate or potentially be disposed of (see below) and jeopardize the scientific potential of kauri.

d) Loss of scientific potential due to wood deterioration and/or disposal

i. This type of risk may develop from either a lack of ability to sample wood that is already extracted but has yet to be milled (eg. it is residing in stockpiles that researchers cannot access) and/or from a lack of support for the science related to subfossil kauri (and stewardship of wood) currently in archive.

ii. The impacts of this risk to the scientific value of subfossil bog kauri could result in diminished potential for current and future tree ring analyses because the wood could disappear in-situ

1. Rot of wood could occur before extracted subfossil kauri or archived samples can be comprehensively evaluated for scientific analysis. In this case, important features like bark, sapwood, heartwood could be lost and impact on the full potential of dendrochronology analyses

2. Limitations from rotting wood has knock on effects for dendroclimatic and palaeoenvironmental analyses and/or makes wood ineffective for radiocarbon dating

3. This type of risk may be exacerbated via the loss of dedicated nationally-based facilities (and personnel) where collecting, evaluating, analysing, and curating subfossil kauri wood samples currently takes place. In such situations wood archives may be disposed of, as has happened at other institutions overseas leading to loss of an internationally significant and irreplaceable resource.

8.2 Recommendations to mitigate risks to scientific values of subfossil kauri

We have considered the major risks identified above (inclusive of their subcomponents) and qualitatively ascribed a risk level (high, moderate, low) to each of them in order to indicate which are the most critical to address. In doing so, we also indicate how each of the main risks and their risk profile may change if mitigation strategies (actions) are adopted (see details in Table 1). Three primary options are used to indicate how current practice and behaviours could be changed, and we describe the risk profile change in the case where an option is adopted. We also indicate what parties might be involved in helping to facilitate the changes.

Option 1: Changes are legislated and/or regulated

Option 2: Changes are adopted as policy/incorporated into approval process

Option 3: Changes are undertaken via adopting best practice/voluntary approaches

Option 1 would be the most ideal/best case scenario, however the actions that can be taken to mitigate the risks to scientific values of subfossil bog kauri will be determined by current legislative frameworks, regulative authorities and funding for science. With regard to the latter determining factor, some of the recommendations rely on scientists being able to train industry operators and/or remain on site during (all or part of) the time wood is being excavated.

a) Loss of knowledge of subfossil kauri excavations (current risk: high).

   i. Scientists are notified of new excavation sites for subfossil kauri

      1. New risk profile under Option 1: Low

      2. New risk profile under Option 2: Moderate

      3. New risk profile under Option 3: High

A pre-excavation site registration survey would be obtained to ensure there was adequate notification and opportunity (either prior to or during the excavation) to evaluate potential for obtaining site stratigraphy, geomorphologic data and subfossil kauri samples. In all cases, site information (eg. location, evidence of subfossil wood, etc) could be vetted prior to excavations, and if approved, the ensuing excavation could proceed with checkpoints that would help to ensure that the location, spatial scale of the excavation, and volume of subfossil wood extracted at any new site was fully documented. If the location happened to be unique (i.e. in an area not previously known for subfossil kauri, or thought to contain subfossil kauri of significant scientific value), it would allow scientists to plan accordingly in order to actively access the site when it was being excavated so as to not unduly hold up work. Parties involved in this process would be current (and potentially traditional) landowners, excavator operators, regional council staff, scientists, and MPI.

   ii. Scientists are provided access to extracted wood for assessment

      1. New risk profile under Option 1: Low

      2. New risk profile under Option 2: Moderate

      3. New risk profile under Option 3: High

Parties that either excavate subfossil kauri, house previously excavated subfossil kauri, or obtain/purchase bulk subfossil kauri (e.g. obtaining for more than personal use) in an on-going way would allow adequate opportunity (either during or just after the excavation, or prior to milling, or prior to export where stump material is concerned) for subfossil kauri samples to be surveyed and sampled. This step would be completed with a check list where the extracted wood has been scaled (in cubic metres) and given a serial number to ensure that the material can be linked back to specific locations (and potentially depths) at unique sites (as best as possible). Parties involved would be current and traditional landowners, excavator operators, regional council staff, scientists, and MPI.

b) Loss of internationally-significant scientific knowledge that only New Zealand subfossil kauri wood or subfossil kauri sites can provide (current risk: high)

i. Scientists are notified of new excavation sites for subfossil kauri

1. New risk profile under Option 1: Low

2. New risk profile under Option 2: Moderate

3. New risk profile under Option 3: High

See explanation about pre-excavation recommendations related to mitigating "Loss of knowledge of subfossil kauri excavations; Scientists notified of new excavation sites".

ii. Palaeoenvironmental surveys are undertaken in relation to subfossil kauri excavations

1. New risk profile under Option 1: Low

2. New risk profile under Option 2: Moderate

3. New risk profile under Option 3: High

A palaeoenvironmental survey would allow the opportunity (either prior to or during the excavation) to retrieve site stratigraphy, geomorphology and subfossil kauri sample information. In some cases, site survey information could be obtained prior to excavations, but in other cases it could be more prudent to evaluate the site as work progressed. In addition, the ensuing excavation could proceed with checkpoints (eg. A stage where extraction stops and scientists are invited to access the site) that would help to ensure that the location, spatial scale of the excavation, and volume of subfossil wood extracted at any new site was fully documented. In addition, any intrinsic scientific values that were further identified and recorded (or physically captured, as with a monolith section) could be achieved in situations where they emerged as digging progressed (e.g. new features were only seen and identified as 'special' in exposed stratigraphy as a result of excavation). In this situation, both wood and stratigraphy could be maximally assessed and documented (or recovered) for science during site alterations as excavations proceeded. Parties involved in this process would be current (and potentially traditional) landowners, excavator operators, regional council staff, scientists, and MPI.

iii. Radiocarbon data are obtained at subfossil kauri sites and for extracted wood

1. New risk profile under Option 1: Low

2. New risk profile under Option 2: Moderate

3. New risk profile under Option 3: High

A minimum number of radiocarbon rangefinder dates would be submitted in concert with a palaeoenvironmental survey for each subfossil kauri site. The material for radiocarbon dating should be selected by trained scientists who are working in conjunction with the parties excavating the wood. It is recommended that at least two radiocarbon dates are submitted at each site up to 2 hectares in size, and an additional date is submitted for larger sites for every 5 additional hectares at larger sites. Parties involved in this process would be current (and potentially traditional) landowners and/or excavator operators and/or timber merchants and scientists.

iv. Geospatial data and unique serial numbers are recorded for each subfossil kauri tree

1. New risk profile under Option 1: Low
2. New risk profile under Option 2: Moderate
3. New risk profile under Option 3: High

Geospatial data related to individual subfossil kauri trees will help in establishing provenance of extracted wood. That information is needed for scientific study where geographic details are required, and also helps to determine what wood from current and future excavations needs to be collected and archived for science. See additional guidance on “Loss of knowledge of subfossil kauri excavations; Scientists are provided access to extracted wood for assessment”. Parties involved in this process would be current (and potentially traditional) landowners and/or excavator operators and/or timber merchants and scientists.

v. Scientists are allowed access to in-situ subfossil kauri

1. New risk profile under Option 1: Low
2. New risk profile under Option 2: Moderate
3. New risk profile under Option 3: High

Stratigraphic relationships between excavated trees are important for dendrochronology and radiocarbon studies. Measurement of tree fall patterns *in situ* are integral to retaining the palaeotempestology potential of subfossil kauri. In-situ subfossil kauri surveys would provide opportunities to link site stratigraphy to past evidence of extreme events (e.g. woody debris layers that may represent destruction of the forest canopy), impacts of geologic events (like tephras and volcanic eruptions), and climate variability and change records held in peats that are often associated with the buried wood. In some situations, those details may be connected to specific wood samples (and the palaeorecords in the wood) via superposition, lateral continuity, and morphosequence relationships. See guidance on “Loss of knowledge of subfossil kauri excavations; Scientists are provided access to extracted wood for assessment” and “Loss of internationally-significant scientific knowledge that only New Zealand subfossil kauri wood or subfossil kauri sites can provide; Palaeoenvironmental surveys are undertaken in relation to subfossil kauri excavations”. Parties involved in this process would be current (and potentially traditional) landowners and/or excavator operators and/or timber merchants and scientists.

c) Loss (or reduced) stewardship capability for subfossil kauri wood and/or capacity for subfossil kauri collection (moderate-low)

   i. Scientific archives underpinning subfossil kauri research are maintained

      1. New risk profile under Option 1: Low

      2. New risk profile under Option 2: Moderate

      3. New risk profile under Option 3: Moderate

Support for curation activities and storage of samples at NIWA and UOA is relatively stable, as both Lorrey and Boswijk are permanent employees at each institution, respectively. Both researchers have undertaken a curation role for subfossil kauri as part of their science programmes and/or general lab oversight duties, and both are developing long-range plans for their research programmes (including shared protocols related to archiving samples). At NIWA, an internal assessment of capability and capacity for continually receiving and working with subfossil kauri samples is re-evaluated each year. Maintenance and growth of the NIWA ancient kauri archive facility has been supported by internal capital expenditure, which also includes regular updates to field kit that is required for collecting subfossil kauri specimens. At SENV TRL laboratory, workshop space, technical support and wood storage has been supported by a series of national research grants. Continuation of the facility is contingent on current and future funding, and use of the facility for supervision and teaching. For GTRL, aperiodic funding has been required to maintain support for subfossil kauri research, and capability and capacity have been accomplished or advanced on a project basis. Parties involved in this process would be subfossil kauri consortium scientists (Lorrey, Boswijk, Hogg, Palmer, Turney) and their host institutions.

   ii. Scientific research programmes are able to actively/rapidly respond and acquire subfossil wood collections

      1. New risk profile under Option 1: Low

      2. New risk profile under Option 2: Low

      3. New risk profile under Option 3: Moderate

Scientific study using subfossil wood requires active and regular collection of new material to augment existing data sets and increase spatial and temporal distribution of kauri data. This activity is largely accomplished by GTRL and NIWA ancient kauri research programmes. SENV TRL has had longstanding collaborations with GTRL for collection of Holocene wood as part of funded research programmes. All parties work with industry partners to obtain material regularly for scientific analysis, and NIWA and GTRL work together and discuss approaches when new sites are identified. For example, GTRL has a longstanding relationship with Nelson Parker and currently obtains slices of subfossil kauri that are stockpiled in a shipping container at Nelson's Kaihu Kauri before being shipped to the GTRL. NIWA works directly with landowners and other industry partners who are excavating wood to collect samples in the field and also at the point of milling, or that are in storage prior to milling. It is imperative that the practitioners are able to maintain time and cost support for obtaining collections of subfossil wood, or else the risk of continually losing wood will become more acute. In addition, see details on "Loss of knowledge of subfossil kauri excavations; scientists are provided access to extracted wood for assessment" and "Loss of internationally-significant scientific knowledge that only New Zealand subfossil kauri wood or subfossil kauri sites can provide; palaeoenvironmental surveys are undertaken in relation to subfossil kauri excavations". Parties involved in ongoing evaluations of this process would be scientists (to ensure funding to cover time is maintained) and their host institutions.

d) Loss of scientific potential due to wood deterioration (low)

  i. Scientific archives underpinning subfossil kauri research are maintained

    1. New risk profile under Option 1: Low

    2. New risk profile under Option 2: Low

    3. New risk profile under Option 3: Low

When subfossil kauri is removed from the ground, it loses water and it may deteriorate if left unattended. In addition, kauri is subject to damage from bioturbation (eg. wood borer) and subaerial erosion. Maintenance of the archives includes processes around dealing with collected samples (drying, formatting, sectioning into radii and offcuts, and sanding and insecticide treatments) that need to be enacted to ensure wood does not deteriorate and so that samples remain stable through time. Commitment for dedicated archive support, curation, and rapid processing of wood samples is required. At present, the ongoing, regular work in our archives represents a continual evaluation of the wood resource for our current research needs that is related to radiocarbon dating, dendrochronology and palaeoclimate reconstructions. Parties involved in ongoing evaluations of this process are scientists and their host institutions (to also ensure there is funding to cover time and that adequate facilities are maintained).

  ii. Scientific research programmes utilizing subfossil wood are maintained and expanded

    1. New risk profile under Option 1: Low

    2. New risk profile under Option 2: Low

    3. New risk profile under Option 3: Low

Science that relies on subfossil kauri will only thrive if new questions can be asked that require the resource to be used. As such, scientists who have recognized track records of handling and analysing subfossil kauri, who are current stewards of subfossil kauri, who have well-established contacts in the subfossil kauri industry, and who understand the environments that subfossil kauri come from require ongoing support for this field of science. They are critical for maintaining low risk related to scientific values of subfossil kauri specimens, and they are essentially the last line of defence for ensuring science around subfossil kauri thrives (and survives). It is highly likely that attempts to repeat past efforts from scratch (eg. chronology building, visits to original subfossil kauri sites) may not be (or are not) possible. Likewise, the scientists involved in the research have a duty to remain current with the literature in the Quaternary sciences and to identify how subfossil kauri can be applied to answer outstanding, current and relevant research questions.

Support for current subfossil kauri research programmes as well as expansion of them to include training and succession planning is therefore warranted. Despite the fact much of the current science around subfossil kauri is undertaken by a mixture of nationally- and internationally-based scientists, a strong foundation of research based at New Zealand research institutions is crucial to reduce the risk to scientific values that rely on subfossil bog kauri research. Evaluating this risk, and the processes by which the risk profile for subfossil kauri scientific values could remain low, would include guidance from the subfossil kauri consortium scientists (the scientists present at the Auckland workshop) in consultation with their institutions as well as the national and international Quaternary science community, and to some extent industry representatives and end users of kauri who benefit from the scientific knowledge obtained from subfossil kauri analyses. In addition, external discussions with national funding agencies who may have an interest in subfossil kauri (eg. The Royal Society of New Zealand, Ministry for the Environment) or vetting regular funding applications to support bodies (eg RSNZ Marsden Fund, MBIE Endeavor Fund, Australia Research Council, etc) could help to 'accelerate' the science related to subfossil kauri to ensure a maximum number of samples were utilized to benefit science outcomes.

Table 1: Key risks for the current and future scientific value of New Zealand subfossil bog kauri. Risk level is qualitatively ascribed at the present day starting point. We indicate a relative change in the risk profile if a risk mitigation solution was legislated (required by national law, with legal ramifications if not adhered to), regulated (guided by policy and enforced via checking at a regional council level) or promoted by way of 'best practice guidelines' (i.e. stakeholder voluntarily undertakes action and does so willingly).

Risks	Current *Risk level*	*Legislation*	after steps	*Regulation*	after steps	*Best practice (voluntary)*	
Stakeholders: Government, society							
Loss of knowledge of swamp kauri locations							
New sites proposed for extractions are not reported	High	Regional council must notify scientists about all permitted sites	Low	Regional council should notify scientists about permitted sites	medium	council and/or extractors are encouraged to contact scientists	High
new extractions are not catalogued and wood is lost	High	Regional council must notify scientists about all permitted sites	Low	Regional council should notify scientists about permitted sites	medium	recommeded that scientists have access to the extracted trees	High
Stakeholders: Landowner, miller, council, scientific community							
Loss of internationally significant scientific knowledge from archives of NZ natural history							
Sites within identified swamp kauri terrain are rapidly exploited	High	Regional council must notify scientists about permitted sites within mapped terrain	Low	As part of the consent process, extractors are required to contact scientists	medium	extractors should contact scientists	High
Wood and environmental context/history is lost	High	Environmental assessment of site (to include palaeoecological parameters); area dug is measured; surface wood is surveyed before removal	Low	As part of the consent process, landowners must undertake a palaeoenvironmental assessment in addition to the environmental (ecological) assessment	medium	Landowners should allow opportunity for scientists to gather palaeoenvironmental data prior to wood extraction	High
information about natural history periods are lost	High	radiocarbon dates are provided for the site (minimum of two dates per site up to 2 hectares; and an additional date every for each additional 5 hectares at larger sites)	Low	minimum of two radiocarbon dates per site	medium	recommended that at least two radiocarbon dates are obtained	High
archives for science are lost or too few	High	if trees are discovered, 100% of trees extracted must be made available for scientific sampling	Low	if trees are discovered, all extracted trees extracted should be made available for scientific sampling	medium	if trees are discovered, all extracted trees extracted should be made available for scientific sampling	High
context of scientific samples and sites are unknown, limits use	High	extracted trees and other samples must have a unique site serial number and geospatial data that is designated on extraction	Low	extracted trees should be given a unique site serial number and a site location that is designated on extraction	medium	individual trees should be appropriately labeled and site location is provided	High
limited scientific information at the scale of an individual swamp kauri tree scale	medium	trees are sampled at the point of milling; scientists allowed access on site when samples are being extracted	Low	each tree is sampled at the milling site to ensure suitable scientific samples are captured	medium	millers allow access to wood before and through the milling process	medium

Stakeholder: Scientific community							
Lack of stewardship capabilites for swamp kauri wood and metadata							
Loss of capability to archive, curate, receive and retain wood and document analyses	medium	New funding is set aside for support of current archives (physical wood storage, processed samples, digital data, paper records) that underpin long-term swamp kauri research	Low	A portion of existing funding is set aside for support of current archives that underpin long-term swamp kauri research	medium	Aperiodic funding is sought for support of current archives that underpin long-term swamp kauri research	medium
Loss of response capacity and capability to collect emerging wood	medium	N/A		N/A		Practitioners in the swamp kauri research maintain their ability to collect wood samples and get them to archive; discuss within institutions how that work can be supported (time and cost)	Low
Stakeholder: Scientific community							
Loss of scientific potential because wood is not analysed quickly enough and deteriorates							
Loss of suitable material for radiocarbon dating	Low	N/A		Institutional support required to cover time and cost	Low	samples dated close to time when logs are extracted in case duplicate material is needed for destructive analyses	Low
dendrochronology	Low	N/A		Institutional support required to cover time and cost	Low	commitment toward chronology development	Low
environmental research	Low	N/A		Institutional support required to cover time and cost	Low	commitment toward undertaking continued fieldwork and gathering data about kauri	Low
dendroclimatology	Low	N/A		Institutional support required to cover time and cost	Low	commitment toward undertaking continued fieldwork and gathering data about kauri	Low

Table 1 (continued).

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10 References cited and bibliography

We have categorised information used in this report, and the divisions of references cited align to several subcategories that are indicative of their level of peer review. In those sections, we also include other works that are relevant to documentation of subfossil bog kauri research and outreach activities related to the work. As such, this reference list is more substantial than what is cited in the main body text.

Journal Articles, theses and book chapters

Ahmed, M., 1984. Ecological and dendrochronological studies on Agathis australis Salisb. (kauri). Unpublished Ph.D. thesis, University of Auckland.

Boswijk, G., 2010. Remembering kauri on the 'Kauri Coast'. *New Zealand Geographer,* 66: 124 – 137.

Boswijk, G., Fowler, A., Palmer, J.G., Fenwick, P., Hogg, A., Lorrey, A., Wunder, J., 2014. The late Holocene kauri chronology: assessing the potential of a 4500 –year record for palaeoclimate reconstruction. *Quaternary Science Reviews,* 90, 128-142.

Boswijk, G., Fowler, A., Lorrey, A., Palmer, J., Ogden, J., 2006. Extension of the New Zealand kauri (Agathis australis) chronology to 1724 BCE. *Holocene* 16, 188–199.

Boswijk, G. 2005. A History of kauri. In (ed.) Dargavel, J. Australia and New Zealand Forest Histories: Auraucarian Forests. Australian Forest History Soceity.

Boswijk, G., Fowler, A., Palmer, J., 2005. Hidden histories: tree-ring analysis of late Holocene swamp kauri, Waikato, New Zealand. Proceedings of 6th National Conference of the Australian Forest History Society Inc. Michael Calver et al. (eds.) Millpress, Rotterdam. pp 517–525.

Bridge, M., Ogden, J., 1986. A sub-fossil kauri (*Agathis australis*) tree-ring chronology. *J. R. Soc. New Zeal.* 16, 17–23.

Bridge, M., 1987. The dendrochronological study of sub-fossil wood in New Zealand. In, R.G. Ward (ed.) *Applications of Tree-ring studies: current research in dendrochronology and related subjects*. BAR Int. Ser. 333, Oxford, England, pp. 227–232.

Cook, E.R., Buckley, B.M., Palmer, J., Fenwick, P., Peterson, M.J., Boswijk, G., Fowler, A., 2006. Millennia-long tree-ring records from Tasmania and New Zealand: a basis for modelling climate variability and forcing, past, present and future. *J. Quat. Sci. 21,* 689–699.

Danisik, M., Shane, P., Schmitt, A., Hogg, A., Santos, G., Storm, S., Evans, N., Fifield, K., Lindsay, J., 2012. Re-anchoring the late Pleistocene tephrochronology of North Island (New Zealand) based on concordant radiocarbon ages and combined 238U/230Th disequilibrium and (U–Th)/He zircon ages. *Earth and Planetary Science Letters* 349-350: 240-250.

D'Costa, D., Boswjk, G., Ogden, J., 2009. Holocene vegetation and environmental reconstructions from swamp deposits in the Dargaville region of the North Island, New Zealand: implications for the history of kauri (Agathis australis). *The Holocene*, 19: 559 – 574.

D'Costa, D.M., Palmer, J., Hogg, A., Turney, C., Fifield, L. K., and Ogden J. 2009. Stratigraphy, pollen and 14C dating of Johnston's Gum Hole, a late Quaternary fossil kauri (Agathis australis) site, Northland, New Zealand. Journal of Quaternary Science 24 (1) 47-59.

Dunwiddie, P.W., 1979. Dendrochronological studies of indigenous New Zealand trees. *New Zeal. J. Bot.* 17, 251–266.

Fowler, A.M., Boswijk, G., Lorrey, A.M., Gergis, J., Pirie, M., Mccloskey, S.P.J., Palmer, J.G., & Wunder, J., 2012. Multi-centennial ENSO insights from New Zealand forest giants. *Nature Climate Change*, 2: 172-176, 2012

Fowler, A., 2008. ENSO history recorded in Agathis australis (kauri) tree rings. Part B: 423 years of ENSO robustness. *Int. J. Climatol.* 28, 21–35.

Fowler, A.M., Boswijk, G., Gergis, J., Lorrey, A., 2008. ENSO history recorded in Agathis australis (kauri) tree rings. Part A: kauri's potential as an ENSO proxy. *Int. J. Climatol.* 28, 1–20.

Fowler, A., Boswijk, G., Ogden, J., 2004. Tree-ring studies on Agathis australis (kauri); a synthesis of development work on late Holocene chronologies. *Tree-Ring Res*. 60, 15–29.

Fowler, A., Palmer, J., Salinger, J., Ogden, J., 2000. Dendroclimatic interpretation of tree-rings in Agathis australis (kauri): 2. Evidence of a significant relationship with ENSO. *J. Roy. Soc. New Zeal.* 30, 277–292.

Güttler, D., Adolphi, F., Beer, J., Bleicher, N., Boswijk, G., Christl, M., Hogg, A., Palmer, J., Vockenhuber, C., Wacker, L. et al. 2015. Rapid increase in cosmogenic 14C in AD 775 measured in New Zealand kauri trees indicates short-lived increase in 14C production spanning both hemispheres. *Earth and Planetary Science Letters* 411: 290-297.

Hayward, B. and Hayward, J. 1995. Fossil forests preserved in volcanic ash and lava at Ihumatao and Takapuna, Auckland. Tane, 35, 127-142.

Hogg, A., Southon, J., Turney, C., Palmer, J., Bronk Ramsey, C., Fenwick, P., Boswijk, G., Friedrich, M., Helle, G., Hughen, K., *et al*. 2016. Punctuated Shutdown of Atlantic Meridional Overturning Circulation during Greenland Stadial 1. *Scientific Reports,* 6, 25902.

Hogg, A., Turney, C., Palmer, J., Cook, E., Buckley, B., 2013. Is there any evidence for regional 14C offsets in the Southern Hemisphere? *Radiocarbon* 55, 4: 2029-2034.

Hogg, A., Turney, C., Palmer, J., Southon, J., Kroner, B., Bronk Ramsey, C., Boswijk, G., Fenwick, P., Noronha, A., Staff, R., Friedrich, M., Reynard, L., Guetter, D., Wacker, L., Jones, R., 2013. The New Zealand Kauri (Agathis australis) research project: a radiocarbon dating intercomparison of Younger Dryas wood and implications for Intcal13. *Radiocarbon* 55, 1–14.

Hogg, A., Lowe, D. J., Palmer, J., Boswijk, G., & Bronk Ramsey, C. Revised calendar date for the Taupo eruption derived from 14C wiggle-matching using a New Zealand kauri 14C calibration data set. *The Holocene*, 22 (4): 439-449, 2012

Hogg, A., Hua, Q., Blackwell, P., Niu, M., Buck, C., Guilerson, T., Heaton, T., Palmer, J., Reimer, P., Reimer, R., Turney, C., Zimmerman, S., 2013. SHCal13 Southern Hemisphere Calibration, 0-50,000 years cal BP. *Radiocarb*. 55, 1889–1903.

Hogg, A., Palmer, J., Boswijk, G., Reimer, P., Brown, D., 2009. Investigating the interhemispheric 14C offset in the 1st millennium CE and assessment of laboratory bias and calibration errors. *Radiocarb*. 51, 1177–1168.

Hogg, A., Fifield, L., Palmer, J., Turney, C., Galbraith, R., 2007. Robust radiocarbon dating of wood samples by high-sensitivity liquid scintillation spectroscopy in the 50-70 kyr age range. *Radiocarbon* 49:2: 379-391.

Hogg, A., Fifield, L., Turney, C., Palmer, J., Galbraith, R., Baillie, M., 2006. Dating ancient wood by high sensitivity liquid scintillation counting and accelerator mass spectrometry - Pushing the boundaries. *Quaternary Geochronology* 1: 241-248.

Hogg, A., 2004. Towards achieving low background levels in routine dating by liquid scintillation spectrometry. *Radiocarbon* 46, 1: 123-132.

Hogg, A., Higham, T., Beukens, R., Kankainen, T., McCormac, G., van der Plicht, J., Stuiver, M., Robertson, S., 1994. Radiocarbon age assessment of a new near background IAEA Quality Assurance material. Proceedings of the 15th International 14C Conference (eds.) D.D Harkness, B.F Miller and E.M Scott. *Radiocarbon* 37, 3: 797 - 803.

Hogg, A., Lowe, D., Hendy, C., 1987. University of Waikato radiocarbon dates I. *Radiocarbon* 29: 263-301.

Lorrey, A.M. 2008. The Late Quaternary palaeoclimate record in kauri tree rings. Unpublished PhD thesis, School of Geology, Geography, and Environmental Science, University of Auckland, New Zealand. 344 pages.

Lorrey, A.M. and Bostock, H. 2016. Chapter 1: The Quaternary climate of New Zealand. In *Advances in Quaternary Science - the New Zealand Landscape*. Springer-Verlag, In press.

Lorrey, A. and Martin, T. 2005. Use of Use of modern tree-fall patterns as a guideline for interpreting prostrate trees at a pre–Last Glacial Maximum palaeoforest site, upper North Island, New Zealand. *Journal of Geophysical Research- Biogeosciences* 110, G2, G02012. 10.1029/2005JG000040. 1-7.

Lorrey, A.M., Martin, T.J., and Palmer, J.G. 2016. Swamp kauri resources of Northland. NIWA client report 2016112AK prepared for the Ministry for Primary Industries, 60 pages.

Andrew M. Lorrey, Tom H. Brookman, Michael N. Evans, Nicolas C. Fauchereau, Cate Macinnis-Ng, Margaret M. Barbour, Alison Criscitiello, Greg Eischeid, Anthony M. Fowler, Travis W. Horton, Daniel P. Schrag, 2016b. Stable oxygen isotope signatures of early season wood in New Zealand kauri (Agathis australis) tree rings: Prospects for palaeoclimate reconstruction, Dendrochronologia, Volume 40, Pages 50-63, ISSN 1125-7865, http://dx.doi.org/10.1016/j.dendro.2016.03.012.

Murphy, J.O, and Palmer, J.G., year Ring width variation in sub-fossil wood samples as an indicator of short term solar variability 2000 YR BP. *Proceedings of the Astronomical Society of Australia*, 10 (1): 68 – 70.

Norton, D.A., and Palmer, J.G. 1992 Dendroclimatic evidence from Australaisa. In R.S.Bradley, P.D. Jones (eds) C*limate since A.D. 1500*. Routledge, London. Revised edition 2003.

Norton, D.A., Ogden, J., 1987. Dendrochronology: a review with emphasis on New Zealand applications. *New Zeal. J. Ecol.*, 10, 77–95.

Ogden, J., Newnham, R.M., Palmer, J.G., Serra, R.G., Mitchell, N.D., 1993 Climatic implications of macro- and microfossil assemblages from late Pleistocene deposits in Northern New Zealand. *Quaternary Research* 39: 107-119.

Ogden, J., Wilson, A., Hendy, C., Hogg, A., Newnham, R. 1992. The late Quaternary history of kauri (Agathis australis) in New Zealand, and its climatic significance. *Journal of Biogeography*. 19: 611-622.

Palmer, J., Turney, C., Hogg, A, Lorrey, A., Jones R., 2015. Progress in refining the global radiocarbon calibration curve using New Zealand kauri (Agathis australis) tree-ring series from Oxygen Isotope Stage 3*. Quaternary Geochronology* (27), 158-163.

Palmer, J., Lorrey, A., Turney, C.S.M., Hogg, A., Baillie, M., Fifield, K., Ogden, J., 2006. Extension of the New Zealand kauri (Agathis australis) tree-ring chronologies into Oxygen Isotope Stage (OIS) 3. *J. Quat. Sci.* 21, 779–787.

Jonathan G. Palmer, Chris S.M. Turney, Edward R. Cook, Pavla Fenwick, Zoë Thomas, Gerhard Helle, Richard Jones, Amy Clement, Alan Hogg, John Southon, Christopher Bronk Ramsey, Richard Staff, Raimund Muscheler, Thierry Corrège, Quan Hua, Changes in El Niño – Southern Oscillation (ENSO) conditions during the Greenland Stadial 1 (GS-1) chronozone revealed by New Zealand tree-rings, Quaternary Science Reviews, Volume 153, 1 December 2016, Pages 139-155, ISSN 0277-3791, http://dx.doi.org/10.1016/j.quascirev.2016.10.003.

Poussart, P.F., 2004. Isotopic Investigations of Tropical Trees. Unpublished PhD Thesis. Department of Earth and Planetary Sciences, Harvard University, Cambridge, Massachussetts, 143 p.

Roig, F. A., Palmer, J. G., Cook, E. R., Boswijk, G., Stahle, D., Villalba, R., & D'arrigo, R. D. 2010. Longues Series Dendrochronologiques Dans L'hemisphere Sud. S. Payette, & L. Filion (Eds.), La *Dendroecologie: Principes, Methodes Et Applications*. Presses De L'universite Laval, Quebec, Quebec pp 647-682.

Santos, GM and Ormsby, K. 2013. Behavioral variability in ABA chemical pre-treatment close to the 14C age limit. *Radiocarbon*, 55, 2-3, 534-544.

Staff, R.A., Reynard, L., Brock, F., and Bronk Ramsay, C. 2014., Wood pretreatment protocols and measurement of tree-ring standards at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon*, 56, 2, 709-715.

Southon, J.R. and Magana, A.L. 2010. A comparison of cellulose extraction and ABA pretreatment methods for AMS 14C dating of ancient wood. *Radiocarbon*, 52, 2-3, 1371-1379.

Turney, C., Palmer, J., Bronk Ramsey, C., Adolphi, F., Muscheler, R., Hughen, K., Staff, R., Jones, R., Thomas, Z., Fogwill, C., Hogg, A., 2016. High-precision dating and correlation of ice, marine and terrestrial sequences spanning Heinrich Event 3: Testing mechanisms of interhemispheric change using New Zealand ancient kauri (Agathis australis). *Quaternary science Reviews*, 137:126-134.

Turney, C.S.M., Fifield, L.K., Hogg, A.G., Palmer, J.G., Hughen, K., Baillie, M.G.L., Galibraith, R., Ogden, J., Lorrey, A., Tims, S.G., Jones, R.T., 2010. The potential of New Zealand kauri (Agathis australis) for testing the synchronicity of abrupt climate change during the Last Glacial Interval (60,000-11,700 years ago). *Quaternary Science Reviews,* 29, 3677–3682.

Turney, C., Fifield, K., Palmer, J., Hogg, A., Baillie, M., Galbraith, R., Ogden, J., Lorrey, A., Tims, S., 2007. Towards a radiocarbon calibration for Oxygen Isotope Stage 3 using New Zealand kauri (Agathis australis). *Radiocarbon* 49, 2: 447-457.

Villalba, R., 2000. Dendroclimatology: A Southern Hemisphere Perspective. In, P. Smolka et al (eds) *Southern Hemisphere Palaeo- and Neoclimates*. Springer-Velage Berlin Heidelberg. pp 27-57.

Conference abstracts and presentations

Boswijk, G. 2005. A history of kauri. *Australian Forest History Society Symposium "History of the Araucarian Forests".* August 9, Queensland Museum, Brisbane.

Boswijk, G., Fowler, A., and Lorrey, A. 2014. WorldDendro Fieldtrip - Northland Kauri (Agathis australis). Field Guide. Northland Kauri: Auckland and Northland, New Zealand, January 21-15, 2014. Fieldguide for the *9th International Conference on Dendrochronology,* Melbourne, Australia, Post Conference Tour (New Zealand).

Boswijk, G., Fowler A.M., Palmer, J., Gergis, J., Lorrey, A., McCloskey, S., & Wunder, J., 2010. The New Zealand Kauri Chronology: Recent advancements in updating and improving the record. In Mielikäinen, K., Mäkinen, H and Tinomnen, M. (eds.) *World Dendro 2010. Abstracts of The 8th International Conference on Dendrochronology*. Rovaniemi, Finland, June 13 – 18, 2010, pp 66.

Boswijk, G., Fowler, A.M., Lorrey, A., Gergis, J., and Palmer, J. 2007. Improving Replication: The addition of new archaeological material to the late-Holocene kauri record. In, XVII INQUA Congress (2007) Abstracts, *Quaternary International* 167-168: 41, 2007

Boswijk, G.; Fowler, A.M.; Lorrey, A.; Gergis, J.; Palmer, J.G. 2007. Improving replication: the addition of new archaeological data to the late-Holocene kauri record [Abstract no. 0311 – INQUA 2007 Abstracts]. *Quaternary International 167–168 (Supplement)*: 41.

Boswijk, G., Fowler, A., & Palmer, J. 2004. Hidden histories: tree-ring analysis of late Holocene swamp kauri, Waikato, New Zealand. *6th National Conference of the Australian Forest History Society Inc.* 12-17 September 2004, Augusta, Western Australia.

Boswijk, G., & Palmer, J.G., 2003. Tree-ring analysis of late Holocene 'swamp kauri' from the Waikato Lowlands. *New Zealand Ecological Society Conference,* Auckland, 16 – 20 November.

Boswijk, G., Fowler, A., & Ogden, J., 2002. New Zealand Dendrochronology: prospects for a 4000 year kauri chronology. *Dendrochronology, Environmental Change and Human History. 6th International Conference on Dendrochronology*, Quebec City, Canada, August 22 – 27. pp 30-32.

Fowler, A., Boswijk,G., Lorrey, A.. 2013. A 4500 year Southern Hemisphere record of ENSO activity from kauri tree rings. *EGU General Assembly Conference Abstracts*, 15, 3598

Fowler, A.M., Boswijk, G., Gergis, J., Lorrey, A., Palmer, J. A multi-century ENSO reconstruction from Kauri Tree Rings, In, XVII INQUA Congress (2007) Abstracts, *Quaternary International* 167-168: 123, 2007

Gontz, A., Lorrey, A., Velez-Ortiz, M. 2015. Using ground penetrating radar to link subfossil kauri and palaeoclimate records in peat, Northland, New Zealand. *Geological Society of America*, Abstracts with Programs, 47, 3, 84.

Hogg, A., Palmer, J. G., Boswijk, G., Bronk Ramsey, C., Reimer, P., & Brown, D. 2009. Assessment of the integrity of the Southern Hemisphere 14C calibration curve and its extension from AD 785 to 200 BC, with particular emphasis on the inter-hemispheric offset. *20th International Radiocarbon Conference*, Big Island, Hawaii, 30 May - 5 June.

Lorrey, A.M. 2014. An overview of palaeoclimate and palaeoenvironmental change records for New Zealand covering 60ka – Present as a contribution to the Southern Hemisphere Assessment of PalaeoEnvironments (SHAPE) project. Program and abstracts, *Australasian Quaternary Association bi-annual meeting,* Mildura, Australia. 26 June-3 July.

Lorrey, A., Palmer, J., Turney, C., Hogg, A., Newnham, R., Boswijk, G., Fowler, A.M. 2009. Advances on the construction, palaeoenvironmental associations, and palaeoclimatic significance of ancient kauri (Agathis australis) tree ring chronologies, Northland, New Zealand, *Past Climates New Zealand*, Wellington, 15-17 May, 2009, p.37-37, 2009. www.paleoclimate.org.nz/pastclimates.

Lorrey, A.; Palmer, J.; Turney, C.; Hogg, A.; Boswijk, G.; Fowler, A.; Ogden, J. 2007. Development of oxygen isotope stage (OIS)-3 New Zealand kauri (*Agathis australis*) chronologies for palaeoclimate analysis [Abstract no. 1004 – INQUA 2007 Abstracts]. *Quaternary International 167–168(Supplement)*: 249.

Lorrey, A., Palmer, J. G., Boswijk, G., Martin, T., Hogg, A., Turney, C., Fowler, A.M. 2008. 'Palaeoclimate studies from Ancient kauri (Agathis australis)', *New Zealand Ecological Society Conference "Ecology on our doorstep"*, Auckland, 28 September - 2 October, 2008

Lorrey, A.M., Palmer, J.G., Boswijk, G., Turney, C.S.M., Hogg, A., Fowler, A.M., and Williams, P.W. 2008. Interpreting ancient kauri (Agathis australis) tree ring records and prospects for a high-resolution climate reconstruction for the OIS3-LGM transition. *AUS-Intimate Meeting*, Onekaka, New Zealand, 12-13 June.

Lorrey, A.M., Fowler, A.M., Boswijk, G., Ogden, J., and Palmer. 2003. The Kauri-climate connection: A New Zealand proxy record of Pacific climate variability and palaeoenvironmental change during the Quaternary. *Geological Society of America*, Abstracts with Programs. Vol. 35 No. 6. p. 415

Lowe, D. J., Hogg, A., Palmer, J., & Boswijk, G. 2011.When was the Taupo Eruption? *Geosciences 2011 Conference*, Nelson, New Zealand, November, 2011.

Turney, C.S.M.; Fifield, L.K.; Hogg, A.G.; Palmer, J.; Hughen, K.; Baillie, M.G.L.; Galbraith, R.; Ogden, J.; Lorrey, A.M.; Tims, S.G. 2007. Radiocarbon calibration and high-resolution correlation through oxygen isotope stage 3 using New Zealand Kauri (*Agathis australis*) [Abstract no. 0895 – INQUA 2007 Abstracts]. *Quaternary International 167–168 (Supplement)*: 250.

Velez-Ortiz, M., Gontz, A., Lorrey, A. 2015. Stratigraphic architecture of a former lowland kauri swamp in Ruakaka, North Island, New Zealand. *Abstract for American Geophysical Union Annual Meeting,* San Francisco.

Velez-Ortiz, M., Gontz, A., Lorrey, A. 2015. Preliminary research plan for integrating relationships of coastal features, kauri trees and climate variation. *Geological Society of America*, Abstracts with Programs, 47, 3, 84.

Williams, P., Ogden, J., Fowler, A., Boswijk, G., Salinger, J., King D., 2002. Palaeoclimate records from Tree-Rings and Speleothems. S*econd New Zealand Palaeoclimate Workshop*. The Royal Society of New Zealand, Wellington. 22 February 2002.

Technical reports

Boswijk, G., Palmer, J., 2012. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Hal Harding's Farm, Pouto Road, Dargaville, Northland. SENV Working Paper 44, The University of Auckland, 29 pp.

Boswijk, G. Palmer, J., 2012. Tree-ring analysis of sub-fossil kauri (Agathis australis) timbers from Trappitt Farm, Babylon Coast Road, Dargaville, Northland. SENV Working Paper 45, The University of Auckland, 25 pp.

Boswijk, G., Palmer, J., 2012. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Gibson's Farm, Babylon Coast Road, Dargaville, Northland. SENV Working Paper 46, The University of Auckland, 24 pp.

Boswijk, G. Palmer, J., 2012. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Verberne Farm, Korariwhero Flat, Dargaville, Northland. SENV Working Paper 47, The University of Auckland, 22 pp.

Boswijk, G., Fowler, A., Bridge, M., 2001. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Furniss Road, Waikato. Dept. Geog. Working Paper 15, The University of Auckland. 28 pp.

Fowler, A., Boswijk, G., Bridge, M., 2001. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Pukekapia Road, Waikato. Dept. Geog. Working Paper 16, The University of Auckland. 25 pp.

Boswijk, G., Palmer, J.G., 2003. Tree-ring analysis of sub-fossil kauri (Agathis australis) from near Lake Whangape, Huntly West, Waikato. Dept. Geog. Working Paper 19, The University of Auckland. 31 pp.

Boswijk, G., 2004. Tree-ring analysis of buried kauri (Agathis australis) from Hoanga Road, Dargaville, and Pouto, north Kaipara Peninsula. SGES Working Paper 24, The University of Auckland, 9 pp.

Boswijk, G., 2004. Tree-ring analysis of a buried kauri (Agathis australis) tree from Tikinui, north Kaipara Peninsula, Northland. SGES Working Paper 21. The University of Auckland, 7 pp.

Boswijk, G. Palmer, J., 2004. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Yakas' Farm, Babylon Coast Road, near Dargaville, Northland. SGES Working Paper 22. The University of Auckland, 17 pp.

Boswijk, G., 2005. Tree-ring analysis of sub-fossil kauri (Agathis australis) from the Chitty's Farm, Colville Road, Dargaville, Northland. SGES Working Paper 27, The University of Auckland, 24 pp.

Boswijk, G., 2005. Tree-ring analysis of sub-fossil kauri (Agathis australis) from the Harding's Farm, Hilliam Road, near Dargaville, Northland. SGES Working Paper 26, The University of Auckland, 27 pp.

Boswijk, G., 2005. Tree-ring analysis of sub-fossil kauri (Agathis australis) from near Maitahi Road. SGES Working Paper 28, The University of Auckland, 18 pp.

Lorrey A.M. and Ogden, J. 2005. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Omaha Flats, Tawharunui Peninsula, New Zealand New Zealand Tree-ring Site Report 22. School of Geography and Environmental Science Working paper 32. ISSN: 1175-8465; ISBN: 1-8777320-18-8

Lorrey A.M., Palmer, J., Turney, C and Hogg, A. 2007. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Colin Payne's Farm, Mangawhai, New Zealand. New Zealand Tree-ring Site Report 25 School of Geography and Environmental Science Working paper 34.

Lorrey A.M., Palmer, J., Hogg, A. and Turney, C. 2005. Tree-ring analysis of sub-fossil kauri (Agathis australis) from Black Swamp Road, Mangawhai, New Zealand. New Zealand Tree-ring Site Report 23 School of Geography and Environmental Science Working paper 33. ISSN: 1175-8465; ISBN: 1-877320-19-6

Popular science articles, public presentations and interviews

Boswijk, G., 2016. Wood, kauri, tree rings. In, P. McNamara, L. Tyler, (Eds.) Celebrating Wood: Back to the Future. Centre for Art Studies, Creative Arts and Industries, The University of Auckland. (Exhibition at Gus Fisher Gallery, May- June 2016).

Boswijk, G., 2012. Dendrochronology and dendroarchaeology. Northland Woodturners and Woodworkers Club. Whangarei, November.

Boswijk, G. 2005. 'Dendrochronology and kauri: reading the story within", Display about kauri tree-ring research comprised of 13 A3 posters and kauri samples used for tree-ring analysis, The Matakohe Kauri Museum, 20 May – 20 June, 2005.

Boswijk, G. 2002. 'Toward a long chronology for New Zealand'. Department of Anthropology Seminar Series, University of Auckland. 23 May 2002.

Boswijk, G. 2001. 'Dendrochronology'. Horticultural Society, Auckland Botanic Gardens, Auckland. April 2001.

Boswijk, G. & Lorrey, A., 2003. Lord of the Rings: what we can learn from tree-rings. Joint Horticultural Society and Auckland Museum Institute Lecture Series, Auckland War Memorial Museum, August 21 2003.

Boswijk, G. & Palmer, J. 2005. Return of the Rings. Matakohe Kauri Museum, May 20 2005.

Fowler, A., and Boswijk, G., 2007. Five centuries of ENSO history recorded in Agathis australis (kauri) tree rings. *PAGES News*, 15 (2): 20-21.

Hogg, A., Turney, C., Palmer, J., Fifield, K., Baillie, M., 2006. The potential for extending IntCal04 using OIS-3 New Zealand sub-fossil kauri. *PAGES News* 14, 3: 11-12.

http://www.waikato.ac.nz/news-events/media/2010/05Kauri%20provide%20a%20unique%20climate%20change%20record.shtml

http://sci.waikato.ac.nz/research/projects-and-case-studies/radiocarbon-dating/kauri

https://www.sciencedaily.com/releases/2010/04/100405103837.htm

http://www.treehugger.com/natural-sciences/ancient-climate-record-could-be-lost-within-10-years.html

http://phys.org/news/2010-03-uk-scientists-unearth-ice-age.html

http://www.nzherald.co.nz/northern-advocate/news/article.cfm?c_id=1503450&objectid=10923569

https://www.utep.edu/leb/pleistNM/radiocarbonSciMag.pdf

http://www.sciencemediacentre.co.nz/2012/02/06/kauri-tree-rings-give-new-insight-into-el-ninola-nina-cycles/

http://ancientkauriproject.com/

http://climatechange.medill.northwestern.edu/2015/02/10/lord-of-the-rings-old-trees-provide-new-insight-into-climate-change/

http://www.wsl.ch/medien/news/zurich_newzealand_treerings/index_EN

http://earthspastfuture.com/

Lorrey, A. 2013. Kauri tree ring research at NIWA. Presentation to the Whangarei Woodturners Guild, Whangarei, 3 September 2013

Lorrey, A. 2009. Climate Change, palaeoclimate, and kauri. Presentation to the University of the Third Age, Birkenhead.

Lorrey, A.M. 2008. Running rings around climate change. *Water and Atmosphere,* 16, 1, 24-25.

Government papers, Newspaper Articles

Anon, 1926. Kauri Pine or Swamp kauri: Important High Court Judgement. *The Timber Trades Journal*, June 19 1926 (no page number). KTC Files, Melbourne University Archive.

Boscawen, H.T., 1911. Notes and Sketch re. Buried Kauri Trees near Dargaville. *Report to Lands and Survey Department*. ATL MS-Papers-2890.

Evening Post, 6 December 1926. Swamp kauri: poor timber exported; experience in Australia proves practically worthless. *Evening Post* 62 (136), 9.

Evening Post, 21 April 1927. Kauri at Home: action in Court; alleged swamp timber. *Evening Post* 63 (93), 12.

Grey River Argus, 26 April 1911. A wood mine: working a timber claim; kauri in the ground. *Grey River Argus*, 8.

Kirk, T., 1889. *Forest flora of New Zealand*. George Disbury, Govt Printer, Wellington.

Popular Mechanics, May 1924. Treasure in buried timber is found in swamp, p. 722.

Rodney and Otamatea Times, November 1914. Soil that Runs Through the Fingers; on a Kauri Swamp Farm. In: *Rodney and Otamatea Times, Waitemata and Kaipara Gazette*, vol. 11, p. 4.

Skeet, H.M., 1912. Department of Lands and Survey (Annual Report on): Appendix III e the Timber Industry: Extracts from Reports of Commissioners of Crown Lands, pp. 27-28. AJHR, Session II, C-01.