THE UNIVERSITY OF WESTERN AUSTRALIA

Dendrochronological potential and population structure of *Callitris columellaris* in the Carnarvon Range, Western Australia

Report prepared for the Western Australian Department of Parks and Wildlife and Central Desert Native Title Services

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1. Background

Callitris columellaris F. Muell. is a native conifer that is widely distributed throughout the semi-arid, arid and tropical zones of Australia. The wood structure of *Callitris columellaris* is typical of other conifers in that they produce distinct growth rings, consisting of two parts - earlywood and latewood (Fig. 1). Earlywood is composed of large, thin-walled tracheids formed at the beginning of each growing season and during the period of active growth. Latewood is composed of smaller, thicker-walled tracheids that appear as a dark band. Latewood is formed toward the end of the growing season, when growth slows down (Stokes and Smiley 1968). The sharp contrast between the last of the latewood cells and the first of the earlywood cells is what delineates the boundary between growth rings.

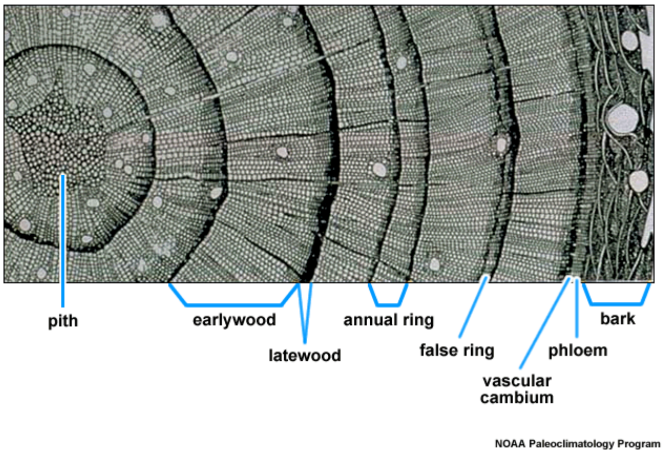

Figure 1: Cross section of a conifer stem showing wood structure and growth rings (earlywood and latewood).

Callitris columellaris trees are shallow-rooted and their growth is generally highly responsive to rainfall (Cullen and Grierson 2009). Where rainfall is distinctly seasonal (e.g., occurs predominantly in one season), *C. columellaris* typically produces one growth ring per year (i.e., annual rings). However, at sites with aseasonal rainfall (evenly distributed throughout the year) or in years when rainfall occurs outside of the typical growing season, *Callitris* may produce more than one ring per year. Extra rings are termed "false" rings and are generally identified by an indistinct boundary between the latewood of one ring and the earlywood of the next.

Over the last decade or so there has been increasing interest in the utility of growth rings of *Callitris* species for understanding past climates, fire history, and tree population dynamics. Growth rings of *Callitris columellaris* have been used to reconstruct rainfall over the last 350 years in semi-arid southwest Australia (Fig. 2, Cullen and Grierson 2009, Sgherza et al. 2010) and over the last 200 years in the semi-arid Pilbara region, northwest Australia (Fig. 2, O'Donnell et al. in prep), as well as for 160 years in tropical northern Australia (Baker et al. 2008, D'Arrigo et al. 2008). Growth rings of *Callitris preissii* have also been used to date past fires as well as examine population age structure in semi-arid southwest Australia (O'Donnell et al. 2010). As yet the potential utility of *Callitris* growth rings in more arid climate zones of Western Australia to elucidate similar questions has not been thoroughly examined.

The aim of this research was to provide a preliminary assessment of the dendrochronological potential of *Callitris columellaris* in the Carnarvon Range in arid central Western Australia (Fig. 2). Specifically, we sought to determine if *Callitris columellaris* growth rings from the Carnarvon Range: 1. can be crossdated (i.e., growth patterns matched among trees); 2. can be used to estimate the age of individual trees and the population age structure; and 3. show potential for reconstructing past climate.

2. The Carnarvon Range

The Carnarvon Range lies within the Little Sandy Desert IBRA (Interim Biogeographic Regionalisation for Australia) region in central Western Australia. The climate of the region is arid, characterised by low rainfall (<250 mm annual) that occurs primarily in the summer but which is highly variable from year to year. *Callitris columellaris* occurs in gullies on the rocky ranges and along the edge of gypsiferous lakes in the region, where it is relatively protected from fire (Beard 1976).

Three locations were targeted for sampling of *Callitris columellaris* – a population in the northern range (25°6’54”S, 120°43’16”E or UTM Zone 51 270,221mE, 7,220,387mN), a population in the southern range (25°16’24”S, 120°39’24”E or UTM Zone 51 264,010mE, 7,202,727mN) and three small populations along the northern edge of Lake Kerrylyn (around 25°1S, 120°43’E or UTM Zone 51 270,000mE, 7,230,000mN) (Fig. 2). All three sampled populations are located within the Birriliburu Indigenous Protected Area (IPA), specifically in the Katjarra area.

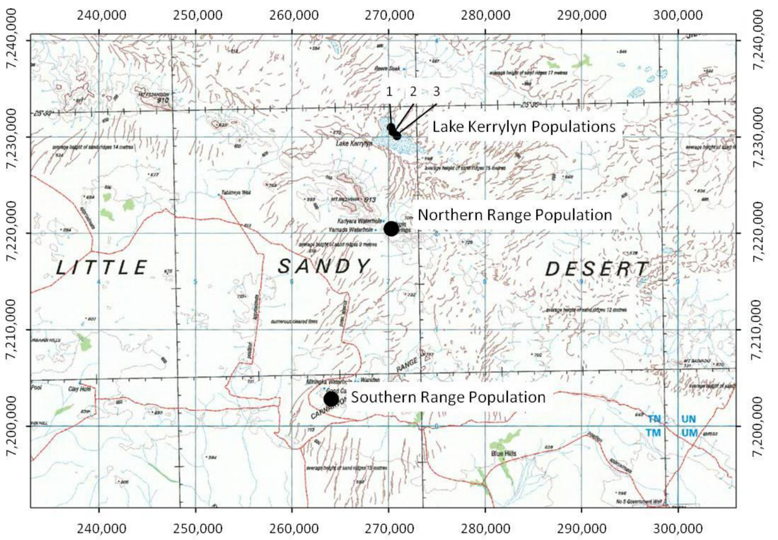

Figure 2: Location of the Carnarvon Range in central Western Australia and the three sampled populations of *Callitris columellaris*

3. Methods

Cores were sampled from the trunks of 44 trees in June 2013 using 5.15 mm-diameter Haglof increment borers by staff from the WA Department of Parks and Wildlife (DPaW). Cores were collected from breast height (approx. 1.3 m) or lower if branches obscured access. Where possible, two replicate cores were sampled from each tree, typically at angles of between 90 and 180 degrees from each other to account for potential growth variation around the girth of the tree.

Cores were air-dried, glued to a mount and sanded to a smooth finish using progressively finer grit sandpaper (80 to 1000 grit). Samples with excessive resin staining at the surface were heated and rubbed down with ethanol to remove some of the resin and improve visibility of growth ring boundaries (see Cullen and Grierson 2009). Growth rings were observed under a binocular microscope (10x magnification) and ring width patterns (sequences of wide and narrow rings) were visually matched (also known as crossdating; see Stokes and Smiley 1968), first among paired cores from the same tree, and then among cores from different trees. Once crossdated, calendar dates were assigned to each ring in each sample. Typically, crossdating should be checked for errors using a quality-control program such as COFECHA (Grissino-Mayer 2001), but owing to several problems (outlined in section 3.1) that limited visibility of ring boundaries, ring widths were not measured and therefore the accuracy of crossdating was not vigorously checked.

3.1 Problems limiting crossdating

We encountered several problems that limited our ability to accurately crossdate and assign calendar dates and ages to the sampled trees. These are summarised below:

3.1.1 Excessive resin: Many of the samples contained high levels of resin, particularly at the heartwood/sapwood interface, which darkens and stains the wood (Fig 3e, f, g) and made ring identification and crossdating very difficult or impossible in some samples. Treatment with heat and ethanol improved visibility slightly in some samples, but not in highly resinous samples. Extraction of resins using hot solvents could improve visual quality further, but this is beyond the scope of the current work.

3.1.2 Missing and very narrow rings: Many of the samples collected from *Callitris* trees in the Carnarvon Ranges were missing rings and/or had sequences of very narrow rings that made crossdating very difficult. The growth of *Callitris columellaris*, particularly in arid and semi-arid climates, is highly responsive to rainfall (Cullen and Grierson 2009; Sgherza et al. 2010; Brodribb et al. 2013). However, particularly at the most arid part of their range, rainfall can be too low in some years to initiate and support tree growth, resulting in "missing" rings, i.e., years where no growth occurs and a ring is not formed. Low rainfall years can also result in very narrow rings, where rainfall may be sufficient to initiate growth, but only for a short period. If several low rainfall years occur in a row, this may result in a sequence of very narrow growth rings (at times only 2-3 cells wide), which makes distinguishing individual rings/years extremely difficult. Old age and poor access to water or other growth limitations can also result in some trees generally producing narrower rings than others (e.g., Fig 3d), which adds further challenges to crossdating at these sites.

3.1.3 Uneven growth around the girth of the tree. Typically, trees produce new growth evenly around the entire circumference of the trunk. However, in years with extremely low rainfall or at extremely dry sites, growth may occur only around a portion of the trunk and not around the entire circumference of the trunk. If this occurs, a ring may be visible in one radius of the trunk and not in others and therefore may be visible in one sample and not the other from the same tree. Because of this, some paired samples that were collected from the same tree could not be matched because rings were missing from only one of the samples.

3.1.4 Rot: Rot can occur in the centre of a tree when the main stem or branch is killed higher up in the tree and eventually rots away. Rot is common in older *Callitris* trees and often results in the destruction of the innermost (centre) rings and causes adjacent wood to become dry and brittle. Consequently, some or many of the innermost rings may be missing from the sample (e.g., Fig 3h) and can severely limit the accuracy of tree-age estimates.

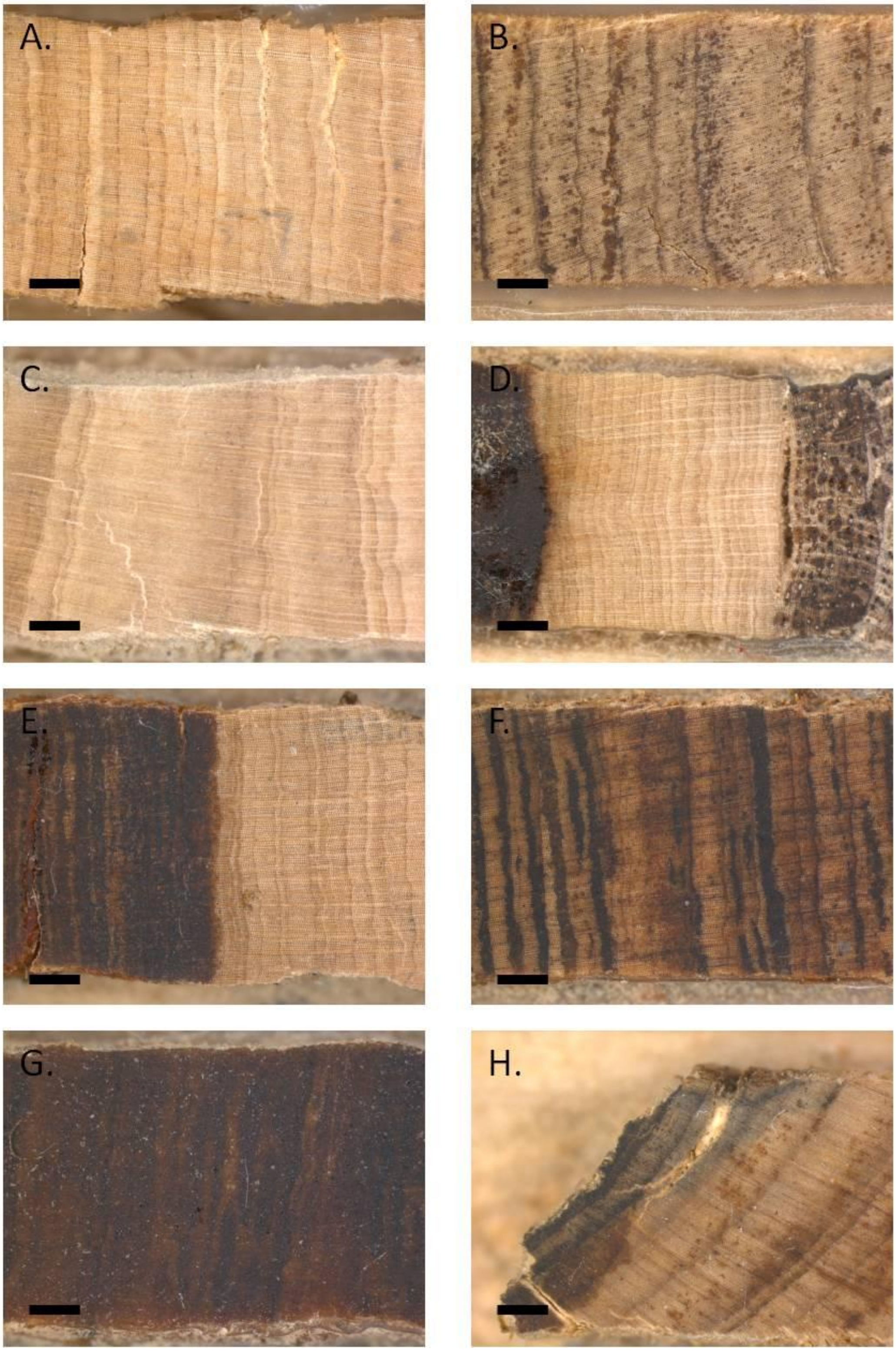

Figure 3: Ring structure of *Callitris columellaris* from the Carnarvon Range, Western Australia. Typical growth rings in (A) sapwood and (B) heartwood. Sapwood showing (C) complacent[1], wide rings with several false (indistinct) boundaries, and (D) very narrow rings. (E) Sharp boundary between sapwood (right) and heartwood with resin (left). (F) Resin forming bands parallel to ring boundaries in heartwood. (G) Thick resin in heartwood. (H) Broken core (missing inner rings) as a result of dry rot in the centre of the tree. Scale bar = 1mm

[1] uniform ring widths, which occur as a result of no or low inter-annual variation in the factor(s) affecting tree growth (e.g., climate).

3.2 Accuracy of dating methods

There are several potential sources of error associated with using tree rings and/or core samples to assign ages to trees, which are described below.

3.2.1 Dating accuracy: Owing to problems mentioned above, which limit our ability to visually identify ring boundaries in many of the samples from the Carnarvon Range, there is potential for error in the calendar dates assigned to each ring. Years with unusually high rainfall can generally be easily distinguished as wide rings in the samples. These rings are generally referred to as "signature rings" and they are easily identified and are consistent among most samples. We used instrumental rainfall records for the region to assign dates to some signature rings in the last 100 years. These signature rings were then used as dating "anchors", ensuring that dates assigned to rings in the last 100 years were accurate and consistent among the samples. Prior to instrumental rainfall records (i.e., 1900) the absolute calendar dates of signature years and therefore tree rings are less certain. We estimate the potential error associated with tree-ring dating prior to 1900 is +/- 5 years

3.2.2 Sample completeness: Where the pith (centre) of the tree was visible within the core sample, a calendar date was assigned to the pith. However, as noted above, in many of the samples, the pith was not visible either because the core direction missed the centre of the tree or rot had destroyed the centre rings. For samples where the pith was not visible, we quantitatively estimated the distance between the innermost visible ring and where the pith of the tree was likely to be based on the curvature of the innermost visible rings (Fig. 4). We then used the mean ring width across the entire core (core length/number of rings) to estimate how many rings were missing from the sample and then assigned a calendar date to the pith.

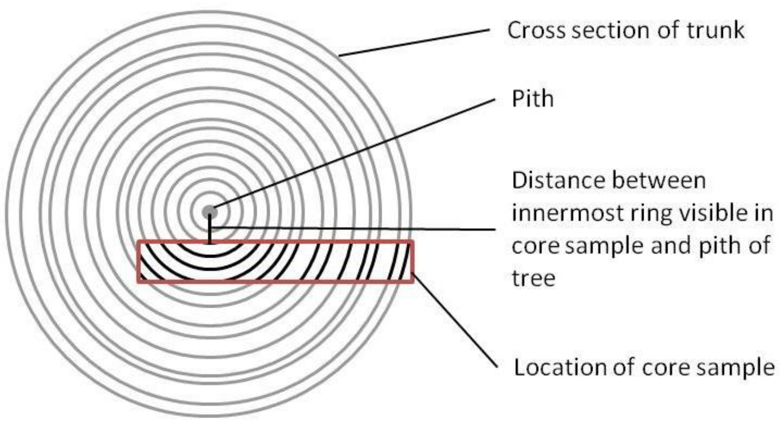

Figure 4: If a core sample is off-centre (i.e., missed the pith), the location of the pith can be estimated by examining the curvature of the innermost rings of the core. The number of rings missing from the sample can then be estimated using the distance to the pith from the innermost rings and the average ring width of the core.

3.2.3 Sample height: Even where the pith of the tree was visible in the sample, the date assigned to the pith only provides an indication of the minimum age of the tree. Actual tree age is likely to be greater than this as it takes some time (years to decades) for trees to grow to the sampling height. Sample height was not measured at the time of sampling; however, cores were generally taken from breast height (approximately 1.3 m) or below if breast height was inaccessible. Although there have been no published studies of the growth rate (in terms of height) of *Callitris*, we assume from their narrow ring widths, that *Callitris* trees in semi-arid and arid climates are very slow growing, so may take several decades to reach a height of 1.3 m. Consequently, the age assigned to the pith of the tree at core height (approx. 1.3 m) may underestimate the age of the tree by several years and possibly several decades.

4. Dendrochronological potential of *Callitris* from the Carnarvon Range

4.1 Crossdating potential

4.1.1 Lake populations

None of the samples from the three lakeside populations could be crossdated. Some had wide, complacent rings (little to no variation in ring width) and diffuse or false boundaries. Others had narrow outer rings, which were dark with resin and impossible to distinguish as well as wide diffuse inner rings. None of the lakeside populations showed signature (wide) rings related to high rainfall years, which suggests rainfall is not the strongest control of growth at these sites or the influence of climate on growth is strongly buffered by the trees' proximity to water close to the ground surface. Other factors such as tree age (in some trees, rings tended to become narrower and more resinous as trees increased in age) and perhaps site factors such as salinity may be contributing to the high variation within this site and the complacency in growth.

4.1.2 Range populations

Both range populations showed similar ring width patterns, particularly the occurrence of signature rings (wide rings) in the years 1872, 1931, 1942 and 2000. The signature rings allowed preliminary crossdating among most samples from the two range populations and suggests some potential for creating a ring width chronology from these sites; however, crossdating has not been thoroughly quality checked owing to the problems with dark resins etc, that were outlined in section 3.1.

4.2 Age determination

We estimated tree ages for both the northern and southern range populations. The southern range population appears slightly older and slower growing (with generally greater age for the same trunk radius) than the northern range population, but both populations included a range of tree ages (Fig. 5). The age range of the southern population (based on estimated pith dates at coring height) was 115-233 years (i.e., 1780-1898, mean age 180 years) and the age range of the northern population was 73-168 years (1845-1937, mean age 119 years) (Fig. 5). These ages should be interpreted as minimum estimates and could potentially underestimate the actual age by up to 30 years. Trees from the lakeside populations could not be crossdated, so their ages were not estimated. However, based on the number of rings visible in the core samples taken from the lakeside populations, tree ages likely range from approx. 50 years to almost 200 years, with the majority of trees within the 100-150 year range.

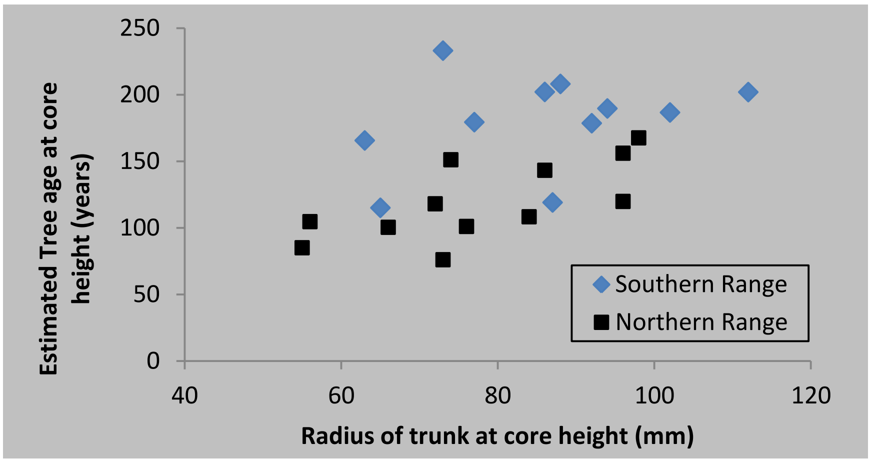

Figure 5: Trunk radius and estimated tree ages at sample height (~1.3 m) of *Callitris columellaris* from southern and northern sites in the Carnarvon Range, Western Australia.

4.3 Potential for climate reconstruction

Given that it was very difficult to visually identify and crossdate growth rings in many of the samples, the width of growth rings was not measured. Continuous ring width chronologies with assigned calendar years for each ring are required to reconstruct past rainfall patterns and drought periods. Consequently, we did not attempt modelling of past climate from the Carnarvon Range samples. However, there may be some potential to develop a master ring width chronology from some of the older trees in the range populations with more and larger samples (i.e., from stem sections) and more extensive resin removal techniques. We identified a number of wide rings that were coincident with known high rainfall years in trees in the range populations, providing some evidence that these trees are "climate responsive", and may contain information about past rainfall amounts. However, given the aridity of the region, there is also likely a high incidence of missing rings across the entire population, which cannot be identified or corrected for even during crossdating. Alternative methods to account for missing rings may include ^{14}C wiggle-matching techniques (Hua 2009); however, these techniques are expensive and may still not resolve cross-dating issues. Thus, we conclude that the likelihood of successfully developing a high-resolution chronology for rainfall reconstruction, even from the range sites, is low. There also appears to be very little potential for climate reconstruction based on growth rings of trees around Lake Kerrylyn since growth was not consistent among trees in the same population and appeared to be responding to factor(s) other than or additional to climate. The sample size collected was, however, quite small and careful selection of further trees may improve results.

4.4 Comparison with tree ring sites in the Pilbara and south-west Australia

The Carnarvon Range is more arid (<250 mm rainfall annually) than other tree ring sites in Western Australia (Fig. 2, ~350 mm annually) that have been successfully crossdated and used to reconstruct past rainfall patterns. The extremely low rainfall in the Carnarvon Range is likely contributing to the difficulty in identifying and crossdating growth rings. Problems with resin, rot, and missing and narrow rings are common to all tree ring sites examined so far in Western Australia, but missing and narrow rings and also uneven growth appears to be a bigger issue at the more arid Carnarvon Range site compared to the semi-arid sites.

The Carnarvon Range site is inland (southeast) from our *Callitris* tree ring site in the Hamersley Ranges of the Pilbara. Interestingly, *Callitris* at the Carnarvon Range site show some synchronicity with *Callitris* in the Pilbara in terms of signature years (unusually wide rings), particularly in the high rainfall years of 1931, 1942, and 2000. This synchronicity between the Carnarvon Range and Pilbara sites is most likely a result of heavy rainfall associated with tropical cyclones tracking from the northwest coast inland near both sites. Isotopic analysis ($\delta^{18}O$) of these rings could confirm cyclone incidence (see Cullen and Grierson 2007) and thus the Carnarvon Range site may have use for assessing extent of cyclone-derived rainfall in the past and/or corroborating low resolution climate patterns (e.g. decadal scale) for the broader central-northern parts of Western Australia.

5. Conclusion

Callitris columellaris from the Carnarvon Range has some potential for use in dendrochronological analysis of tree age and population dynamics, particularly if methodical issues associated with sample accuracy and height as well as resin staining are resolved. Ultimately, the potential utility of the Carnarvon Range site for use in reconstructing high resolution records of past climate is limited, but may have some potential for identifying "big rainfall" years through cross-referencing with other records, e.g., from the Pilbara.

6. Acknowledgements

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