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MORPHOMETRICS OF THE WEDGE-TAILED EAGLE *Aquila audax*

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Morphological measurements were made from 233 wild Wedge-tailed Eagles *Aquila audax* on the Nullarbor Plain, 116 museum specimens from southern Australia and 30 dead birds from New South Wales. In the birds from the Nullarbor Plain, reversed sexual size dimorphism (female larger than male) was found in all characters examined. Among the museum specimens (a) I found no evidence of geographical variation across southern mainland Australia and (b) a number of specimens were probably incorrectly sexed. Overall, the length of tail appeared to increase with age in females but not in males.

INTRODUCTION

The Wedge-tailed Eagle *Aquila audax* is Australia's largest raptor and is among the largest of its genus. Regarded as vermin by pastoralists during the 1800s and much of the present century, the species was not fully protected throughout Australia until 1989. In Western Australia, bounties were paid by the State Government until 1968 and some sheep stations continued to pay their doggers for kills even after that date. From 1967 to 1976, the CSIRO Division of Wildlife and Ecology conducted a detailed ecological study of the species (Brooker and Ridpath 1980; Ridpath and Brooker 1986a,b; Ridpath and Brooker 1987). This paper summarizes data on the morphometrics of captured eagles and carcasses obtained during the CSIRO survey on the Nullarbor Plain, Western Australia, as well as data from specimens held in Australian museums and from some dead birds measured in central New South Wales in 1965.

METHODS

1. Living birds and carcasses from Nullarbor Plain

Birds were assigned to one of three age classes (young, medium, old) based primarily on plumage colour (light, medium and dark respectively), in particular the colour of the median and lesser wing coverts on the dorsal wing surface (see Ridpath and Brooker 1986a). Measurements were made of **wing length** (folded wing, flattened chord between carpel joint and longest primary, to nearest 0.5 cm); **wing span** (wings spread, dorsal aspect, not stretched, to nearest 0.5 cm); **wing area** (measured from a tracing of the flattened wing on graph paper, to nearest 0.1 cm^2); **total length** (tip bill to tip tail, head flat, to nearest 0.5 cm); **tail** (central rectrix, to nearest 0.5 cm); **mass** (to nearest 10 g); **mass adjusted** (mass minus estimated weight of food in crop; i.e. 300 g for full crop, 150 g for half full crop. M. Brooker unpubl.); **bill length** (tip to front of cere, to nearest 0.1 mm); **bill depth** (in front of cere, bill held together, to nearest 0.1 mm); **bill width** (level with front of cere, to nearest 0.1 mm); and cere length (to nearest 0.1 mm).

Note that the bill lengths (tip to front of cere) used in this paper may appear to be inconsistent with data published elsewhere because our measurement was erroneously defined in Marchant and Higgins (1993) as 'bill plus cere'.

From these measurements, the following indices were calculated:

Bill index:	length × depth × width × 10^{-5}
Sexual dimorphism:	$\frac{(\text{female mean} - \text{male mean}) \times 100}{0.5 \times (\text{female mean} + \text{male mean})}$
Mass loading:	mass adjusted/wing area (g/cm^2)
Linear loading:	cube root mass/square root wing area ($g^{0.33}/cm$)
Aspect Ratio A:	wing span squared/wing area
Aspect Ratio B:	total wing length squared/wing area (total wing length estimated from wing tracings)

Although 233 adult birds were handled during the course of the Nullarbor study, a full set of data was not obtained from every individual. The number of measurements taken depended on factors such as the state of decomposition of a carcass and the number of handlers. The sex of a dead bird was determined by autopsy whenever possible.

2. Museum specimens

Wing and tail lengths (measured to nearest 1 mm) were measured by the author (Victoria Museum, Melbourne), Ian Mason (Australian National Wildlife Collection, Canberra; Australian Museum, Sydney; Queensland Museum, Brisbane; South Australian Museum, Adelaide) and Ron Johnstone (Western Australian Museum, Perth). Specimens were allocated to one of three age classes based on plumage colour and the sex given on the label was noted. Only museum data from the southern mainland were used to examine geographic variation as there were insufficient numbers from northern Australia (n = 5) and Tasmania (n = 3) for adequate comparison.

3. Carcasses from New South Wales

Wing lengths and bill lengths were measured and sex was determined by autopsy.

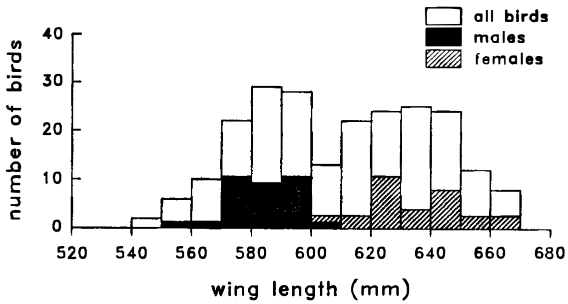

Figure 1. *Frequency histogram of wing lengths of male, female and unsexed adult Wedge-tailed Eagles from the Nullarbor Plain, Western Australia.*

RESULTS AND DISCUSSION

All measurements of Wedge-tailed Eagles from the western Nullarbor Plain and central New South Wales are presented in Tables 1 and 2 respectively, and the wing lengths of the 233 Nullarbor birds are shown in Figure 1.

There were significant differences between sexes in all of the Nullarbor measurements, with the females being larger and heavier than the males (Table 1). Indices of sexual dimorphism (see Methods) calculated from these data were 8.2 for wing length, 7.7 for bill length and 7.5 for cube root adjusted mass, which are of the same order as the indices for Wedge-tailed Eagles given by Baker-Gabb (1984) (6.2, 7.2 and 9.6 respectively, where the same indices for 19 other Australian diurnal raptors ranged from 1.0 to 21.9).

Size variation in southern Australia

Comparison of wing lengths and tail lengths of museum specimens from south-eastern Australia with those from south-western Australia (Table 3) showed no evidence of geographic variation (ANOVA, $P > 0.05$). Nor were there significant differences between the wing lengths of the museum specimens from southern Australia (N = 91) and those of the Nullarbor birds (N = 233) (Mann-Whitney rank sum test, $P = 0.285$) or their distributions ($\chi^2_9 = 13.6$ ns) or between the wing lengths of the sexed New South Wales birds (Table 2) and the sexed Nullarbor birds (Table 1).

Mis-sexed museum specimens

A number of the museum specimens are probably incorrectly sexed. The standard deviations (SD) of tail and wing length for museum sexed birds (Table 3) were approximately double that of the anatomically sexed birds from the Nullarbor (Table 1) but similar to the SDs of all unsexed Nullarbor birds. Moreover the ranges of wing lengths of the anatomically sexed birds from the Nullarbor (Fig. 1) showed minimal overlap between sexes. Consequently, I re-sexed all museum specimens using the relationship obtained between sex and wing length from the known-sex Nullarbor birds (i.e. birds with a wing length of 60 cm or less were deemed to be male, $P < 0.05$; whereas those of 61 cm or more were deemed female, $P < 0.05$).

According to this re-allocation, at least 22 of 56 (39%) museum birds sexed as male were probably female and 6 of 35 (17%) sexed as female were probably male (Table 4). Of these mis-sexed birds, 37% were juveniles and 20% were adults. Thus, males seem more likely to have been mis-sexed than females and juveniles seem more likely to have been mis-sexed than adults, as was also the case for museum specimens of the Golden Eagle *A. chrysaetos* in North America (Bortolotti 1984).

Size variation with age

The mean tail lengths, wing lengths and adjusted mass of males and females (sexed on wing length) of different ages (as determined by colour) are plotted in Figure 2. In both the Nullarbor birds and the museum specimens (of mainland origin), there appeared to be a positive relationship between tail length and age for females but not for males. There was a similar (but less obvious) trend in wing length and adjusted mass. In other words, old females appeared to be larger than young females but old males were no larger than young males. This suggests that either (a) females continue to grow as they age but males do not, which seems

TABLE 1

Measurements of Wedge-tailed Eagles from the western Nullarbor Plain.

Character	Sex	N	Mean	SD	Range	◆ Level of Significance
Wing length mm	M	26	587	10.7	560–605	***
	F	24	638	15.2	610–665	
	?	183	613	29.1	545–670	
Wing span mm	M	26	1 930	35.7	1 840–2 015	***
	F	23	2 090	52.8	1 960–2 185	
	?	135	1 996	89.8	1 780–2 185	
Wing area cm^2	M	12	3 893	223.3	3 678–4 310	**
	F	4	4 376	170.4	4 420–4 580	
	?	15	4 389	471.6	3 818–5 250	
Body length mm	M	5	852	25.4	815–885	***
	F	9	921	23.4	890–950	
	?	43	874	51.8	800–980	
Tail length mm	M	6	370	11.8	355–385	***
	F	6	410	11.8	385–425	
	?	60	384	26.0	345–440	
Mass g	M	23	3 132	341.7	2 300–3 585	***
	F	23	3 800	412.1	3 050–4 750	
	?	167	3 543	542.6	2 450–4 900	
Mass adjusted g	M	23	2 985	264.7	2 300–3 425	***
	F	22	3 748	363.7	3 050–4 450	
	?	141	3 404	500.4	2 450–4 370	
Bill length (BL) mm	M	13	45	2.7	37.5–48.3	***
	F	21	49	1.6	46.3–51.8	
	?	157	47	2.8	36.2–52.7	
Bill depth (BD) mm	M	12	30	0.9	29.0–31.7	***
	F	19	33	1.2	30.7–35.1	
	?	148	31	2.0	21.7–35.5	
Bill width (BW) mm	M	13	18	1.4	15.2–20.4	***
	F	21	20	1.1	18.5–22.3	
	?	158	19	1.5	15.8–22.8	
Bill index	M	12	246	26.3	183–276	***
($L \times D \times W \times 10^{-5}$)	F	19	327	32.5	264–404	
	?	148	285	46.5	145–397	
Cere length mm	M	11	18	1.4	15.0–20.5	*
	F	20	19	1.3	15.8–21.5	
	?	134	18	1.7	12.0–21.8	
Bill length +	M	11	63	3.2	553–670	***
Cere length	F	20	68	2.4	639–723	
	?	134	65	3.8	482–730	

◆ Level of significant difference between sexes (t-tests): * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

TABLE 2

Wing length and bill length measurements for 30 Wedge-tailed Eagles found dead in central New South Wales in 1965.

Measurement	Sex	N	mean	SD	Range
Wing length (mm)	M	13	594	15.4	570–620
	F	17	643	20.8	610–690
Bill length (mm)	M	13	46	1.4	43.0–48.0
	F	17	49	2.1	44.0–53.0

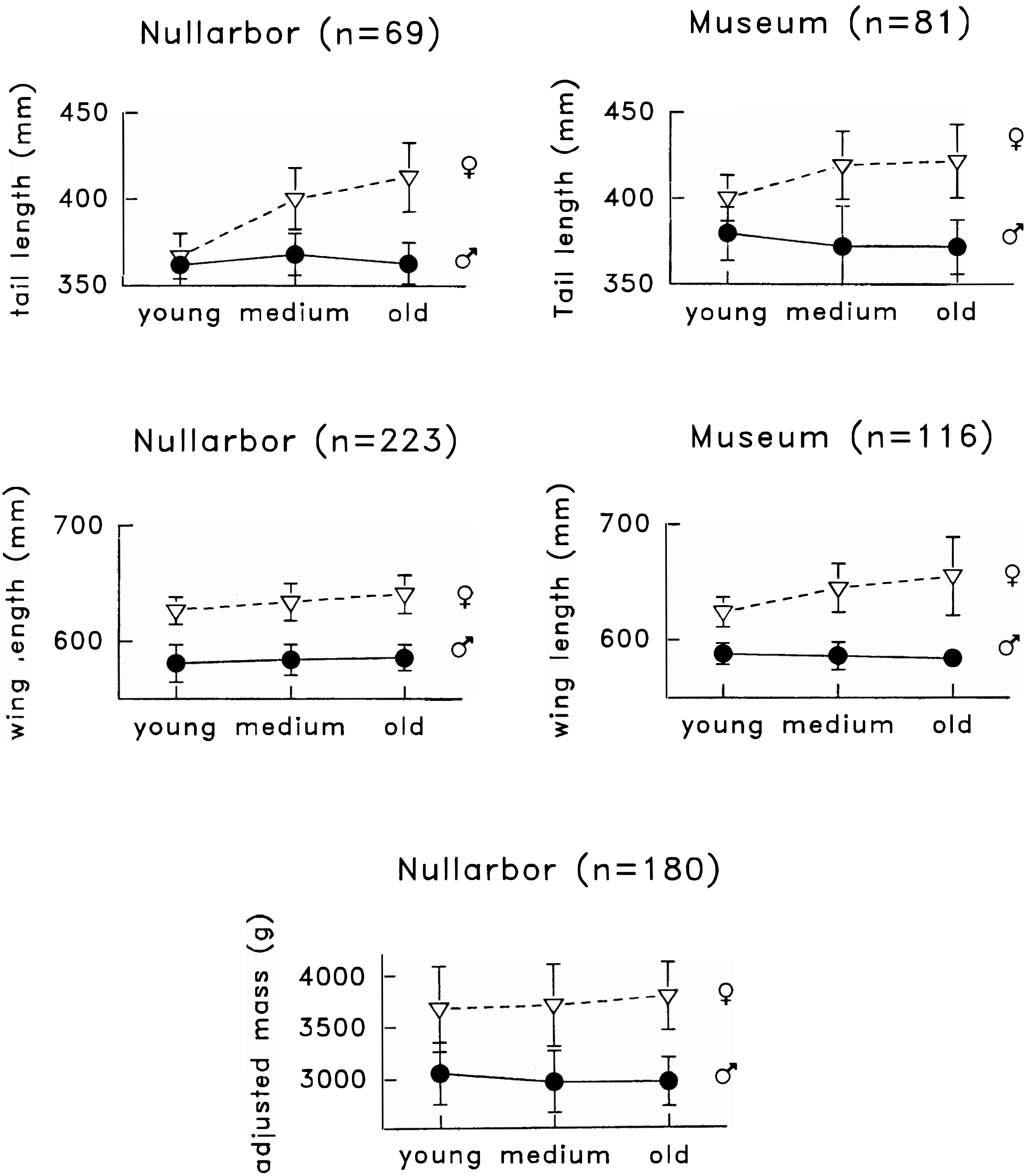

Figure 2. *Mean tail lengths, wing lengths and adjusted mass for male and female Wedge-tailed Eagles (sexed on wing length) of different ages (as determined by colour).*

TABLE 3

Tail (a) and wing lengths (b) for Wedge-tailed Eagles from southern Australia (museum specimens, sex according to label) (SE = south-east mainland Australia; SW = south-west Australia).

(a) Location	Sex	N	Tail Length (mm) mean	SD	Range
SW	M	12	395	20.6	362–425
	F	7	416	15.5	394–435
	?	1	379	—	—
	all	20	402	21.2	362–435
SE	M	30	389	26.8	334–448
	F	22	416	28.0	350–470
	?	4	400	15.9	386–418
	all	56	401	29.2	334–470

(b) Location	Sex	n	Wing length (mm) mean	SD	Range
SW	M	12	601	19.0	575–637
	F	7	634	21.8	610–669
	?	1	590	—	—
	all	20	612	25.2	575–669
SE	M	36	612	28.2	563–666
	F	25	636	29.9	578–694
	?	10	603	25.8	565–640
	all	71	619	30.8	563–694

TABLE 4

The numbers of museum specimens of each sex, comparing the sex allocation given on the label with that obtained from the Nullarbor wing length relationship.

Sex according to label	Sex according to wing length: Juvenile and Immature			Adult			Total
	Male	Female	Indeterminate	Male	Female	Indeterminate	
Male	20	20	6	6	2	2	56
Female	5	23	—	1	6	—	35
Not recorded	9	11	2	1	1	1	25
Total	34	54	8	8	9	3	116

TABLE 5

Aerodynamic indices for Nullarbor Wedge-tailed Eagles (equations according to Mendelsohn *et al.* 1989 and Mueller *et al.* 1981).

	N	mean ± SD	range
Mass loading (g/cm^2) (mass/wing area)	31	0.8 ± 0.09	0.56–0.93
Linear loading ($g^{0.33}/cm$) ($\sqrt[3]{mass}/\sqrt{wing\ area}$)	31	0.2 ± 0.01	0.20–0.25
Aspect ratio A (wing $span^2$/wing area)	31	9.4 ± 0.68	8.30–10.96
Aspect ratio B (total wing $length^2$/wing area)	25	4.2 ± 0.21	3.76–4.70

unlikely; or (b) large females survive better than small females. This second explanation would be consistent with hypotheses of reversed sexual size dimorphism (RSD), in which females are selected for large size because these are the better survivors, while males are selected for small size perhaps for dietary or behavioural reasons (Snyder and Wiley 1976; Newton 1979; Olsen 1995).

Aerodynamic indices

Aerodynamic indices for mass loading, linear loading, aspect ratio A (as in Mendelsohn *et al.* 1989) and aspect ratio B (as in Mueller *et al.* 1981) were calculated for birds with available data (Table 5). No significant differences in the indices were found, either between sexes or between ages in this small sample.

Comparisons with other species of Aquila

A full comparison of *A. audax* measurements with those of congenerics was not possible because either the equivalent data were not available or the sexing was as unreliable as it was in specimens from Australian museums. The measurements most readily available for other species were wing and tail length, which are plotted in Figure 3 as averages for both sexes (all ages combined).

Wedge-tailed Eagles have the longest tails relative to wing length of any species of *Aquila.* Noakes (1993) discussed two possible explanations for this — (a) long tails favour extra manoeuvrability or (b) long tails are a secondary sexual character. Tails are used for steering and manoeuvring, so raptors with 'longer, more graduated' tails tend to be the dense forest species (Brown 1976). However, Wedge-tailed Eagles are found in most habitats in Australia, from forest to near-treeless grasslands and succulent steppes and much of Australia is relatively treeless. An explanation for this apparent inconsistency could be that they evolved as forest species but now fill niches previously occupied by extinct open-country species. During the Pleistocene, Australia had a higher diversity of large raptors than at present, according to Rich and van Tets (1984). On the other hand, if males choose which females to mate with, then choosing a large-looking female (i.e. one with a long tail) may be a cue to the choice of a good survivor.

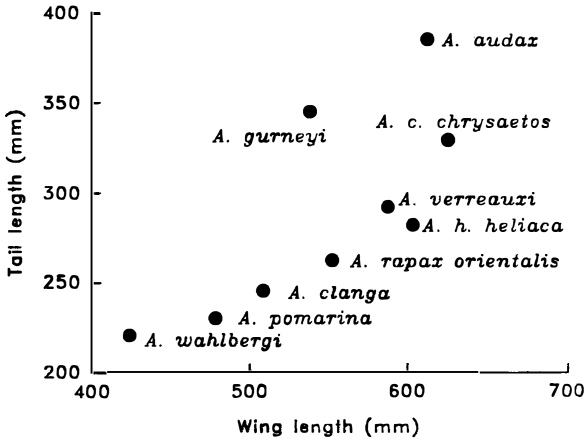

Figure 3. *Mean (sexes combined) wing and tail lengths for eight species of* Aquila *(data from Cramp 1980, Brown and Amadon 1968; R. Simmons, pers. comm. and present study).*

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BOOK REVIEW

Field Guide to the Birds of Australia. Ken Simpson and Nicolas Day. Penguin Books Australia Ltd. Melbourne, 1996. 400 pages, 131 colour plates, $35.00.

Most bird watchers have a preference for one of the three main field guides available for Australian birds. One of the guides has accurate illustrations, concise text and is a convenient size for carrying in a pocket. Another guide has adopted a different approach with small illustrations, extensive text with detailed descriptions of plumage and distribution but it is too large to conveniently carry in a pocket.

Simpson and Day's guide falls somewhere in between. The illustrations in all editions have been excellent and had adequate text but it also was too large to carry in the pocket. However, for bird banders who tend to have different requirements of field guides to bird observers, Simpson and Day is valuable because of the size and quality of the plates as well as often including illustrations of juveniles.

This new edition, the fifth, is the first of the field guides to incorporate the new arrangement of birds as detailed in *The taxonomy and species of birds of Australia and its territories* by Christidis and Boles (1994). Most of the original plates are retained but there are nineteen new plates. Some of the existing plates are modified to show where changes in family relationships have occurred. For example, the Plains Wanderer is now included with the waders but is retained in the plate illustrating quail. This sometimes detracts from the appearance of individual plates and suggests that aesthetics were sacrificed for expediency, to ensure this was the first field guide to contain the new taxonomic arrangement. Of concern in the copy that I reviewed was the colour balance of many of the plates. There was an almost fluorescent glow to the greens and yellows in many of the plates including the orioles and the yellow breasted boatbill. I hope this was just an early production problem and has been corrected in later printings.

The species accounts include a coding system for the abundance of each species. On each of the distribution maps breeding and non-breeding areas are marked; unfortunately these maps are very small and are inadequate for defining the range of the species in the absence of supporting text. At the end of the main section three pages are devoted to rare birds that have been accepted as valid records for Australia. The back of the guide incorporates a summary of the characteristics of each family group of birds and the breeding season of most species. Also included is a concise explanation on the DNA–DNA hybridization technique and how it has changed our understanding of the relationship of many of the world's bird families.

Overall this edition maintains the high standard of previous editions and has the advantage of incorporating the new taxonomic sequence for Australian birds. For those already with a copy of Christidis and Boles (1994) the main value of this fifth edition lies in its new illustrations particularly of juveniles, e.g. the woodswallows. This new edition is unlikely to change your allegiance from one of the alternative guides but birders purchasing their first field guide should find it very satisfactory.

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Graham Fry

Hurstville Grove, NSW