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NOTES ON THE WEIGHT, FLYING ABILITY, HABITAT, AND PREY OF HAAST'S EAGLE (*Harpagornis moorei*)

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INTRODUCTION

Apart from the publications of Haast (1872, 1874, 1881), Owen (1879), Hamilton (1893, 1894), Shufeldt (1896), and Oliver (1930, 1945, 1955), most statements on Haast's Eagle have been anecdotal or repetitions of previous work. Early workers' conclusions, based on examination of specimens, have often been misquoted, particularly about the length and proportions of the wing bones, by others who have not seen material themselves. This has led to the present popular impression that the bird was becoming flightless. There has been little original work on the species since Oliver examined the structure of the palate (Oliver 1945).

Most authors who have discussed the eagle have commented on its size, possible relationships, and habitat (e.g. Duff 1949, Haast 1872, Hamilton 1893, McCulloch 1982). My own interest in the bird was aroused by discussions at the Ornithological Society's 1975 summer school of ornithology in Nelson. The suggestion was made that the eagle was as large as the teratorns of the Californian (Rancho La Brea) tar pits, which were predatory birds larger than the present-day Californian and Andean Condors (Feduccia 1980).

I set out to calculate the eagle's weight and to see whether there was anything about its proportions or structure which would have prevented its flying. From the results, I speculated further on its habitat, flight pattern, and probable prey.

METHODS

I assumed that the weights of birds of different body size are related to the difference in trunk volume and calculated the body weight by proportion. This method has been used for estimating body weights of other extinct birds

(McNeill Alexander 1983). For Haast's Eagle, I used body dimensions of a mounted skeleton (Otago Museum Cat. no. C40.8) assembled from material collected at Castle Rocks in western Southland by Augustus Hamilton in the 1890s (Hamilton 1893, 1894). The trunk volume of this specimen was compared with those of mounted skeletons of the Australian Wedge-tailed Eagle (*Aquila audax*) (AV5209) and White-bellied Sea eagle (*Haliaeetus leucogaster*) (AV5210 - Java) in Canterbury Museum.

I did not use limb bone lengths in weight measurement because no formulae were available when this study was done. Those now available for the wing are highly dependent on wing proportions. Relationships based on leg bone dimensions have been derived from samples including many higher taxa (e.g. Prange *et al.* 1979).

Means and ranges of weights for the two living species were available from several literature sources. I used those in Brown & Amadon (1968) and Brown (1976).

The dimensions used were: trunk length (TL), from the anterior of the furcula bow to the posterior tip of the pygostyle; maximum trunk width (MTW), measured across the thoracic ribs as mounted; and maximum trunk depth (MTD).

Dimensions of the Otago Museum skeleton of Haast's Eagle were then expressed as proportions of the same measurements of mounted skeletons of the living eagles. From these proportions, the weight of the living Haast's Eagle was calculated.

I estimated the wing span of the Otago specimen of Haast's Eagle by first estimating the normal angular relationship between the wing bones in a spread wing and then drawing a reconstruction of the wings and associated flight feathers. For the feathered sections, I used standard wing lengths for large raptors from Brown & Amadon (1968) as a guide. Although some long-winged birds, such as albatrosses, have short flight feathers, I assumed that the feather proportions in Haast's Eagle were similar to others in the Accipitridae. A relatively short ulna is characteristic of broad-winged forms, such as the large forest eagles, and not of open-country species (pers. obs.).

Tail length was then based on wing proportions, according to possible aerodynamic requirements for bird tails. The stalling speed of a very heavy, broad-winged bird tends to be higher than in birds with a high aspect ratio wing; and a long, broad tail can provide compensatory lift at high angles of attack and low air speeds (Maynard Smith 1953).

The mounted skeleton of Haast's Eagle in Otago Museum is of a small individual, smaller than many others represented by fewer elements in various collections and so it was assumed that it was a male. Females are generally larger than males in hawks and eagles (Brown & Amadon 1968). A possible wing configuration for the larger female was obtained by increasing the length of the major wing bones to the largest known and increasing the feather outline in linear proportion.

RESULTS

Body Weight

The measurements of the mounted skeletons of the three eagle species are given in Table 1. The dimensions of the skeleton of Haast's Eagle as

TABLE 1 — Trunk measurements of mounted skeletons of Haast's Eagle (*Harpagornis moorei*) and two living Australian eagles. TL, trunk length (mm); MTD, maximum trunk depth (mm); MTW, maximum trunk width (mm).

Dimension	Species		
	Harpagornis moorei	*Haliaeetus leucogaster*	*Aquila audax*
TL	340	324	270
MTD	135	99	78
MTW	190	144	120

TABLE 2 — Trunk dimensions of mounted skeletons of Haast's Eagle (*Harpagornis moorei*) expressed as proportions of the corresponding dimensions of mounted skeletons of two Australian eagles, and weight of Haast's Eagle as a proportion of body volume (product of trunk dimensions) of the other species. Abbreviations as in Table 1.

Dimension	Species	
	Haliaeetus leucogaster	*Aquila audax*
TL	1.05	1.26
MTD	1.32	1.58
MTW	1.36	1.73
Weight	1.88	3.44

TABLE 3 — Live weights (g) for *Aquila audax* and *Haliaeetus leucogaster*, from literature sources, as acknowledged. First set for *Aquila audax* gives mean, followed by range and number of individuals.

Species	Weight (source)	
	Brown & Amadon (1968)	Poole (1938)
Haliaeetus leucogaster	2475-2800	
Aquila audax	3402 (2495-4536; 43)	4664
	Up to 5000?	
	3346 (mean of 127)	

proportions of the corresponding dimensions of the two living species are given in Table 2.

Published weights (Table 3) suggested that the Wedge-tailed Eagle should have been heavier than the sea eagle, but those for the sea eagle were based on a small sample and it is possible that larger individuals exist. It

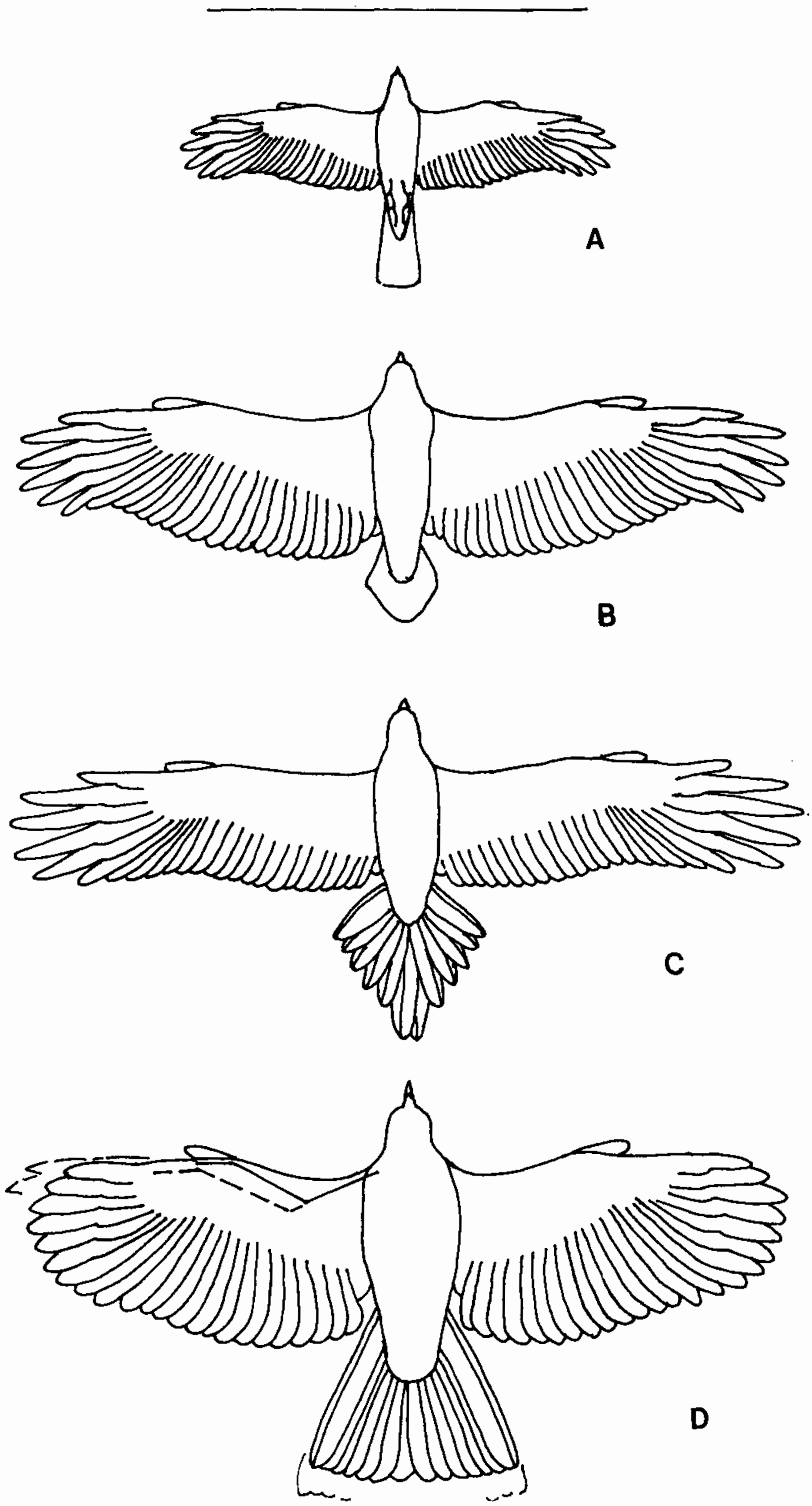

FIGURE 1 — Ventral views of large raptors, with wings fully spread: A, *Circus approximans*; B, *Haliaeetus leucogaster*; C, *Aquila audax*; D, *Harpagornis moorei*. Solid line in left wing of *H. moorei* indicates pattern of major wing bones used in reconstruction of male; broken line indicates pattern of female wing bones, and tip of first two primary feathers. See Table 4 for wing spans and other parameters. Scale bar 1 metre.

was assumed, therefore, that the sea eagle skeleton was from a very large female and that the Wedge-tailed Eagle skeleton was from a bird of average diminsions. Alternatively, the specimen may be misidentified, as are some others in the collections acquired by Canterbury Museum last century (R.N. Holdaway, pers. comm.).

The Wedge-tailed Eagle was assumed to have weighed 3.346 kg (mean, n = 127, Brown & Amadon 1968). If trunk volume is proportional to live body weight, the male Haast's Eagle from Castle Rocks weighed about 11.5 kg in life. Using data for the White-bellied Sea Eagle, the weight of the Haast's Eagle was 5.26 kg. In view of the doubt about the identification of the sea eagle, the weight based on the Wedge-tailed Eagle skeleton was accepted.

The longest ulna of Haast's Eagle in Canterbury Museum (AV36405; 279 mm) was 17% longer than that of the Otago Museum skeleton (C40.8). Weight is proportional to the cube root of linear dimensions but the square root of areas. As ulna length is a measure of wing area rather than of body size, body weight should be proportional to the linear measurement cubed divided by the measurement squared. Therefore, the female weight was calculated as male weight x $1.17^{3/2}$, which gave 11.5 x 1.27 = 14.46 kg for the female.

Wing proportions

Figure 1 shows scale outlines of the Australasian Harrier (*Circus approximans*), Haast's eagle, and the Wedge-tailed and Australian Sea Eagles. Both eagles have been suggested as near relations of Haast's Eagle (Oliver 1930, 1945, 1955, Shufeldt 1896).

The scar of the supracoracoideus muscle was large in comparison with those for the other two eagles (Figure 2), which suggested that Haast's Eagle had a more powerful upstroke of the wing. However, I did not have enough

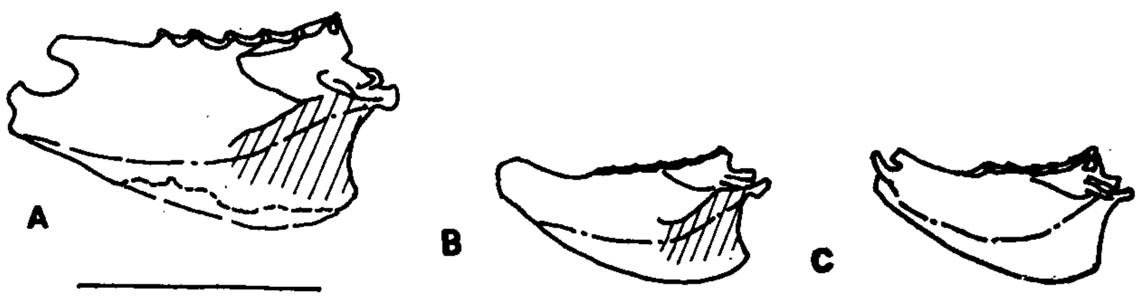

FIGURE 2 — Right lateral views of sterna of: A, *Harpagornis moorei*, lower edge of keel reconstructed; B *Aquila audax; C, Haliaeetus leucogaster.* Scar of supracoracoideus muscle indicated by hatching. Scale bar 100 mm.

TABLE 4 — Weight (W, kg), wing span (span, mm), wing area (area, m^2), wing loading (L, g cm^{-2}), span loading (SL, g cm^{-1}), and aspect ratios (AR, $span^2$/area).

Species	Sex	W	Span	Area	L	SL	AR
Aquila audax		4.5	2.25	0.573	0.785	20.0	8.84
Haliaeetus leucogaster		2.8	2.20	0.643	0.435	12.7	7.54
Circus approximans		0.7	1.23	0.194	0.360	5.68	7.8
Harpagornis moorei	♂	10.35	2.14	0.821	1.261	48.4	5.58
	♀	14.46	2.43	0.959	1.502	59.5	5.66

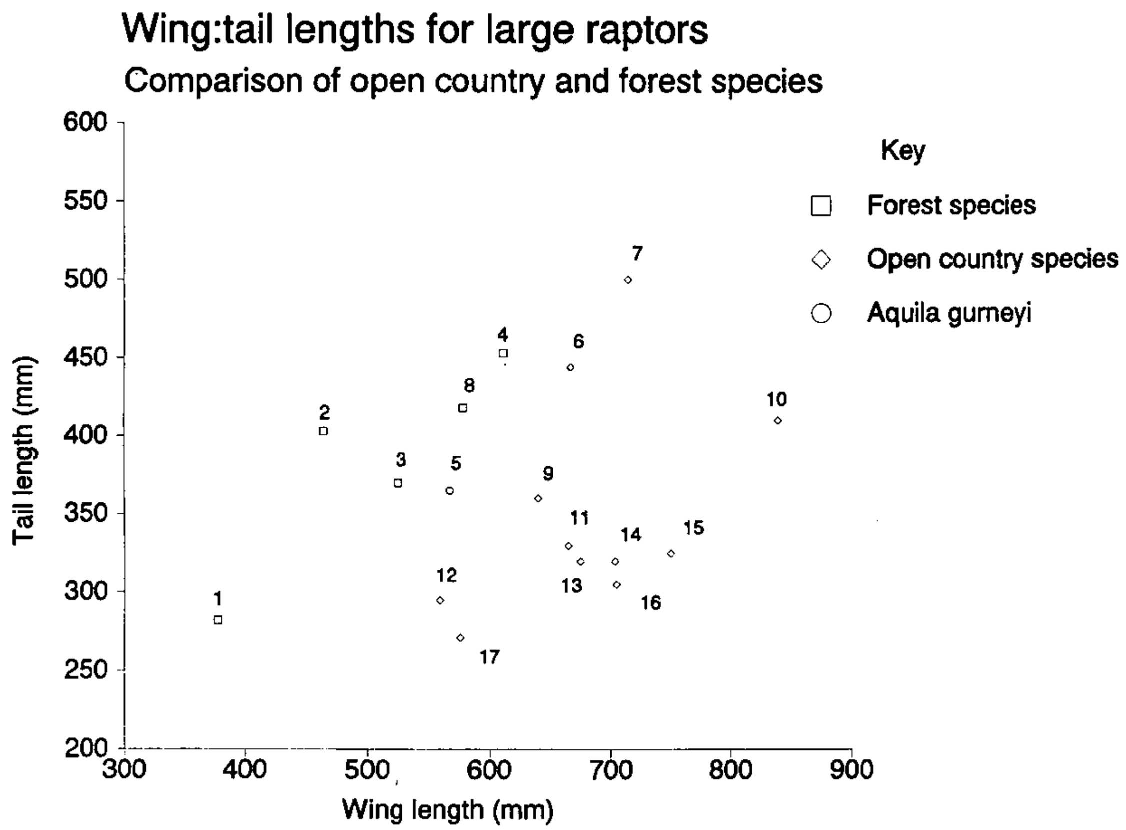

FIGURE 3 — Standard wing versus tail measurements for a range of large raptors from forest and open country habitats. Data from Brown & Amadon (1968). Where only ranges available, points plotted were largest from overall, or female where differentiated, ranges. Means were used where given. Species: 1, *Spizaetus ornatus;* 2, *Morphnus guianensis;* 3, *Stephanoaetus coronatus;* 4, *Pithecophaga jefferyi;* 5, *Aquila gurneyi;* 6, *Aquila audax;* 7, *Gypaetus barbatus;* 8, *Harpia harpyja;* 9, *Aquila verreauxi;* 10, *Aegypius monachus;* 11, *Aquila heliaca;* 12, *Aquila rapax;* 13, *Polemaetus bellicosus;* 14, *Haliaeetus albicilla;* 15, *Gyps fulvus;* 16, *Aquila chrysaetos;* 17, *Haliaeetus leucocephalus.* Note position of *Aquila gurneyi.*

data to show whether the scar was *proportionately* larger in Haast's Eagle, and so this is conjectural.

Wing spans, areas, and aspect ratios obtained from the illustrations in Figure 1 are summarised in Table 4. The span and aspect ratio estimated for Haast's Eagle were lower than those for the other species, which all inhabit open country (Brown & Amadon 1968). Wing and tail lengths for a range of large raptors from forest and open-country habitats are plotted in Figure 3.

DISCUSSION

The live weights estimated here for Haast's Eagle, about 11.5 kg for a male and over 14 kg for the female, make this eagle up to 30% heavier than the largest living eagle, the South American Harpy (*Harpia harpyja*) (Brown & Amadon 1968). Even if the method overestimated the weights by 10%, the bird would still have been much heavier than the Harpy. This great weight was borne on wings which were proportionately shorter but broader than open country eagles such as the Australian Wedge-tailed Eagle and the White-bellied Sea Eagle.

Aerodynamic considerations (Maynard Smith 1953) support the idea that broad short wings are associated with a comparatively long tail, unlike the short tails of most open-country eagles. In turn, short, broad wings and long tails are characteristic of forest eagles (Brown 1976 and Figure 3). If Haast's Eagle had the long tail normally associated with its proportionately (not absolutely) short wings, it probably inhabited forest.

This is supported by evidence on former vegetation patterns in New Zealand. It is now generally accepted that New Zealand was mainly forested before Polynesians arrived about 1000 years ago (McGlone 1988, Molloy *et al.* 1963). Sites such as Pyramid Valley, where bones of Haast's Eagle have been found, were in areas where forest was the dominant vegetation (Molloy *et al.* 1963) and the eagles must have been living in forest at those sites.

The only species presently placed either in the genus *Aquila* or in *Haliaeetus,* which normally inhabits forest, is Gurney's eagle (*Aquila gurneyi*) of New Guinea (Brown & Amadon 1968). This bird seems to have different proportions from typical *Aquila* (Figure 3) and may not belong in that genus at all (Brown & Amadon 1968).

The very large bones of Haast's Eagle have led to the notion that the bird flew poorly and spent much of its time on the ground (e.g. McCulloch 1982, Millener 1984). Indeed, some authors have suggested that it was becoming flightless (Duff 1949). This would be a very surprising evolutionary path for a large eagle to take, and is not supported by the full development of the bones of the wing and shoulder girdle. It is also probably based on a misreading of Haast's and Owen's original comments (Haast 1874, Owen 1879) on the proportionately short ulna. This has been, for example in Duff (1949), translated into a short wing, when both the earlier authors were only stressing the different proportions and not the absolute length of the wing. Neither Haast nor Owen doubted that the bird could fly well (Haast 1874, Owen 1879).

While it could certainly fly, its great weight would have caused some physical and aerodynamic problems for Haast's Eagle. Takeoff should be the most difficult phase of flight in very large birds (Maynard Smith 1953). Unlike the very large vultures, large eagles do not need take-off run (A. Kemp, in litt.) and rise from a standing start. The African Crowned Eagle (*Stephanoaetus coronatus*) can take off almost vertically from the forest floor (Brown 1982) by jumping into the air and flapping vigorously.

The legs of Haast's Eagle had very large muscles, as shown by the points of attachment on the leg bones themselves and on the pelvis (pers. obs.). Strong legs may have allowed the birds to spring into the air, too. If the supracoracoideus muscle was disproportionately large in Haast's Eagle, as the large scar on the sternum suggests, the wing upstroke would have been powered during take-off and initial climb to a tree limb.

Very large birds, including forest eagles (Amadon & Brown 1968) fly infrequently but rapidly. Forest eagles usually watch for prey from perches in tall trees, and then attack with great speed and agility. The Harpy can manoeuvre through the South American rain forests at 60-80 km h^{-1} (Brown 1976). There are no data on the proportions of red and white muscle fibres in the pectoral muscles of forest eagles, but it would not be surprising if there were a high proportion of white fibres. These produce a high power output for brief periods, in contrast to the red fibres which are used in sustained, aerobic activity.

The size of Haast's Eagle suggests that it, too, would have flown down from high perches to attack its prey and that it had reasonably high food requirements. These points raise the question of its probable prey. Three groups of large herbivores were present in the Holocene fauna, and all are reasonable candidates: the flightless geese (*Cnemiornis*), the gruiform adzebills (*Aptornis*), and the moas (Dinornithidae and Emeidae). Prey smaller than the Takahe (*Porphyrio mantelli*) or Kakapo (*Strigops habroptilus*) would have been too difficult to grasp and hold with the huge talons.

Of the likely prey, the geese and moas may have been major items in the diet. The adzebills, if rarity of remains indicates rarity in life, would have been too uncommon to have been a staple. However, the eagle should have had little difficulty in knocking down and killing a goose or a moa, particularly the smaller species such as *Anomalopteryx didiformis, Megalapteryx didinus,* and *Euryapteryx geranoides.*

Larger prey, such as *Pachyornis elephantopus* or the species of *Dinornis*, would not have been out of the question, however, because the African Crowned and Martial Eagles kill antelopes several times their own weight, up to 5 times its body weight for the Crowned Eagle (Brown 1982). That such a large and powerful predator as Haast's Eagle, equipped with enormous talons, could take birds weighing up to 200 kg is not impossible when an eagle tackling an antelope has to deal with a four-legged animal capable of maintaining its balance and running off into dense vegetation. A goose or a moa could have been knocked off its feet by a high-speed strike from the heavy predator, and then killed by repeated grips with the talons.

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