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SHORT NOTE

Two new radiocarbon ages for Haast's eagle (*Hieraaetus moorei*) (Aves: Accipitridae) and comments on the eagle's past distribution and possible survival into the 19th century

RICHARD N. HOLDAWAY
Palaecol Research Ltd, PO Box 16 569, Hornby, Christchurch 8042, New Zealand

Haast's eagle (*Hieraaetus moorei*) was the top predator of large vertebrates in the South Island, New Zealand, until its late Holocene extinction (Holdaway 1992; Holdaway, in Worthy & Holdaway 2002). It was never found in the North Island (Holdaway 1992; Holdaway, in Worthy & Holdaway 2002). During the most recent — Weichselian-Otiran — glaciation which lasted from 110,000 to 18,000 years ago, the eagle's distribution included Northwest Nelson (Worthy 1993; Worthy & Holdaway 1994) and the West Coast (Worthy & Zhao 2006). There are no eagle fossils of glacial age known from east of the Main Divide, but this may reflect a shortage of fossil deposits of that age rather than of eagles.

During the Holocene (the past 10,000 years) the situation was reversed. The remains of many eagles have been recovered from both natural and archaeological sites throughout the eastern South Island (Worthy & Holdaway 2002), from the coast to the glacial valleys of Central Otago (Worthy 1998a). So far, only one eagle of Holocene age (Table 1) has been collected from west of the Divide, and that was from near the top of Mt Owen, in SO 209, a 15 m deep pothole at nearly 1,500 m altitude, in a subalpine environment (Worthy & Holdaway 2002).

The eagle's distribution pattern through time has been determined mainly from the association of its remains with the radiocarbon-dated individuals of moa (Aves: Dinornithiformes) and other birds (Holdaway 1992; Holdaway, in Worthy & Holdaway 2002). The five radiocarbon ages measured previously on eagles (Fig. 1; Table 1) fit these patterns in space and time. They also provide the only dated evidence for the Holocene survival of a population west of the Main Divide.

Until now only one radiocarbon age, NZA7912 (2,096 ± 72 ^{14}C years BP) (Fig. 1; Table 1) has been available for an eagle from east of the Main Divide (Worthy 1998b). That was measured on a rib of the larger (female, S2134; Te Papa Museum of New Zealand collection) of two eagles excavated for Augustus Hamilton at Castle Rocks, Southland, in the 1890s (Hamilton 1893, 1894). The chronology of the eagle's presence in the eastern South Island has been assessed otherwise, as noted above, on the basis only of ages of deposits where other taxa have been radiocarbon dated or inferred from the species represented therein (Holdaway 1992).

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Correspondence: *turnagra@gmail.com*

Table 1. Radiocarbon ages for Haast's eagle (*Hieraeetus moorei*). CRA, Conventional radiocarbon age (^{14}C years Before Present (BP). Calibrated dates in years (cal BP), based on SHCal20 curve. S, specimen in Museum of New Zealand Te Papa Tongarewa, Wellington. Av, specimen in Canterbury Museum, Christchurch. Mean, weighted mean of measurements; δ^{13}C, AMS measurement, except Pyramid Valley, which are IRMS measurements; C:N, molar carbon to nitrogen ratio of collagen. NA, not available. Sources: 1, Worthy & Holdaway (1994); 2, Worthy (1998a); 3, Worthy & Holdaway (2002); 4, Worthy (1993).

							Calibrated dates (cal BP)			
Site	**Museum**	**Lab. no.**	**CRA**	**SD**	**δ^{13}C**	**C:N**	**Mean**	**SD**	**Median**	**Source**
Hawkes Cave Site 3	S27952 or S28340	NZA3243	16,543	112	-21.4	NA	19,924	175	19,932	1
Hawkes Cave Site 5	S27951	NZA3194	13,175	102	-22.1	NA	15,764	161	15,764	1
Castle Rocks	S2134	NZA7912	2,096	72	-23.3	NA	2,026	100	2,021	2
Mt Owen (SO209)	S27773	NZA905	2,159	196	-22.5	NA	2,124	252	2,110	3
Honeycomb Hill	S22472.13	NZA361	15,541	218	-21.5	NA	18,788	257	18,801	4
Pyramid Valley	Av6177/6178	UBA42949	1,935	25	-22.4	3.28	1,828	44	1,836	This paper
Pyramid Valley	Av6012	UBA42950	2,871	31	-22.7	3.31	2,945	61	2,941	This paper

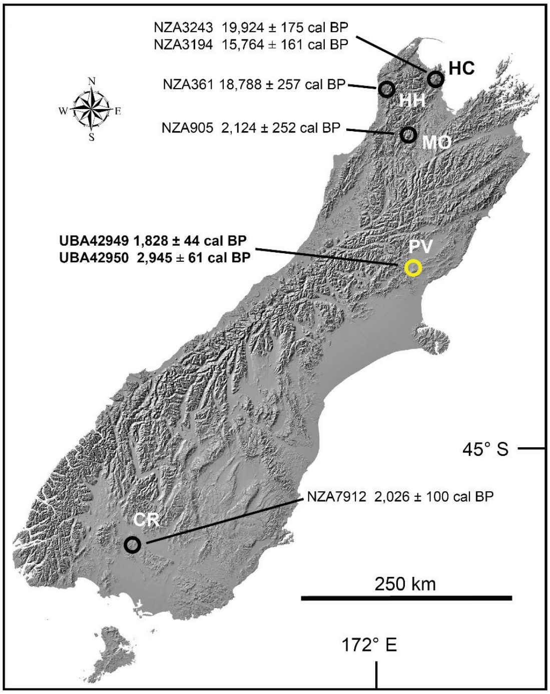

Figure 1. Distribution of radiocarbon-dated specimens of Haast's eagle (*Hieraeetus moorei*), with calibrated dates (weighted mean ± 1SD) cal BP, (calibrated years Before Present, i.e. 1950 CE). Dates in **bold** are reported here for the first time. Sites: HC, Hawkes Cave, Takaka Hill; HH, Honeycomb Hill cave system, Oparara River; MO, Cave SO 209, Mt Owen; PV, Pyramid Valley; CR, Castle Rocks. The distribution of dated individuals does not constitute the known distribution of the eagle. Details of radiocarbon ages and sources in Table 1. Digital Elevation Model courtesy of School of Earth and Environment, University of Canterbury, Christchurch, New Zealand.

At least four eagles (Holdaway & Worthy 1997) have been excavated from the lake bed at Pyramid Valley, North Canterbury, and all must have been deposited there at some time in the past 5,000 years, the duration of deposition at the site (Gregg 1972; Johnston 2014; Johnston *et al*. in press). Two of the four eagles were sampled for dating: non-essential material of the other two was too limited for sampling. The eagle and other large species in the deposit – takahe (*Porphyrio hochstetteri*), adzebill (*Aptornis defossor*), goose (*Cnemiornis calcitrans*), and kakapo (*Strigops habroptilus*) – have been neglected historically in favour of dating the four species of moa (Allentoft *et al.* 2014; Holdaway *et al*. 2014).

All the published radiocarbon ages referred to here were measured by accelerator mass spectrometry (AMS) on bone collagen. Radiocarbon ages for the two eagles were measured (by AMS) at the 14Chrono Laboratory, Queen's University, Belfast, UK, and the conventional ages were calibrated via OxCal4.4 (Bronk Ramsey 1995, 2009), referenced to the SHCal20 curve (Hogg *et al.* 2020). Small (309, 670 mg) bone samples, chosen to avoid features of potential morphological interest, were submitted for dating. Collagen was extracted using a method based on that of Brown *et al.* (1988) but using a Vivaspin® filter cleaning method introduced by Bronk Ramsey *et al.* (2004).

The radiocarbon ages on the Mt Owen and Castle Rocks eagles were measured by the Rafter Radiocarbon Laboratory (now of GNS Science), after 1977, and are reported according to the agreement of that year on Radiocarbon Reporting Conventions (Stuiver & Polach 1977). Before that all ages reported by that laboratory before the 1977 agreement were reported according to best practice at the time, which varied depending on sample type, and evolved over the years. All results have now been recalculated from the original counting data, according to the S&P1977 conventions. Depending on the sample type and original reporting practice, the results may change by up to several hundred years from the original report. The count data were recalculated for this study and no rounding was applied to the error measurement reported. These factors affect ages on moa bones measured before 1977, which are often used in comparison with more recently measured ages.

Both eagles yielded calibrated radiocarbon dates in the past 3,000 years (Table 1). Based on current understanding (Moar 1970; Burrows 1989; Johnston 2014) of the environment surrounding the Pyramid Valley lake, both birds inhabited a lowland forest that hosted an avifauna of nearly 50 species (Holdaway & Worthy 1997), including several ranging in size from Finsch's duck (*Chenonetta finschi*) to moa (Worthy & Holdaway 1996, 2002), that were large enough to have been potential prey for the eagle.

Worthy & Zhao (2006) inferred the presence of the eagle at Kids Cave, near the Nile River, Westland, during the Last Glacial Maximum. They interpreted damage to large bones of species such as kea (*Nestor notabilis*), extinct coot (*Fulica prisca*), paradise shelduck (*Tadorna variegata*), and South Island goose (*Cnemiornis calcitrans*), as beyond the capacity of either the extinct harrier (*Circus eylesi*), whose bones were recovered from the site, or New Zealand falcon (*Falco novaeseelandiae*) but recorded no bones of the eagle itself. The species listed are indeed likely prey for the eagle, but the statement that "This is the first time prey remains have been ascribed to Haast's eagle." (Worthy & Zhao 2006: p. 402) is clearly incorrect. Moa killed by eagles had been identified before (Worthy & Holdaway 1996, 2002; Holdaway 2015) and the eagles are unlikely not to have fed on the moa they had killed.

In contrast to the Pyramid Valley birds, the date for the Mount Owen bird (Table 1) (Worthy & Holdaway 2002: figure 8.23) shows that eagles could also find suitable prey in more open environments, perhaps similar to those available during glacial periods. In addition, its presence there shows that small isolated populations could survive for millennia in rare suitable habitats west of the Main Divide after the climate warmed at the end of the glaciation. The rapid post-glacial spread of lowland rain forest through northwest Nelson quickly surrounded Mount Owen, isolating its high basins. Encircled then by many kilometres of unfavourable wet forest and separated by the central ranges from the eastern populations, at least 400 generations of a tiny population (the area of habitat was limited) of eagles apparently survived there in isolation. The eagle's presence there would also speak to the continued abundance of prey such as weka (*Gallirallus australis*) and takahe in that environment. The upland moa (*Megalapteryx didinus*), South Island giant moa (*Dinornis robustus*), and *Pachyornis australis* were certainly there during the Holocene (Worthy 1989a,b). Remains of a weka were found in SO 209 with the eagle.

Absence of evidence (the absence of eagles from Holocene-aged deposits from west of the Main Divide after 15,000 years BP, with the exception of the much later high-altitude occurrence on Mt Owen), is, of course, not evidence of absence (i.e. eagles were not present in the west Holocene forests). However, two factors support the contention that, in this instance, it does. First, the concept of consilience, where multiple, independent observations yield the same result, which was famously the procedure adopted by Charles Darwin in *On the origin of species*. In the present instance, the absence of eagles from one site with a continuous fossil record might be interesting, the absence of eagles – and of their prey species – from all such sites within the period of interest is information.

Second, west of the Divide the eagle is always associated in the deposits with the same "eastern" fauna of moa and other taxa (Worthy & Holdaway 1993, 1994). The "eastern" fauna vanishes from the deposits, replaced by a wet forest fauna, during the glacial-interglacial transition just as the eagle record ceases too. In major moa sites in the eastern South Island, only the collection from the deposit at Herbert lacks eagles, probably an artefact of the collection philosophy ("collect the moa") adopted at the time. The eagle is otherwise ubiquitous in the presence of the emeid moa during the Holocene east of the Divide and west of the Divide during the glaciation. If the eagle was indeed living in the wet Holocene forests west of the Divide it was living with species such as *Anomalopteryx didiformis*, with which it has never been associated elsewhere.

True forest eagles, especially the largest, the African crowned eagle (*Stephanoaetus coronatus*) and the harpy eagle (*Harpia harpyja*), prey mostly on arboreal mammals (McGraw *et al*. 2006; Swatridge *et al.* 2014; Symes & Antonites 2014; Aguia-Silva *et al*. 2014, 2015; Miranda 2018) that live in the productive canopy biome. The crowned eagle supplements with this diet with antelopes of up to 30 kg killed as they drink at waterholes within the forest (Brown & Amadon 1968). The low productivity at and near the floor of a rain forest limits populations of large herbivores (Cerling *et al*. 2004) and hence, even more so, those of their predators.

The two "large hawks" that European explorer Charles ("Charlie") Douglas shot in the Landsborough Valley, South Westland, in the late 1860s (Pascoe 1957) are unlikely to have been Australasian harriers (*Circus approximans*) as confidently proposed by Sir Robert Falla in a footnote to the quotation. Douglas was a surveyor of note (Nathan 2017) and an astute observer (Holloway 1957): he was unlikely to have measured so badly the birds he shot as to make them twice the size of a harrier. The eagle was discovered after Douglas's observations and he could hardly have been boasting that he had shot living examples of something not known to exist.

The 2,000 year BP date on the Mt Owen female shows that the species was able to survive near the end of the Holocene in subalpine areas. The last area of the South Island that could – and, obviously did, support takahe and other eagle prey – was south of Mt Owen. Takahe survive in mountain valleys farther south today. The landscape of the upper reaches of the Landsborough Valley is not unlike the montane basins on Mount Owen. In the 1860s, before the introduction of deer and other ruminants, the montane basins would have retained much of the character of the pre-human vegetation (Worthy & Holdaway 2002: figure 8.22). Before prey species such as takahe and weka were extirpated or severely reduced in numbers by introduced mustelids after the early 1880s, the area could have provided suitable habitat and prey for a small population of eagles. Douglas's record should not be dismissed out of hand.

The female eagle that died in SO 209 near the summit of Mount Owen just over 2,000 years ago (Holdaway 1992) was unlikely to have been the last bird of its population. Its (almost complete) skeleton does, however, provide an opportunity to test the hypothesis of the long-term survival of a genetically limited population of large raptors. Advances in analysis of ancient DNA mean that the hypotheses of long isolation of the Mt Owen population and a potential genetic shift could be tested against the copious (for a large raptor) material available from east of the Divide (Holdaway 1992) and even the better-preserved bones amongst the much older eagle material from Honeycomb Hill Cave (Worthy 1993) and Takaka Hill (Worthy & Holdaway 1994). The near contemporary individuals from Pyramid Valley would be ideal comparators for the Mount Owen female in such a study.

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