Radiocarbon, Vol 66, Nr 5, 2024, p 1006–1019 DOI:10.1017/RDC.2023.75
Selected Papers from the 24th Radiocarbon and 10th Radiocarbon & Archaeology International Conferences, Zurich, Switzerland, 11–16 Sept. 2022

THE SIZE INHERITED AGE EFFECT ON RADIOCARBON DATES OF ALLUVIAL DEPOSITS: REDATING CHARCOAL FRAGMENTS IN A SAND-BED STREAM, MACDONALD RIVER, NSW, AUSTRALIA

Rachel Wood[1,2]* • Fleur King[3] • Rebecca Esmay[1] • Qianyang Chen[4] • Larissa Schneider[5] • Emilie Dotte-Sarout[6] • Stewart Fallon[1] • Kirstie Fryirs[7] • Richard Gillespie[5] • Russell Blong[7]

[1]Radiocarbon Facility, The Research School of Earth Sciences, The Australian National University, Canberra, ACT 2601, Australia
[2]School of Archaeology, University of Oxford, Oxford, OX13TG, UK
[3]Department of Archaeology and History, School of Humanities and Social Sciences, La Trobe University, Melbourne, Victoria, 3086, Australia
[4]School of Computer Science, University of Sydney, Camperdown, NSW 2050, Australia
[5]School of Culture, History and Language, College of Asia and the Pacific, The Australian National University, Canberra, ACT 2601, Australia
[6]School of Social Sciences, University of Western Australia, Australia
[7]School of Natural Sciences, Macquarie University, North Ryde, NSW, 2109, Australia

ABSTRACT. Radiocarbon dates on charred plant remains are often used to define the chronology of archives such as lake cores and fluvial sequences. However, charcoal is often older than its depositional context because old-wood can be burnt and a range of transport and storage stages exist between the woodland and stream or lake bed ("inherited age"). In 1978, Blong and Gillespie dated four size fractions of charcoal found floating or saltating in the Macdonald River, Australia. They found larger fragments gave younger age estimates, raising the possibility that taphonomic modifications could help identify the youngest fragments. In 1978 each date required 1000s charcoal fragments. This study returns to a sample from the Macdonald River to date individual charcoal fragments and finds the inherited age may be more than 1700 years (mode 250 years) older than the collection date. Taphonomic factors, e.g., size, shape or fungal infestation cannot identify the youngest fragments. Only two fragments on short-lived materials correctly estimated the date of collection. In SE Australia, this study suggests that wood charcoal will overestimate the age of deposition, taphonomic modifications cannot be used to identify which are youngest, and multiple short-lived materials are required to accurately estimate the deposition age.

KEYWORDS: charcoal, inherited age, old-wood effect, radiocarbon.

INTRODUCTION

Radiocarbon (^{14}C) dating of plant materials and charcoal derived from alluvial, lacustrine, and fluvial settings is complicated by substantial variations in inbuilt and/or inherited age. Inbuilt age, also known as the "old-wood effect," refers to the time that has elapsed between growth of the woody tissue and the age of the growing edge of the tree or shrub and the time of charring (McFadden 1982; Schiffer 1986). "Inherited age" also includes the time taken for this material to be deposited in a depositional environment such as rivers and lakes. Both have the potential to erode the quality of chronologies derived from charred plant materials. Whilst the old-wood effect can be minimized by identifying shorter lived taxon or tissues, the latter is more difficult to account for and more variable as it can be impacted by multiple processes (Blong et al. 2023). These include the severity and frequency of fire in the landscape, as well as the range of transport and storage stages which incorporate charcoal into mobile regolith and move it downslope and through the fluvial environment to its final place of deposition. Although

*Corresponding author. Email: rachel.wood@arch.ox.ac.uk widely acknowledged and explored through the dating of various sample types (e.g., Oswald et al. 2005; Howarth et al. 2013), chronologies of lake cores, fluvial systems and sediment horizons are frequently obtained using ^{14}C dates on charred plant remains. It is therefore worthwhile to continue to explore the size of the inherited age of charred plant remains and assess how best to reduce its impact on chronologies. This paper will focus on so-called "natural" regolith that make up fluvial deposits, i.e., contexts that do not directly result from archaeological sociocultural activities.

Several strategies have been used to assess and to minimize the effect of inherited age. Some have combined ^{14}C and OSL assays to improve precision and resolution of age estimates for alluvial sequences (e.g., Cohen and Nanson 2008; Cheetham et al. 2010) or used only short-lived and fragile organic materials rather than charcoal (e.g., Ely et al. 1992). Where this is not possible, the most common approach is to date a number of charcoal fragments and select the youngest of the age estimates or those in stratigraphic order as the most appropriate (e.g., Nelson et al. 2003; Frueh and Lancaster 2014; Rockwell et al. 2015; Collins et al. 2016). Within OxCal, a "Charcoal Outlier Model" has been proposed where most charcoal fragments are assumed to give the correct age, and outliers are expected to exponentially decrease toward older age estimates (Ramsey 2009a; Dee and Ramsey 2014). Unfortunately, this approach leads to questions such as: Does the youngest age represent the age of the deposit, and how many charcoal fragments need to be dated to identify the age of the deposit (Streig et al. 2020)? Others have derived local estimates for the inherited age of charcoal and used these to correct the age estimates on charcoal to better reflect the deposition age (e.g., Gavin 2001; Frueh and Lancaster 2014; Streig et al. 2020), but this is a time consuming, expensive, and difficult approach.

Blong and Gillespie (1978) showed that ^{14}C dates on finer (0.5–1.0 mm) charcoal fragments were older than coarser fragments (4.0~8.0 mm) on a sample of charcoal collected floating or saltating down the sand-bed stream of the Macdonald River, New South Wales (southeastern Australia) (Figure 1; Table 1). Whilst this has long been used as a cautionary example of why not to ^{14}C date fine charcoal in sediment sequences, it also implies that it may be possible to preferentially select the charcoal fragments with minimal inbuilt age. This is not a novel proposal with, for example, Nelson et al. (2003) selecting the largest, most angular and least decayed fragments of charcoal to reduce the likely inherited age in their study of the Seattle fault zone. The charcoal in Blong and Gillespie's (1978) study was dated by liquid scintillation, and each dated sample contained 1000s of charcoal fragments. With the ability to ^{14}C date individual charcoal fragments with AMS, we devised a new case-study to establish how much the inherited age of charcoal varied and to identify whether the youngest charcoal fragments could be selected on the basis of taphonomic characteristics observed in the charcoal fragments.

METHODS

Sample Collection

The Macdonald River, a tributary to the Hawkesbury River, drains a catchment area of about 2425 km^2 (NSW, Australia). Most of the catchment has relatively steep slopes underlain by Triassic sandstones, with a narrow discontinuous floodplain extending up valley from the tidal limit at about 15 km upriver from the junction with the Hawkesbury River (Henry 1977; Mould and Fryirs 2018). The valley slopes are wooded with wet, moist and dry sclerophyll

https://doi.org/10.1017/RDC.2023.75 Published online by Cambridge University Press

Table 1 ^{14}C dates produced on a sample of charcoal collected floating or saltating down the Macdonald River in 1976 (Blong and Gillespie 1978). Dates were produced by liquid scintillation, on bulk samples of charcoal fragments pretreated with an acid-base-acid procedure.

Size range	Laboratory code	Conventional age (BP)	Calibrated age (cal BP, 95% probability range)
4.0~8.0 mm	SUA-617	645 ± 100	734–469
2.0–4.0 mm	SUA-618	965 ± 100	1051–668
1.0–2.0 mm	SUA-619	1380 ± 100	1425–982
0.5–1.0 mm	SUA-620	1530 ± 100	1698–1276

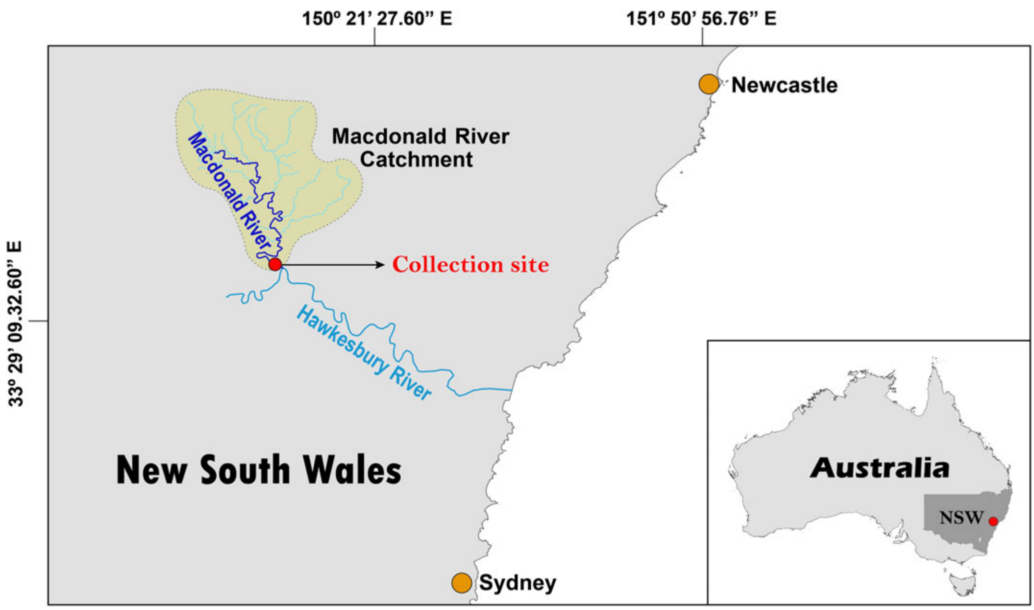

Figure 1 Location of the Macdonald River and sampling location for the charcoal sample which produced SUA-617–620 and the charcoal sample which produced SUA-1134 and all new dates presented in this paper.

forests, grassy woodland, warm temperate rainforest and dry rainforest (NSW National Parks and Wildlife Service 2003; Department of Environment and Climate Change 2008).

Major floods occurred between 1949 and 1955 triggering significant geomorphic change including channel widening, cutoff formation and channel and floodplain aggradation and sediment slug formation (Henry 1977; Erskine 1986). The valley also flooded in March and June 1978. Since the 1980s, geomorphic and vegetative recovery has been occurring including the formation and stabilisation of in-channel benches that act to narrow the channel (Mould and Fryirs 2018). Most recently the catastrophic floods of 2021 and 2022 have reworked and redeposited significant volumes of in-channel and floodplain sand, but the geomorphic structure of the river has not changed significantly (Fryirs pers. comm.).

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Fire is a frequent occurrence within the forest environment in SE Australia, and fires are known to have affected the valley and catchments of the Macdonald River (NSW NPWS 2003). Since the 1967/1968 fire season there has been a high frequency of repeated bushfire events within the NPWS estate, which has resulted in many thousands of hectares burnt over an average 5–12-yr fire interval (NSW NPWS 2003:37–40). The timing of many of these bushfires have been during periods of high fire danger that quickly escalate to severe fire conditions.

This paper examines the distribution of ages of individual charcoal fragments from the sample used to generate SUA-1134 (440 ± 80 BP, unpublished) collected 15.5 km upstream of the Macdonald confluence with the Hawkesbury River on 15 September 1978. This sample, like that used to generate SUA-617–620 (Table 1), was collected during low flow in the shallow stream and from channel bars 2–3 cm above water level. Charcoal that was not required for ^{14}C dating in the 1970s was stored in glass bottles with screw top lids. We were able to randomly select 36 charred plant "charcoal" fragments for this study. Note that in contrast to SUA-617–620 which were collected in 1976 before a flooding event, SUA-1134 was collected shortly after a series of floods. The two samples therefore reflect the inherited age of charcoal at different stages of valley recovery. Blong et al. (2023) discuss the implications of this further.

Taphonomic Characterization of Charcoal

The 36 fragments were placed in the freezer-drier of a Christ Alpha 1-2 LDplus lyophilizer (John Morris Scientific, Sydney, Australia) to remove any fine loose powder in the Palaeoworks Laboratory at the Department of Archaeology and Natural History, Australian National University. Samples were viewed using scanning electron microscopy (JCM-6000 PLUS, NeoScope - Benchtop SEM, Coherent Scientific, Australia) with an accelerating voltage of 15 kV at high vacuum. To assess surface morphology (elongation, roundness, length) of the charcoal fragments (Table 2), scanning electron micrographs were produced at ×22 and ×80 magnification for all charcoal fragments, and at ×400 and ×1000 magnification for most samples.

Dendrological and taphonomic analysis was undertaken using an Olympus BX51 brightfield/darkfield reflected light microscope at the Department of Archaeology and History microscope laboratory, La Trobe University in Melbourne and viewed at ×50 to ×500 magnifications. A qualitative assessment of each fragment was described according to 12 dendrological features and taphonomic modifications (Table 2). In addition to the fragment size, identified by Blong and Gillespie (1978) as a potential indicator for inherited age, characteristics such as vitrification, clay infill, precipitate nodules, fungal infestation, elongation, and roundness were assessed as potential indicators of the duration of transport and storage on the journey to the collection site. Growth structure, taxonomic identification and wood calibre were assessed to understand the potential for inbuilt age.

Radiocarbon Dating

After microscopy, 36 charcoal fragments were physically cleaned under a binocular microscope with a scalpel to remove sediment and degraded material, though some clay remained trapped within vessels and other anatomy structures. After manual removal of clay, three samples were too small to proceed with ^{14}C dating. 33 samples were cut or crushed to ca. 2 mm using a scalpel, prior to reaction in HCl (1 M, 30 min, 70ºC), NaOH (1M, 30 min, 70ºC, solution changed until it remained colorless) and HCl (1 M, 30 min, 70ºC). Between each treatment, the sample was rinsed 3 times in ultrapure water, or until it remained colorless (Wood et al. 2023).

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Table 2 Dendrological features and taphonomic alterations assessed from external surface observations of the 36 charcoal fragments. A code for each attribute is included for correlation with Supplementary Table 2. In each case, a code of "0" implies that the measurement, assessment or observation was not possible, often because of small sample size, high vitrification or an inability to fracture the fragment.*

Characteristic	Code	Attribute	Wood charcoal anatomy features
Growth structure	G1	Root wood charcoal	Elongated and/or irregular vessels and fiber cell patterning
	G2	Vascular cambia stem wood charcoal	Large vessels/vascular bundles in centrifugal pattern
	G3	Xylem wood charcoal	Heartwood and sapwood vessel elements and fiber cells
	G5	Carbonized endocarp	Spherical floristic structure with seed coat patterning
Taxa	T1	Wood anatomy features	Intact anatomical structures on one or more sections of the transverse, tangential or radial anatomical planes
Wood caliber	W1	Large branch or trunk wood	Weakly angled or parallel rays
	W2	Large branch or smaller trunk wood	Moderately angled rays
	W3	Small branch or twig	Strongly angled rays
	W4	N/A	Vascular cambium or endocarp
Vitrification	V1	No reflectance	Anatomy intact
	V2	Low brilliance-refractiveness	Recognisable anatomical structure, low fusion, few radial cracks
	V3	Strong brilliance	Some anatomical structures undetectable, many radial cracks
	V4	Total fusion	Few anatomical structures present, non-recognisable mass, homogenisation, sub-conchoidal fractures
Clay infill	C1	Negligible	Negligible surface coverage and/or infill of vessels and fiber cells
	C2M	Moderate reddish-brown coating	$<$50% surface coverage and/or infill of vessels and fiber cells
	C2E	Extensive reddish-brown coating	$>$50% surface coverage and/or infill of vessels and fiber cells
Precipitate nodules	P1	Absent	No nodules observed
	P2M	Minimal whitish nodules	$<$50% surface coverage and/or vessel and fiber cell infill
	P2E	Extensive whitish nodules	$>$50% surface coverage and/or vessel and fiber cell infill

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Table 2 (*Continued*)

Characteristic	Code	Attribute	Wood charcoal anatomy features
Fungal infestation	F1	Absent	No fungal preservation in anatomical structures
	F2H	Hyphae present	Fungal hyphae preservation in anatomical structures
	F2S	Spores present	Fungal spore preservation in anatomical structures
	F2HS	Hyphae and spores present	Hyphae and spore presentation in anatomical structures
Decay alteration	D1	None	Fiber cell walls intact
	D2	Minor intensity	Cavities in cell walls
	D3	Medium intensity	Perforated cell walls
	D4	High intensity	Collapsed cell walls
Elongation		Ranges 0.1–1.0	Extremely elongate (0.1) or flat to perfectly equant (1.0)
Roundness		Ranges 0.088–1.000	Angularity of corners from angular (0.088) to perfectly rounded (1.000)
Length (a)		A axis	Measurement (mm) of longest axis (maximum dimension)
Length (b)		B axis	Measurement (mm) of other axis

*Growth structures defined from Ilvessalo-Pfäffli (1995:6–32); Carlquist (2001), Raven et al. (2005), Hather (2013:1–8), Pearsall (2015); taxa wood anatomy features defined in Wheeler et al. (1989); wood caliber and vitrification levels applied from Marguerie and Hunot (2007); clay infill inferred using Marcelino et al. (2018), mineral precipitates inferred using Vidal-Matutano et al. (2019); fungal infestation described from Moskal-del Hoyo (2010); decay alteration levels from Henry and Théry-Parisot (2014); elongation and roundness defined from Blott and Pye (2008).

After freeze-drying the charcoal was combusted in a sealed quartz tube in the presence of CuO wire and Ag foil. The resulting CO_2 was cryogenically collected and purified prior to graphitization over an iron catalyst for measurement on an NEC Single Stage AMS at the Australian National University (Fallon et al. 2010). Dates were calculated following Stuiver and Polach (1977) using an AMS derived $\delta^{13}C$. All age estimates have been calibrated against SHCal20 (Hogg et al. 2020) or Bomb21 SHCal1-2 (Hua et al. 2022) in OxCal v.4.4 (Ramsey 2009b). To assess the cleanliness of the charcoal, the %C was measured volumetrically during collection of the CO_2 gas. Except where the charring temperature is very low, charcoal normally contains >50 %C (Ascough et al. 2011; Wood et al. 2023). If much lower than this, substantial amounts of clay may be present in the dated sample, potentially affecting the date obtained.

RESULTS

Charcoal Taphonomy

As most samples had high vitrification levels with prominent mineral precipitates that penetrated and obscured cellular structures, taxa identifications were not possible for the majority of fragments according to systematic protocols detailed in Wheeler et al. (1989) and Leney and Casteel (1975). This was compounded by the inability to hand fracture fragments to observe the three internal planes (transverse, longitudinal tangential and longitudinal radial) required for taxonomic identification due to their small 2 mm (and less) size as well as the poor preservation and friable condition of fragments that risked being shattered prior to dating. Therefore, microscopic observation was limited to the outer exposed surfaces of each charcoal fragment. Only one fragment could be identified (S-ANU66935) as cf. *Eucalyptus* (Figure 2a) based on solitary vessel grouping, diagonal vessel arrangement and presence of tyloses within some of the vessels (Hopkins et al. 1998; King and Dotte-Sarout 2019).

As detailed in Table 2, dendrological features recorded in the charcoal anatomy were growth structure and wood caliber. Of the dated samples, wood growth characteristics consisted of primary growth tissue determined as root wood (n=1) and stem wood (n=1), with the majority being secondary wood growth comprising xylem heartwood/sapwood (n=26) and indeterminable fragments (n=5). The root wood charcoal comprised simplified cellular structures in a wavy to elongated pattern and an absence of the complex anatomical features typical of xylem wood (Raven et al. 2005; Hather 2013). Successive cambia of young stem wood were observed as radiating bands of concentric “cylinders” (large vessels) (Carlquist 2001:273). The secondary growth (older) xylem wood charcoal displayed a range of anatomical features consisting of vessels, fiber cells, axial parenchyma and rays that were recognizable on the outer surfaces of the charcoal fragments. Two endocarps (the inner layer of a fruit directly around the seed), were identified by their floristic round shape and diagnostic surface patterning (Pearsall 2015).

It is possible to establish whether a charcoal fragment is derived from a large branch or trunk, or a small branch or twig, by examining the angle or parallelism of rays (Marguerie and Hunot 2007) (see Table 2, wood caliber). The assemblage consisted predominantly of charcoal fragments from larger branches or tree trunks (n=11), with the remaining (n=3) from medium branch/small trunk and smaller branch/twig. However, most were indeterminable (n=19) due to poor preservation and small fragment size that precluded sufficient observable area in the transverse and tangential planes.

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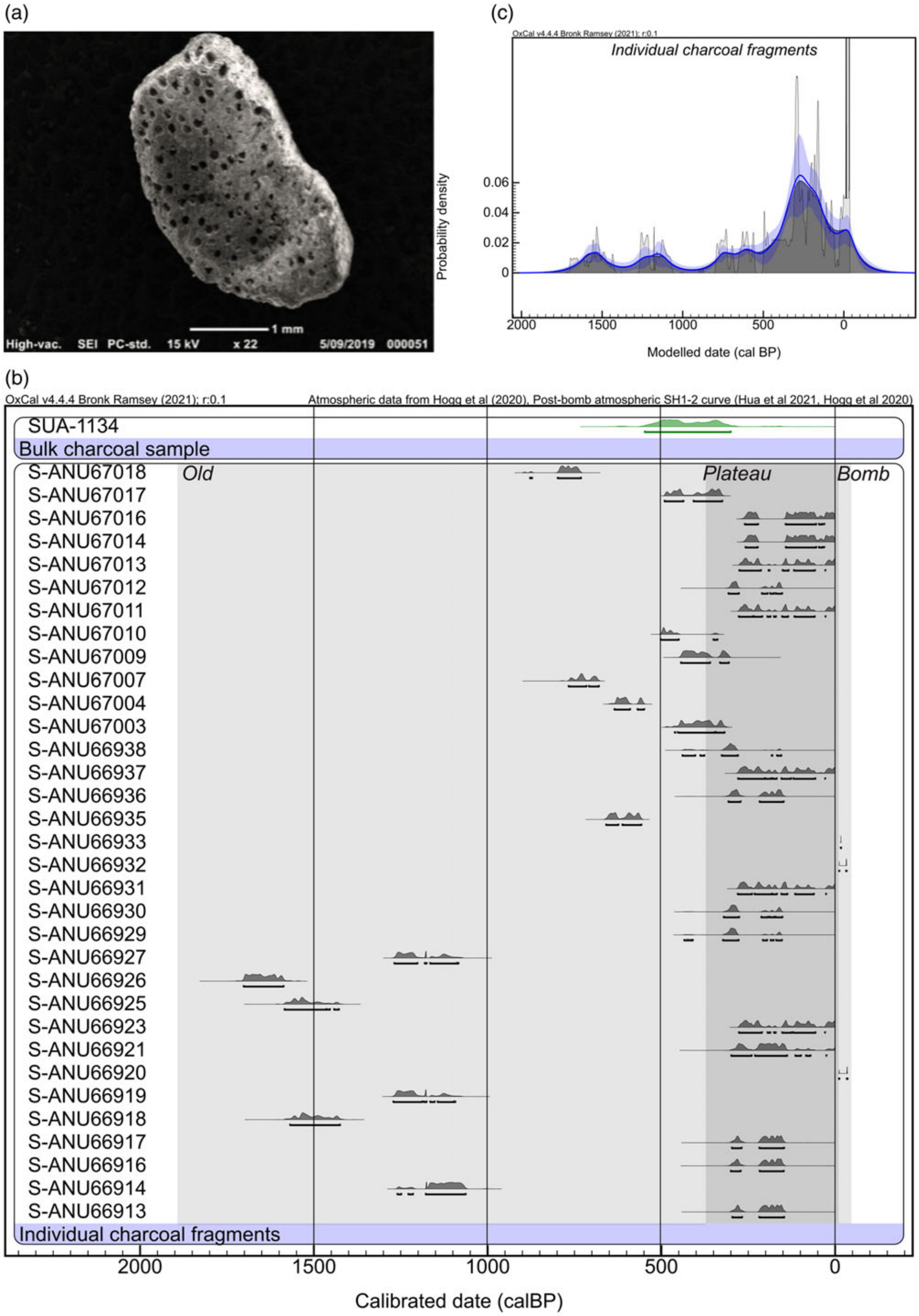

Figure 2 Charcoal and ^{14}C dates from the Macdonald River, collected in 1978: a) transverse plane of charcoal sample #19 (S-ANU66935) identified as cf. *Eucalyptus*; b) ^{14}C dates on individual charcoal fragments (grey) compared to the original age estimate on a bulk sample (green). These have been split into three groups, old, plateau and bomb; c) a Kernel Density Model including ^{14}C dates on individual charcoal fragments, calculated and plotted in OxCal (Ramsey 2017). (Please see online version for color figures.)

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Taphonomic charcoal alterations are useful markers that provide an understanding of post-depositional processes following charring such as vitrification, mineralization and precipitates (infills), fungal infestation and decay (Allué et al. 2009; Henry and Théry-Parisot 2014; Allué and Mas 2020). Vitrification (glassy appearance) of part or all of the cell anatomy structures was prominent in the charcoal samples at varying levels from fusion of cells (n=28) to strong refractiveness (n=4) and minimal in an endocarp sample (n=1). Clay infills (n=29) were prominent while mineral precipitates were absent to negligible (n=31). There was an absence of fungal hyphae and spores (n=20) in many fragments, including an absence of cell decay (n=32) that signified rotted wood prior to charring (Henry and Théry-Parisot 2014).

Radiocarbon Dating

Ages ranged dramatically within the sample, with the oldest being more than 1700 years old, scattering around the original Sydney Radiocarbon lab age (Figure 2b; Supplementary Table 1). All dates are interpreted as being reliable, as all except one contained more than 50%C after pretreatment. One sample (S-ANU66932) appeared poorly charred and was only 48%C after pretreatment.

Only three charcoal samples fell within the bomb period (post AD 1950), and only two were within error of the 1978 collection date. To have a 70% chance of obtaining at least one date within 20 years of collection (i.e., within the bomb peak), 10 pieces of charcoal would need to be dated. The mean age when weighted by charcoal fragment mass is 965 ± 100 BP, significantly older than the original bulk estimate of 440 ± 80 BP. Placing these dates within a single Phase Kernel Density Model in OxCal (Ramsey 2017) shows a peak some 250 years prior to collection, with three smaller peaks at older ages (Figure 2c).

DISCUSSION

To establish whether the dendrological and taphonomic indicators analysed were able to predict which charcoal fragments were youngest, ^{14}C dates were divided into three age groups; Bomb (<cal AD 1955 n=3), Plateau (300–0 cal BP; cal AD 1650–1955, n=16) and Old (> 300 cal BP; >cal AD 1650, n=14). These groups were defined by the shape of the calibration which limits precision, particularly within the plateau period, complicating interpretation.

To minimize inbuilt age, it is logical to sample short-lived material and many studies have employed or recommended this approach to minimize the effect of inherited age (Ely et al. 1992; Howarth et al. 2013). In this sample, we had three short lived fragments—two endocarps and one piece of xylem stem wood (Figure 3). Two (S-ANU66920 and 66932) dated to within 20 years of 1978. The other falls in the plateau group and has an inherited age of 20–320 years. In contrast, xylem wood, and wood from large branches or trunk was always found to have an inherited age of more than 20 years. Whilst the short-lived material in this study produced the youngest ages, this is not always the case, and Strieg et al. (2020) and Biasi et al. (2002) both report short-lived macrofossils in palaeoseimic contexts that are considerably older than their contexts.

In contrast, none of the taphonomic attributes were clearly correlated with age. To illustrate this, four attributes are presented in Figure 3. Surprisingly, given the results of Blong and Gillespie (1978), it was not possible to identify which charcoal fragments were most likely to produce the youngest ages from length, elongation or roundness. Similarly, fungi seem distributed throughout all age groups in a similar way. This is likely because of the relatively

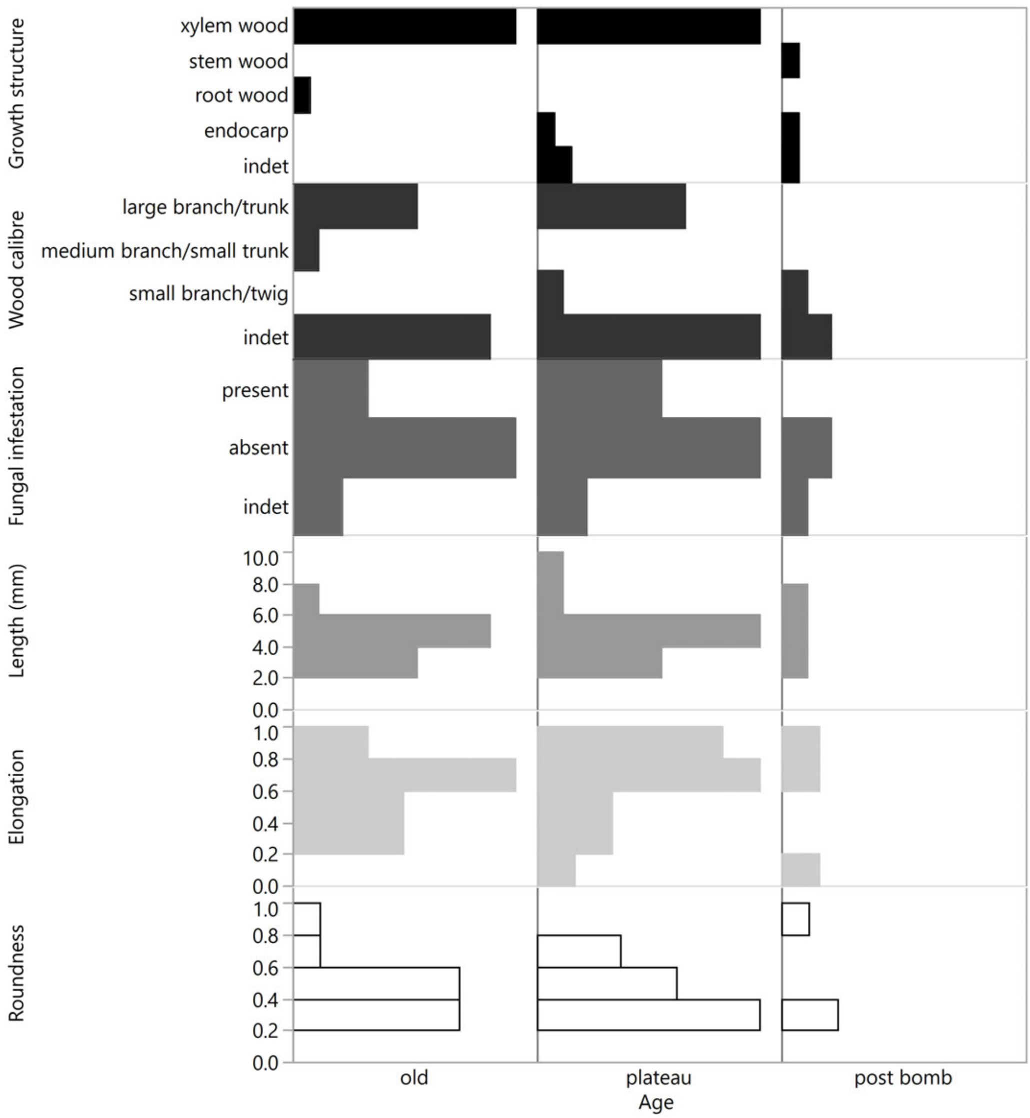

Figure 3 Histograms of dendrological and taphonomic characteristics of dated charcoal fragments compared to ^{14}C age groups: bomb = cal AD < 1955; plateau = cal AD 1650–1955; old = cal AD > 1650.

small number of charcoal fragments that were studied in comparison to the 1000s that needed to be used to generate a ^{14}C age in the 1970s. The implication is that when sampling for ^{14}C dating, sampling larger less degraded material is unlikely to help select younger wood charcoal fragments.

The inherited age of the charcoal fragments is variable, with the 33 fragments spanning more than 1700 years, and most likely to be around 250 years old. This figure of 250 years is similar to several studies of inbuilt and inherited ages and may be an appropriate estimate for the expected inherited age where other data are not available. For example, Gavin (2001) found

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that the inbuilt age of charcoal from a forest floor of the west coast of Vancouver Island (Canada) ranged between 0 and 670 years, with most charcoal being around 200 years older than the most recent fire event, whilst Streig et al. (2020) found that the most likely (mode) charcoal sample at the Hazel Dell (HD) paleoseismic site on the San Andreas fault, California, is around 220 years older than the age of the deposit that contains it.

However, further data is required to assess whether 250 years can be used as a prior assumption for the likely inherited age for charcoal within SE Australia and incorporated into statistical models. As Blong et al. (2023) discuss, it is not possible to deconvolve the range of inherited ages we observe with the large number of causal factors, including the age of the biomass, the frequency, severity, and impact of burning events and transport and storage processes throughout the valley. It is not clear, for example, how collection of this sample shortly after a flooding event would impact the inherited age in comparison to collection during a drought. Moreover, the impact of human land management must be considered, as this has changed throughout Australia's history (Fletcher et al. 2021). High species diversity is well recognised in the region owing in part to past fire regimes (NSW NPWS, 2003). Prior to European invasion, Aboriginal land management practices in SE Australia shaped the forest vegetation and fuel structure, with many forest types containing fewer shrubs and more grass and herbaceous species (Mariani et al. 2022). It has been shown that fire activity in the Sydney Basin catchments, including the Macdonald River, increased in the past 3000 years, coinciding with an increase in stone artefacts in the archaeological record (Mooney et al. 2007; Attenbrow, 2003, 2004). We therefore suggest that it is possible that the inherited age of charcoal entering the MacDonald River prior to European invasion, and especially the 20th century (Constantine IV et al. 2023), may be different to that measured here. Whilst this study provides a best estimate for the likely inherited age of charcoal entering fluvial systems in similar environments across SE Australia, further study is required to confirm whether this estimate is suitable for other environments and palaeocontexts.

CONCLUSIONS

^{14}C dates on charcoal from alluvial, fluvial (and by extension lacustrine) deposits are susceptible to large and variable inherited ages, where charcoal fragments more than 4 mm in size are often more than 200 years older than their date of deposition. Whilst analysis of charcoal taphonomy identify the more poorly preserved, friable or fragile charcoal that may not survive the aggressive ^{14}C pretreatment process, it was not possible to predict which charcoal fragments are likely to be the youngest in a sample of charcoal from the Macdonald River. However, as routinely noted, short-lived materials are more likely to give a more representative age for deposition and taxonomic identification is critical. Indeed, none of the fragments of longer-lived "wood" charcoal dated from the Macdonald River produced an age estimate within error of the date of collection. Modeling of wood charcoal should consider the possibility that no dated sample represents the age of deposition. Whilst this study has focused on individual charcoal fragments, it raises concerns around the ^{14}C dating of microcharcoal, which can dominate the carbon fraction within some bulk sediment or poorly purified pollen extracts. In these samples, a portion of the charcoal may be derived from fragmented wood charcoal, as well as shorter lived materials such as grasses, and the degree to which this type of date can be affected by an inbuilt age needs to be established.

The analysis of multiple samples of charred plant remains—whether from short lived materials or wood charcoal—is required to ensure that the inbuilt age derived from storage and transport

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through the regolith and fluvial system is identified. Where short lived remains are not sampled, it may not be possible to accurately obtain an estimate for deposition in a fluvial environment. Therefore, it is critical to consider how the material dated relates to the question asked. For example, when studying vegetation change with palynology it may be best to date pollen grains, and when understanding deposition history a method such as OSL may be most appropriate. ^{14}C dating of charcoal fragments should only be undertaken where no other method is possible, where it is possible to model the local likely inherited age, or where "unknown uncertainties" of several hundred years are not important.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2023.75

ACKNOWLEDGMENTS

We acknowledge the Darkinjung elders, past, present and emerging, as the Traditional Owners of the land between St Albans and the Hawkesbury River and other Traditional Owners of the Macdonald Valley. We also thank John Munns and family who farmed the area near our main charcoal collection site in the 1970s.

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https://doi.org/10.1017/RDC.2023.75 Published online by Cambridge University Press