Egg Weight Loss During Incubation in Captive Australian Kestrels *Falco cenchroides* and Brown Goshawks *Accipiter fasciatus*

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Studies of breeding in birds often involve finding and inspecting nests. Because of difficulties in locating and climbing to nests and the problem of repeated disturbance, an estimate of the state of development of any egg found can be useful in estimating hatching date, or alternatively, extrapolating to date of laying. With this in mind we weighed and measured eggs of Australian Kestrel *Falco cenchroides* and Brown Goshawk *Accipiter fasciatus* throughout incubation.

In 1981 and 1982 we bred one pair each of Australian Kestrel and Brown Goshawk; the Australian Kestrels were two different pairs and the Brown Goshawks the same pair in both years. (The Goshawks bred again in 1983.) The Australian Kestrels used a nest-box lined with bark and soil and the Brown Goshawks built their own nest from sticks and twigs left in the pen each day (see Olsen & Olsen 1980, 1981; Olsen *et al.* 1982 for details). The eggs were weighed within 24 h of laying and approximately every 2 days thereafter, at the same time each day, until pipping (i.e. when the chick had pierced the shell). They were measured at laying with calliper to 0.1 mm; weight was taken on a Mettler balance to 0.01 g.

Results and discussion

Egg dimensions

Egg breadth is the least variable measurement of eggs (Bergtold 1929); this was the case in our study (coefficient of variation for egg length 2.1 and egg breadth 2.0 for Australian Kestrels; 4.0 and 1.8, respectively, for Brown Goshawks) (Table 1). The first egg laid was usually the shortest in length (four out of five clutches) and the last tended to be longest (three out of five clutches). The eggs laid in the middle of the clutch tended to be heaviest (five out of five) and greatest in volume (three out of five).

Early laid eggs were rounder than those laid later (first laid egg roundest in four of five clutches) and had the greatest hatchability. All eggs hatched in one clutch, none in another. In the remaining three clutches all first-laid eggs hatched, two second-laid eggs, one third-laid, one fourth-laid and no fifth-laid eggs hatched.

Egg weight

The weight of the egg had no apparent effect on hatchability. The fresh weight of an egg (w) can be calculated from its linear dimensions as $W = K_wLB^2$ where L is egg length, B is breadth and K_w is the species specific weight constant (Hoyt 1979). K_w for Australian Kestrels was significantly smaller than for Brown Goshawks (Table 1, $t = 0.11$, 21 *d.f.*, $P < .01$). The constants were well within the range of values found for other birds (0.527-0.597, Hoyt 1979).

Egg weight loss

The loss of weight during incubation was linear between the start of incubation and pipping for each egg (Fig. 1, Table 2). Some eggs lost weight at a slightly slower rate before incubation started than after and all eggs showed a dramatic decrease in weight once the chick pierced the shell. Daily weight loss was not related to fresh egg weight within each species but was significantly correlated for both species combined ($r = 0.96$, *d.f.* 10, $P < .01$).

Total weight loss (as a percentage) was highly variable between eggs, especially for both Australian Kestrel clutches (Table 3). Eggs that failed to hatch showed similar weight loss to eggs that hatched (6% for both of two Australian Kestrel eggs, 10% and 12% for two Brown Goshawk eggs). Total weight loss over the incubation period (to pipping) was low for Australian Kestrels (10%). Sixteen percent is about average for many birds (Furness & Furness 1981) and 16% was reported for the American Kestrel *Falco sparverius* (Bird & Lague 1982) and Peregrine Falcon *F. peregrinus* (Cade *et al.* 1977). This percentage is common to all species regardless of clutch size, egg weight or incubation period (Drent 1975). However, Bird & Lague (1982) report significant differences in weight loss between years and between first and second clutches. Most last laid eggs in our clutches lost more weight than those laid first (Table 3). This, and Bird & Lague's finding that second clutches lose more weight than the first, suggests that eggs laid later in the clutch or in second clutches may have thinner shells (or a larger total effective pore area) than eggs laid early in the season and therefore

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TABLE 1 Egg measurements for Australian Kestrel and Brown Goshawk. Mean ± *s.d.* (range). K_W (a) is for calculation of weight at laying; K_W (b) for weight at start of incubation.

Australian Kestrel				
Clutch No. (year)	1 (1981)	2 (1982)	Total	
No. of eggs	4	5	9	
Length (cm)	3.69 ± 0.09 (3.57-3.77)	3.79 ± 0.06 (3.72-3.86)	3.75 ± 0.08	
Breadth (cm)	2.99 ± 0.02 (2.96-3.01)	3.09 ± 0.03 (3.06-3.13)	3.04 ± 0.06	
K_W (a)	0.551 ± 0.0047 (0.553-0.556)	0.540 ± 0.0049 (0.532-0.545)	5.544 ± 0.0073	
K_W (b)	0.549 ± 0.0045 (0.543-0.553)	0.540 ± 0.0041 (0.532-0.545)	0.543 ± 0.0074	
Fresh weight (g)	18.14 ± 0.53 (17.39-18.64)	19.51 ± 0.40 (19.07-20.09)	18.90 ± 0.84	
Brown Goshawk				
Clutch No. (year)	1 (1981)	2 (1982)	3 (1983)	Total
No. of eggs	5	4	5	14
Length (cm)	4.75 ± 0.12 (4.58-4.78)	4.62 ± 0.22 (4.33-4.74)	4.76 ± 0.23 (4.43-5.08)	4.72 ± 0.19
Breadth (cm)	3.80 ± 0.08 (3.77-3.88)	3.82 ± 0.08 (4.33-4.82)	3.85 ± 0.06 (3.78-3.93)	3.83 ± 0.07
K_W (a)	0.554 ± 0.0062 (0.547-0.563)	0.554 ± 0.0031 (0.549-0.556)	0.557 ± 0.0038 (0.553-0.563)	0.555 ± 0.0046
K_W (b)	0.551* (0.548-0.554)	0.550* (0.546-0.554)	—	0.551 ± 0.0041
Fresh weight (g)	38.04 ± 1.08 (36.74-39.69)	37.19 ± 1.1 (35.77-38.13)	39.40 ± 2.30 (37.52-43.29)	38.28 ± 1.77

* 2 eggs each year

lose more water. DDT affected raptor populations are known to lay thin shelled eggs (Ratcliffe 1967, 1970); greater weight loss in these eggs than in normal shelled eggs may be a cause of embryo mortality and reduced hatchability.

Our unpipped Australian Kestrel eggs lost between six and 11% of their fresh weight and our Brown Goshawk eggs lost 10-11%. The former values are low compared with a range of 7-22% for the American Kestrel (Bird & Lague 1982) and 12-18% recommended for artificially incubated Peregrine Falcon eggs (Weaver & Cade 1983). Perhaps the kestrel taxon have a greater range of tolerance to egg weight loss than do peregrines. Australian Kestrel eggs lost an average of 2% of their fresh weight in each of the four weeks of incubation and Brown Goshawks lost 3%. These values increase to 3% and 4%, respectively, when the loss includes the sudden drop following pipping. This latter value compares well with 3-4% found for American Kestrels and Peregrine Falcons (Cade *et al.* 1977; Bird & Lague 1982).

TABLE 2 Equations relating fresh egg weight (W) to the number of days from pipping (D, pip day = 0); $r = 1$ in each case. Taken to the day before pipping, i.e. the linear period of weight loss.

	Australian Kestrel	Brown Goshawk
1982	Egg 1 W = 17.91 + 0.04 D	Egg 1 W = 31.37 + 0.14 D
	Egg 2 W = 17.71 + 0.05 D	Egg 2 W = 33.85 + 0.14 D
	Egg 3 W = 18.58 + 0.05 D	
1981	Egg 1 W = 16.14 + 0.04 D	Egg 1 W = 33.83 + 0.14 D
	Egg 2 W = 17.17 + 0.04 D	Egg 4 W = 35.73 + 0.13 D
	Egg 3 W = 17.07 + 0.06 D	
	Egg 4 W = 16.17 + 0.07 D	

Daily loss in weight was between 0.04 and 0.07 g ($\bar{X}$ 0.05 ± 0.01, $n = 7$) for Australian Kestrels and 0.13-0.14,

($\bar{X}$ 0.13 ± 0.01, n = 4) for Brown Goshawks — a steady loss for the individual egg. The equivalent figure for American Kestrels, and large falcons is 0.03-0.05 (Cade *et al.* 1977; Bird & Lague 1982). Large falcons have larger (heavier) eggs than kestrels and the Brown Goshawk is intermediate. This suggests a possible genus-specific daily weight loss, that is, that *Accipiter* eggs lose weight more rapidly than those of falcons (genus *Falco*). Because weight loss can be a predictor of metabolic rate (Rahn *et al.* 1974) this difference between genera may be related to the rate of development of the embryo and *Accipiter* embryos may develop faster than those of *Falco.* Accipiter chicks do appear to be better developed (more mature) at hatching than do those of falcons and grow faster (Olsen & Olsen unpubl.). This is consistent with Lack's (1968) suggestion that the easiest or perhaps the only way to evolve a particular growth rate of young is to alter the whole rate of development including that of the embryo.

Attempts to estimate the stage of incubation of an egg from its linear dimensions and weight have not yielded accurate predictions (e.g. Furness & Furness 1981; Saunders & Smith 1981). We found no correlation between daily weight loss and fresh weight of the egg or any other measure of size or volume. Because of this and the large but unpredictable (in terms of egg measurements) variation in weight loss shown in Figure 1, we abandoned attempts to calculate an accurate predictor of day of incubation (and therefore day of hatching). A rough estimate can be made by first estimating the weight of the egg at the start of incubation using the formula $W = 0.543\ LB^2$ for Australian Kestrels and $W = 0.551\ LB^2$ for Brown Goshawks. Then,

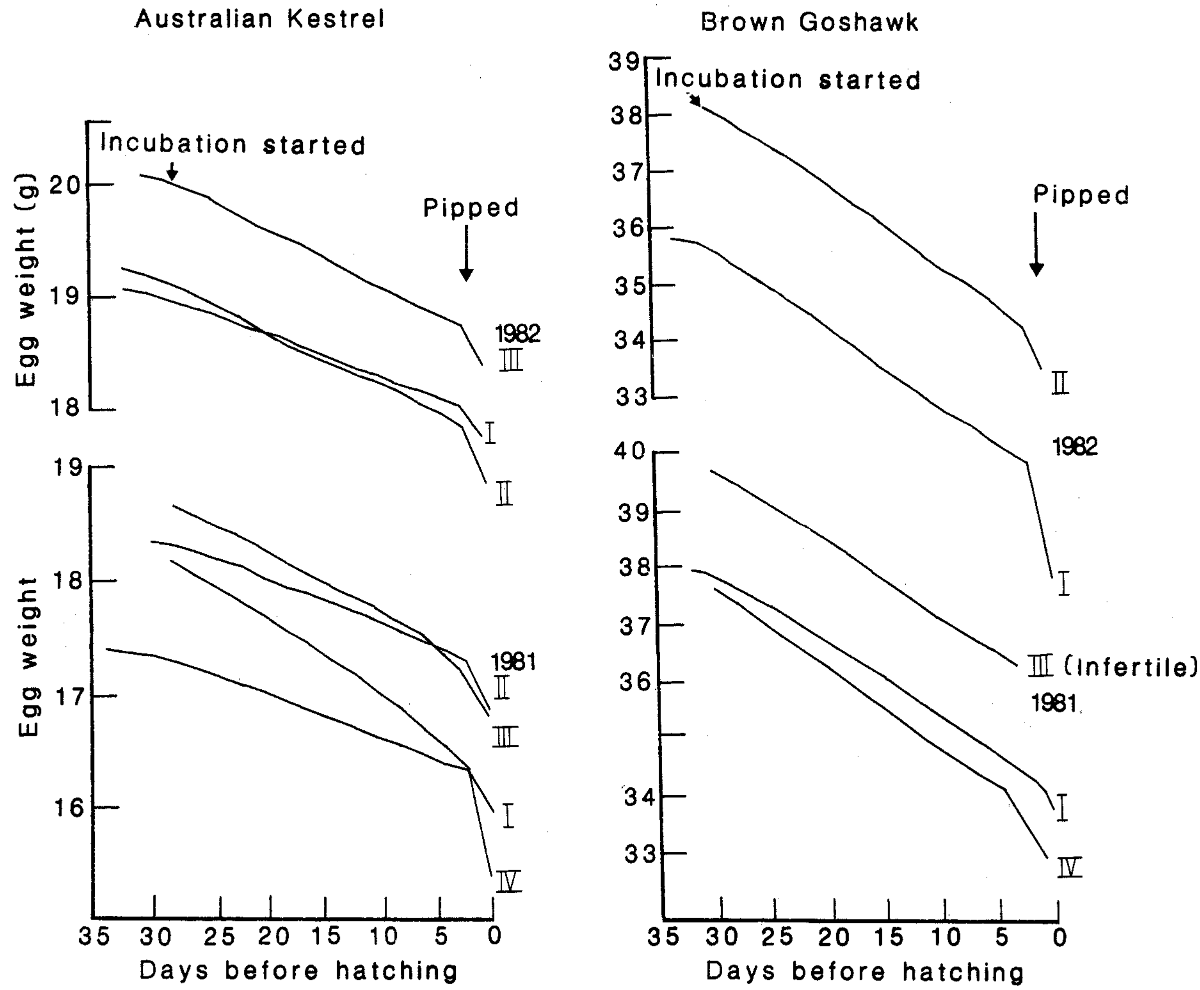

FIGURE 1 Relationship between egg weight and number of days before pipping for seven Australian Kestrel eggs (from two clutches) and four Brown Goshawk eggs (from two clutches) that produced chicks.

TABLE 3 Weight loss of individual eggs in 2 clutches each of Australian Kestrel and Brown Goshawk, as a percentage. c (coefficient of variation) = 100 × ($s.d./\bar{X}$). Only eggs that hatched are included.

Period	Australian Kestrel 1982				1981			$\bar{X} \pm s.d.$	c	Brown Goshawk 1982		1981		$\bar{X} \pm s.d.$	c
Laying to pipping*	7	10	9	9	9	14	16	10.57 ± 3.21	30	17	—	—	—	—	
Laying to before pipping	6	8	7	7	6	8	11	7.57 ± 1.72	23	11	11	10	11	10.75 ± 0.50	5
Start of incubation to pipping*	7	10	9	8	8	14	16	10.29 ± 3.46	33	17	—	—	—	—	
Start of incubation to before pip	5	7	7	6	6	10	11	7.43 ± 2.23	30	11	11	10	11	10.75 ± 0.50	5

* the incubation period was 28 days for Australian Kestrels and 30 days for Brown Goshawks; this figure includes water loss due to pipping.

the number of days before pipping = 28 - [(W - weight when found)/0.05] for Australian Kestrels and 30 - [(W - weight when found)/0.14] for Brown Goshawks. However, it must be born in mind that the error was as high as five days in our small sample.

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