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SHORT NOTE

Implications of possible production trends in radiocarbon measurements on *Pachyornis* moa (Aves: Dinornithiformes) from the Glencrieff site, north-eastern South Island, New Zealand

RICHARD N. HOLDAWAY*
Palaecol Research Ltd, 167 Springs Road, Hornby, Christchurch 8042, New Zealand, ORCID 0000-0002-0297-9676

The fossil collections from the site at Glencrieff (42°58′08″S 172°34′03″E), North Canterbury, provide evidence for the species composition of, and perhaps relative numbers in, moa populations in the glacial-interglacial period in that area (Worthy & Holdaway 1996; Rawlence *et al.* 2011). Three taxa, *Dinornis robustus* (Dinornithidae), a *Pachyornis* sp. that Rawlence *et al.* (2011) report as *P. elephantopus*, and *Emeus crassus* (both Emeidae) were certainly present, with five, 22, and 21 individuals, respectively. Evidence for the presence of *Euryapteryx* rests on identification of a single leg bone (Rawlence *et al*. 2011).

A suite of 12 accelerator mass spectrometry (AMS) radiocarbon ages for *Pachyornis* (Rawlence *et al*. 2011) augmented the single *Pachyornis* and two *Emeus* ages published earlier (Worthy & Holdaway 1996). The ages reported by Rawlence *et al*. (2011) were measured by the Australian National University Laboratory (Canberra) on five individuals of *Pachyornis* in three tranches of three, one of two, and a single age. Each of the tranches of three was measured on a single bone with different pretreatments, over – judging by the gaps in the ANU number series (ANU16xx; ANU49xx; ANU76xx) – three successive periods. The tranche of two was measured during the second and third (ANU49xx & ANU76xx) dating episodes and the single age was measured during the first (ANU16xx). The date numbers are reported here as cited in Rawlence *et al.* (2011): the current prefix for ANU AMS ages is SANU.

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*Correspondence: *turnagra@gmail.com*

The term “pre-treatments” is taken here, as in Rawlence *et al.* (2011), to include the processes involved in graphitisation of each carbon sample in preparation for measurement in an accelerator. Others may restrict the term to the processes of extraction and purification of protein from the bone, but graphitisation or generation of CO_2 for insertion in the accelerator obviously also takes place before the measurement and can, as is discussed by Rawlence *et al*. (2011), introduce non-target carbon into the sample. Biochemical treatments were not uniform across the three tranches. While Rawlence *et al*. (2011) note that sample preparation for ANU1605-1610 performed at the University of Wollongong included an ultrafiltration stage, the protocol was changed for ANU4079-4937 and ANU7612-7625. For these “The 8 μm Eezi filter dialysis step was not included as this is not necessary to retrieve pure collagen (Higham *et al* 2004)”. It is not clear from this whether or not the ANU treatment included ultrafiltration as the Eezi filter process was not mentioned separately for the ANU1605-1610 samples.

As part of another project, I recalibrated all the moa ages from Glencrieff, using the most recent Southern Hemisphere calibration curve, SHCal20 (Hogg *et al.* 2020), invoked in the OxCal 4.4 software (Bronk Ramsey 2009). The calibrated date distributions differed from those suggested by Rawlence *et al*. (2011). The differences are explored and assessed here. In addition, the presence of *Euryapteryx* in the early Holocene of North Canterbury as implied by the ages on the other two moa taxa is questioned: there are issues of identification by morphology and by consideration of the overall likelihood in terms of numbers of specimens per individual in the whole collection.

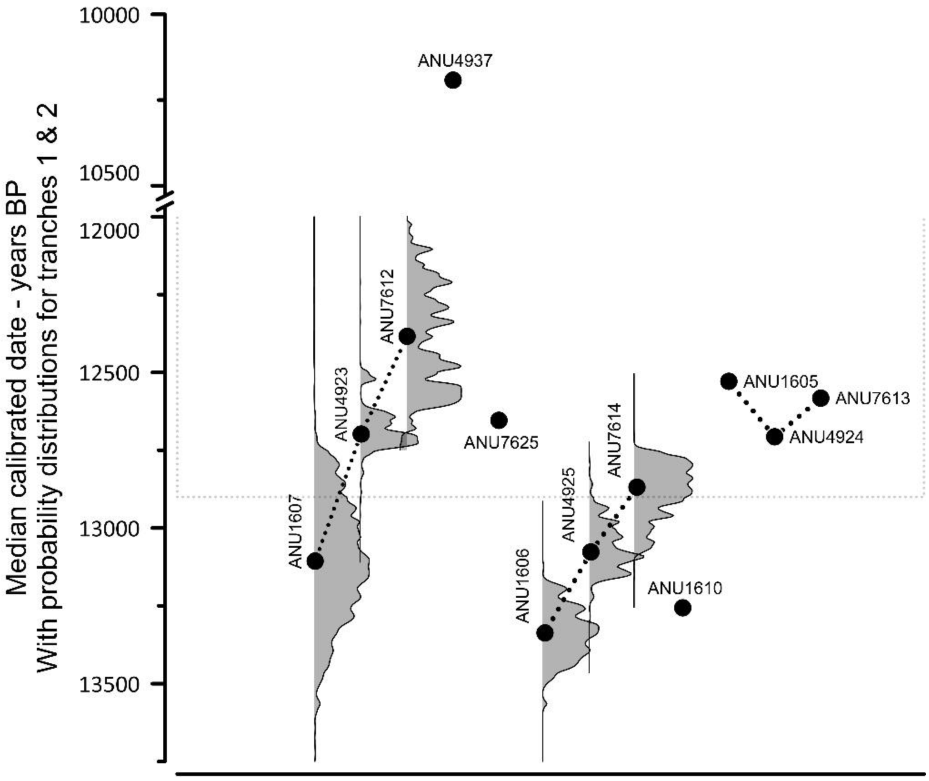

Figure 1. Median calibrated calendar dates of radiocarbon ages on *Pachyornis* moa individuals from the Glencrieff site, North Canterbury, South Island, New Zealand. Calibrated date probability distributions shown for ages in Tranches 1 and 2. Broken line, Younger Dryas period (ends *c*. 11,700 BP). Note break in y-axis.

There are trends towards younger ages in the series ANU1607, ANU4923, and ANU7612 on specimen S32670.9 (Museum of New Zealand Te Papa Tongarewa collection) and on ANU1616, ANU4925, and ANU7614 measured on S32670.3 (same collection) (Fig. 1). The single age (ANU1610) on specimen S32670.7 was, as with the other ages in the ANU16xx series, older. In contrast, the age (ANU4937) on specimen S32670.8 was, at a conventional radiocarbon age of 9070 ± 80 BP, much younger than any other, including ANU7625, which was within the range of the ANU76xx age series for S32670.9 and S32670.3 (Fig. 1). Ages in the third tranche of three, on specimen 32670.2, were all within the age range of the ANU76xx series on other samples (Fig. 1).

The trends to younger ages with measurement date and treatment in two of the three age series and the median dates for the others in each series mean that it was inappropriate for Rawlence *et al*. (2011) to statistically combine the *Pachyornis* ages. The only ages that can be used with confidence at present are those in the ANU76xx series. This agrees with Rawlence *et al*.'s (2011) statement that "The ages obtained for the bones using the UF3 method [i.e. the 76xx tranche] are the most reliable" in the first paragraph of their discussion. With this condition, the date span of occupation in the site area is *c*. 500 and not 1000 years. All ANU76xx series median dates and probability distributions lie in the first half of the Younger Dryas (Fig. 1), a return to glacial climate. The YD is not supposed to have affected New Zealand (Barrows *et al.* 2007; Kaplan *et al*. 2010) or Australia, but see Holdaway (2021).

The three other ages for Glencrieff moa were measured at the Rafter Radiocarbon Laboratory, GNS Science, Lower Hutt and published in 1996 (Worthy & Holdaway 1996). Two are on individuals of *Emeus* (NZA4018, NZA4079), and one on *Pachyornis* (NZA4162). The *Pachyornis* date (11898 ± 82 ^{14}C years BP; calibrated mean 13722 ± 115 SD) is older than any of the ages reported by Rawlence *et al*., including those questioned here (Fig. 2). This raises, of course, at least three questions: which of the ANU series should be retained; is there an issue with the NZA age; and was there a gap in the presence – or at least of the deposition – of *Pachyornis* in Glencrieff? These questions cannot be answered without further radiocarbon ages on both taxa, preferably from the area excavated in the 1990s.

It might be argued that the Rafter ages, which were measured on samples prepared by the ABA (acid, base, acid) protocol, are unreliable and that an additional stage of "ultrafiltration" (UF) is necessary to provide useable radiocarbon ages on bone. However, an interlaboratory comparison (Kuzmin *et al.* 2018) in which four leading radiocarbon laboratories dated samples from a single bone of an elk (*Alces alces*) (moose in North American terminology) from western Germany, of similar vintage to the moa in the Glencrieff site, failed to show evidence for systematic unreliability of ABA-processed samples with respect to those subjected to ultrafiltration (Fig. 2). The regions of highest probability for UF treatments were *c*. 150 years at most from the centres for ABA-treated samples. There is therefore no *prima facie* case for rejecting Rafter ABA-protocol radiocarbon ages on moa bone or indeed bone of any other vertebrate.

Hence, with the presently available ages on moa from the site, it is reasonable to posit that the bulk of the probability distributions of the calibrated dates for the two *Emeus* (which overlap almost entirely) sit at the "young" end of the *Pachyornis* distributions (Fig. 3). This raises at least the possibility that *Emeus* replaced *Pachyornis* in the area. I tested this by applying Sequence analysis in the OxCal4.4 software to the two radiocarbon age series, invoking the "Overlapping" option as replacement was unlikely to have been instantaneous.

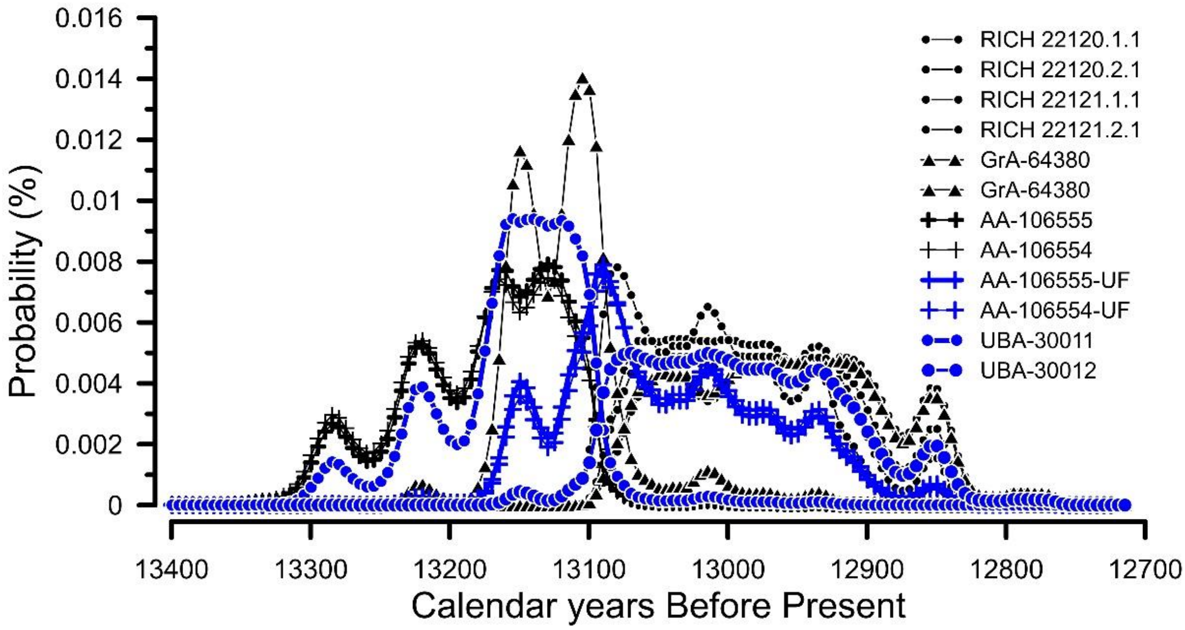

Figure 2. Calibrated calendar date probability distributions of ages generated in an interlaboratory comparison of organic chemistry pre-treatment protocols on a single bone of European elk (*Alces alces*) (American moose). Black, Acid-Base-Acid (ABA) treatments; Blue, ABA followed by ultrafiltration. Symbols, laboratories. RICH, Royal Institute for Cultural Heritage, Department of Laboratories, Belgium; GrA, Groningen; AA, Arizona; UBA, 14Chrono, Belfast. Data from Kuzmin *et al.* (2018).

The highest probability for a change was c. 12,500 BP (Fig. 3). Clearly there is a need for longer series radiocarbon ages on both taxa for this hypothesis of species replacement, and that of an association with a brief return to glacial climate, to be tested.

Rawlence *et al*. (2011) reported 22 individuals (830 bones) of *Pachyornis* and 21 individuals (873 bones) of *Emeus crassus* in the combined collections from the site. The 2007 excavation was of an area south of, and separate from, the 1996 excavation (Worthy & Holdaway 1996). This second excavation yielded four left and eight right tarsometatarsi of *Pachyornis* and three left and four right tarsometatarsi of *Emeus*. From the 2007 excavation they reported a single bone, a left tarsometatarsus, of *Euryapteryx*. Including the 118 bones representing 5 individuals of *Dinornis robustus*, 1822 bones of moa have been identified from Glencrieff: of these, only one has been attributed to *Euryapteryx*.

Given the high recovery rates for elements per individual in *Pachyornis* (37.7) and *Emeus* (41.6), the presence of only a single bone of *Euryapteryx* seems anomalous. It is not always straightforward to separate the limb bones of *Emeus* and *Euryapteryx* on their morphology. In 100 individuals identified as *Emeus* by morphology and morphometrics in collections from Bell Hill Vineyard, Pyramid Valley, and Rosslea, all within 10 km of Glencrieff, 18 were re-identified genetically as *Euryapteryx* (Allentoft *et al.* 2014).

The reverse must be possible. Could the Glencrieff left tarsometatarsus be the "missing" left tarsometatarsus

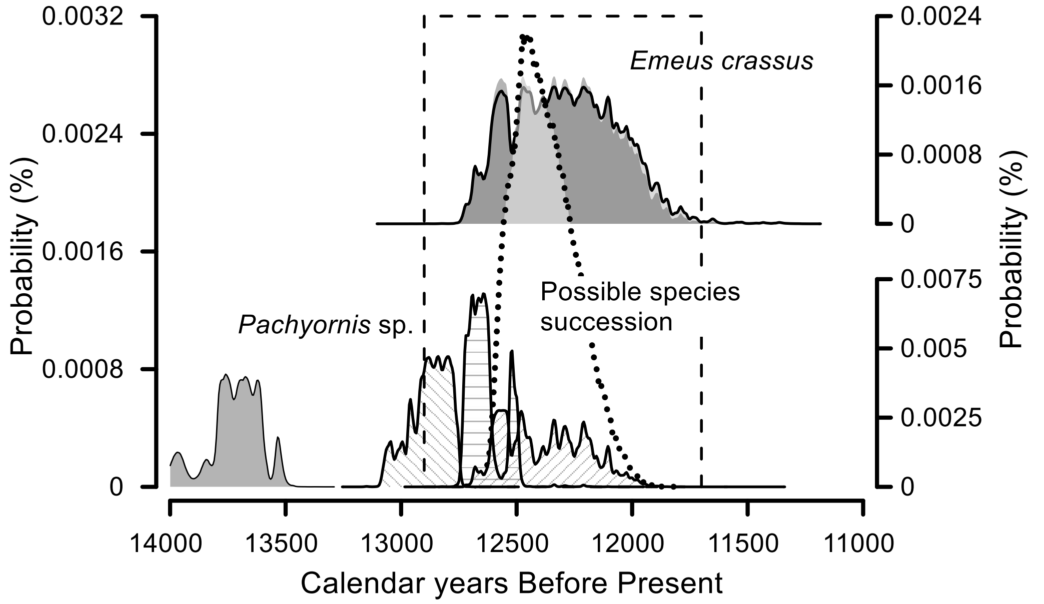

Figure 3. Calibrated date probability distributions for samples of *Emeus crassus* and *Pachyornis* sp. from Glencrieff, with probability distribution for date of possible species succession. Dashed box, Younger Dryas. NZA ages shaded.

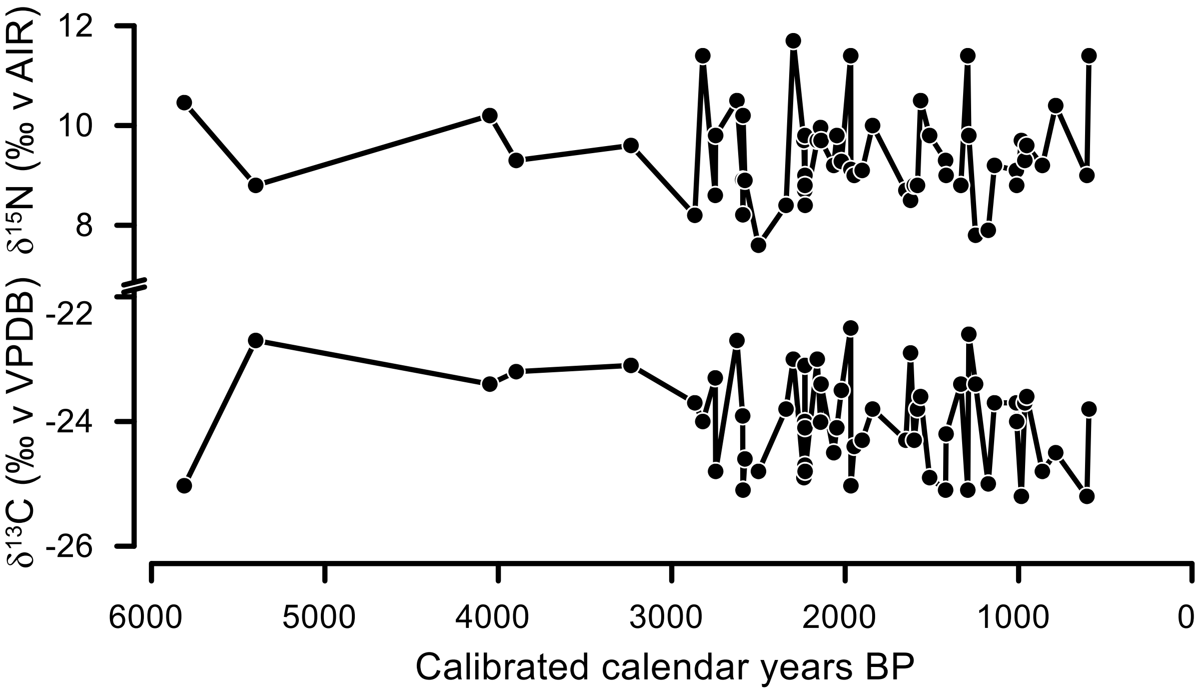

Figure 4. Median calibrated dates on *Euryapteryx* individuals from Pyramid Valley, Bell Hill Vineyard, and Rosslea sites, North Canterbury, South Island, New Zealand, arrayed against their carbon and nitrogen stable isotope ratios. The earliest two are from Rosslea, 1 km west of Bell Hill Vineyard, itself 5.8 km east of Pyramid Valley. The next oldest are two from Pyramid Valley, 1.5 km east of Glencrieff. Data from Allentoft *et al.* (2014) and Holdaway *et al.* (2014). Note break in y-axis.

of *Emeus*? If it is indeed referrable to *Emeus* – and this is testable by ancient DNA – then the first dated postglacial presence of *Euryapteryx* in North Canterbury is, at *c*. 5,800 years BP, the oldest *Euryapteryx* in the Rosslea deposit (Fig. 4) (Allentoft *et al.* 2012). Hence, on available radiocarbon ages, the oldest post-glacial *Euryapteryx* in the northern South Island are those from Irvine's Cave in Takaka Valley (Worthy & Holdaway 1994). That northern population was extirpated, apparently, by the return to glacial climate signalled by the renewed presence of *Pachyornis australis*, which preferred high altitude/glacial vegetation (Rawlence *et al*. 2012; Holdaway & Rowe 2020; Holdaway 2021).

An apparently earlier presence of *Euryapteryx* in North Canterbury was reported as its representing 33% of all moa individuals recovered from loess on Banks Peninsula (Worthy 1993). Only one moa, a *Pachyornis* from "base of 10 m thick loess deposit that overlay volcanic rock", has been radiocarbon dated. Its conventional radiocarbon age of 27,700 ± 1,400 years BP (NZ5382) corresponds, referenced to the SHCal20 calibration curve, to a calendar date of 32,428 ± 1614 years BP. Most if not all of the *Euryapteryx* individuals had been recovered from much shallower (0.75 – 3 m) depths, in loess thought to be less than 25,000 years old (Worthy 1993). The Port Hills loess is easily eroded (Trangmar & Cutler 1983); it is possible that several metres have been lost since Polynesian fires removed the forest several centuries ago.

Airfall tephra from the Oruanui eruption of Taupō volcano 25,400 years ago was 100 mm deep at Christchurch (Vandergoes *et al*. 2013). That depth of tephra causes significant damage to vegetation and fauna (Oppenheimer 2011) and could well have eliminated moa populations. More radiocarbon ages will be required before the presence of *Euryapteryx* after the eruption and before 6,000 BP can be tested. If any DNA has been preserved in the usually poorly preserved bones from the loess, analysis would allow a test of the hypothesis presented here of a recent, post-glacial, colonisation.

Keywords radiocarbon ages, radiocarbon sample treatment, *Euryapteryx*, *Emeus*, climate

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