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Estimating the age of Corncrake *Crex crex* chicks from body weight and the development of primary feathers

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Two methods for ageing Corncrake *Crex crex* chicks are described. Data on the body weight of chicks of known age, from broods of radio-tagged females, were used to produce a formula for determining the age of chicks of unknown age. This method was, however, prone to error for chicks older than about 22 days after hatching. An alternative method, based on the ratio of the length of the waxy sheath on a primary feather to the maximum chord wing length, was developed using measurements of captive-bred chicks of known age. This method performed well for chicks aged 22-45 days old, but required testing on wild chicks before application because of possible effects of captive rearing. Estimates of the age of wild chicks from both weight and primary development indicate that the two methods gave similar results and, hence, that the latter method was useful for chicks older than 22 days.

Determination of the timing of breeding is important in studies of the conservation of Corncrakes *Crex crex*, because the relative timing of breeding and grass mowing has strong effects on breeding success and population status (Green 1996, Green *et al* 1997). Timing of breeding can be ascertained by estimating hatching dates from the apparent ages of chicks seen or captured in the field. The age of chicks can be judged from the general appearance of the developing plumage (Broyer 1995, Deceuninck *et al* 1997, Salzer & Schäffer 1997), but it is difficult to do this repeatably and to know how accurate it is. Chicks can also be aged from measurements of body weight or linear dimensions, but some measurements increase to near the fully grown value at an early age and then level off (Salzer & Schäffer 1997). This means that ages of chicks more than 15-20 days estimated from all or most measurements are subject to substantial error. This paper reports a method for ageing wild Corncrake chicks younger than about 22 days from their body weights and for older chicks (22-45 days old) from a measurement of the state of development of their primary feathers.

METHODS

Captive-bred birds

A captive population of Corncrakes is maintained at the Zoological Society of London's Whipsnade Wild Animal Park (WWAP) near Dunstable, Bedfordshire, England. This population was founded from a breeding population kept in private aviaries at Mörtitz, Germany, which in turn was founded from injured wild birds collected in Germany and Poland. Corncrake chicks bred at WWAP in 2002, 2003 and 2004 were individually marked with rings so that individuals of known age could be measured. Most of the chicks were hand-reared by keepers at WWAP until they were about 14 days old, though a few were reared to this age by their mothers. They were then transferred to open-air aviaries at the Nene Washes, Cambridgeshire, England where they were fed on commercial high protein chick crumbs and insects. Measurements of these chicks were made before they were released as part of a reintroduction programme.

Wild Corncrake chicks of known age in Scotland and Ireland

Adult female Corncrakes were captured and radio-tagged before egg-laying and tracked to locate nests. Hatching dates of the broods of radio-tagged females were determined and their chicks were captured by radio-locating the mother, pegging a mist net to the ground about 20 m away and then driving the chicks into it. Details are given in Green *et al* (1997) and Tyler & Green (2004). Fifteen broods were captured and measured on the Isle of Coll, Argyll, Scotland (56° 36'N 6° 37'W) in 1994 and one brood on the Shannon Callows (floodplain of the River Shannon), Co Offaly and Co Roscommon, Republic of Ireland (53° 13'N 7° 58'W), in 1992.

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Wild Corncrake chicks and juveniles of unknown age in Scotland

Corncrake chicks were caught on the Isle of Coll in August-September in each year between 1998 and 2003 by driving them into cage traps set with drift fences of rigid plastic netting. Birds were aged as chick or juvenile if they had greyish green irides (Salzer & Schäffer 1997).

Measurements

Corncrakes were weighed to the nearest gram with a spring balance, the maximum chord wing length was taken to the nearest millimetre with a stopped metal ruler (Redfern & Clark 2001) and the length of the waxy sheath at the base of the 7th primary (numbered descendently, from proximal to distal) was measured. This measurement was taken between the proximal end of the sheath where it meets the skin and the distal end where the growing feather emerges and was either taken to the nearest millimetre with a metal ruler (wild birds) or to 0.1 mm with dial callipers (captive-bred birds).

Model of the weight of wild chicks in relation to age

Weight data were used from 67 measurements of wild chicks from 16 broods of known age from the Isle of Coll and the Shannon Callows and 25 wild juveniles with no waxy sheath on their primaries from Coll. Following Tyler & Green (2004), a Gompertz model was fitted with its asymptote fixed at 168.91 g, which is the mean weight of fully grown juveniles on Coll as estimated in their study. The Gompertz model is one of several different mathematical models used to describe the growth of birds. Others include the logistic and von Bertalanffy models. All of these give a sigmoid (S-shaped) relationship between size or weight and age, but they differ slightly in shape and particularly in the size at which the maximum growth rate occurs. To fit their model, Tyler & Green used non-linear least squares regression and the mean weight and age of the chicks in each brood as an independent datum. However, for the current application, information was required on variation of the weight of individual chicks, so this method was not appropriate. Instead, the Gompertz model was fitted by a maximum-likelihood method using the weight W and age AGE of a chick as an independent datum, including multiple weighings of the same chick (Eq 1):

$$W = 168.91 \times \exp(V \times \exp(-K \times AGE)), \qquad \text{(Eq 1)}$$

where K is the slope and V is the logarithm of the mean weight of a newly hatched chick as a proportion of the asymptotic weight.

Weights of individuals were assumed to be normally distributed about the expected mean weight at a given age E(W), but it was considered plausible that the standard deviation D describing this variation could vary with age. This variation was modelled as a power law function of expected weight (Eq 2):

$$D = Q \times \mathrm{E}(W)^R, \qquad \text{(Eq 2)}$$

where Q and R are constants. Note that if $R = 1$, the coefficient of variation of weight D/E(W) is constant with respect to age. Estimates of V, K, Q and R were obtained by maximising the log-likelihood of the observed weight and age data under the model specified above using the NONLIN module of SYSTAT (SYSTAT Software Inc, Point Richmond, CA, version 5.03). The 25 wild juveniles with no waxy sheath on their primaries from Coll, which were of unknown age, were taken to be 60 days old, since they were likely to have been from first broods hatched in mid-June (Green *et al* 1997) and were mostly captured in mid-August. For illustrative purposes, the boundaries of the interquartile range of weights at a given age, ie the bounds including the weights of the central 50% of chicks, were calculated as E(W) ± 0.6745 x D.

Model of the relationship between feather development and age

It was intended to apply the ageing technique developed using data from captive-bred Corncrakes from a stock derived from wild birds from Poland and Germany to wild birds in Scotland. Mean wing length, other linear dimensions and weight are larger for birds from Scotland/Ireland than Germany/Poland (RE Green, unpublished data). To allow for this, the length of the waxy sheath was expressed as a proportion of the maximum chord wing length to give the ratio *WAX / WNG*. The relationship between *WAX / WNG* and age was modelled using a variant of the method of Underhill & Zucchini (1988). This approach, rather than least squares regression, was necessary because, like the moult scores for which Underhill and Zucchini's method was developed, *WAX / WNG* is a bounded variable which cannot be less than zero. As is the case for birds observed with moult scores of zero that may not begin to moult for many weeks, observations of *WAX / WNG* = 0 do not imply that the chick has just lost the last wax from its primaries at the exact time at which it was measured; it might have done so much earlier. Least squares regressions fitted to such data tend to give unrealistic results when used for prediction. The age at which *WAX / WNG* reached zero was assumed to follow a normal distribution defined by mean m and standard deviation s, *WAX / WNG* was assumed to change at a constant linear daily rate b with age for all chicks. The log likelihood of the observed values of *WAX / WNG* for specified values of m, s and b was calculated from the probability density function and cumulative probability function of the normal distribution. The set of parameter estimates that maximised the log likelihood of the data under this model was obtained by a quasi-Newton method using the NONLIN module of SYSTAT. Asymptotic standard errors of m, s and b were obtained from SYSTAT. An alternative method for the estimation of b was to calculate the mean daily rate of change of *WAX / WNG* for each of 16 captive-bred chicks that were remeasured after intervals of four to 15 days. Two chicks with *WAX / WNG* = 0 when the second measurement was made were excluded from this calculation because their waxy sheath could have disappeared before they were measured.

RESULTS AND DISCUSSION

Relationship of mean weight to age derived from data from wild chicks of known age and individual variation about the mean

The Gompertz model relating mean weight to age was similar to that fitted previously to the same data using a different method (Tyler & Green 2004). Parameter estimates were $V = -3.015$, $K = 0.08747$, $Q = 0.718$, $R = 0.617$. Since $R < 1$ the coefficient of variation (standard deviation as a proportion of the mean) declined with age, but in absolute terms individual variation in weight increased with age (Fig 1).

Estimating age from weight

Rearranging the Gompertz equation gives the following formula for estimating the age of a chick of unknown age from its weight (Eq 3):

$$AGE = -\log_e(-(\log_e(W/168.91)/3.015))/0.08747 \quad \text{(Eq 3)}$$

Applying this formula to the data for chicks of known age from Coll and the Shannon Callows gives a mean absolute error of estimated age of 1.3 days (maximum error 5.9 days). However, it is expected that this good performance in estimating the age of relatively young chicks (91% of the sample were less than 20 days old) would not be achieved for older chicks. Fig 1 shows that, whilst the estimated ages of 15 day old chicks with typical levels of departure from the mean weight would only be in error by about one day, the equivalent error for 35 day old chicks would be five to seven days. The same problem in ageing old chicks can be expected for any measurement that begins to level off at an early age and has considerable variation about the mean. The

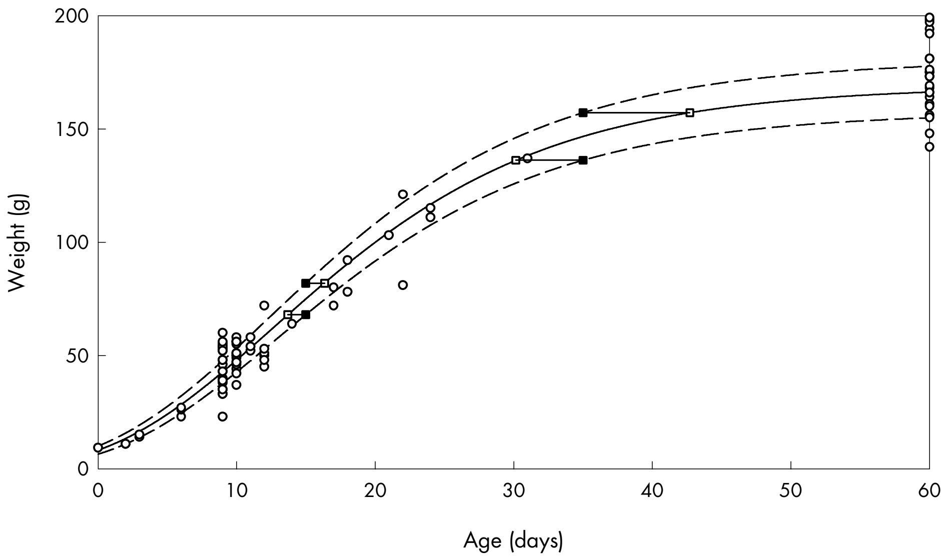

Figure 1. Fitted Gompertz relationship (solid curve) between the mean weight of Corncrake chicks and age $W = 168.91 \times \exp(-3.015 \times \exp(-0.08747 \times AGE))$. Observed weights of wild chicks of known age up to 31 days old and of wild juveniles with no waxy sheath on their primaries (plotted at 60 days old) are shown by open circles. Dashed curves show the upper and lower bounds of the modelled interquartile range (see text). Filled squares show the sizes of four hypothetical chicks at the interquartile range bounds above and below the mean at 15 and 35 days old. If the true age of these chicks was unknown, but ageing was attempted using the growth curve, the estimated ages would be given by the open squares. True and estimated ages for the same chick are joined by horizontal lines. It can be seen that ageing errors are small for typical 15 day old chicks, but become much larger for 35 day old chicks.

mean lengths of the middle toe, tarsus and combined head and bill reach 90% of their asymptote at 15, 19 and 20 days old respectively and vary about the fitted curve about as much as weight (Salzer & Schäffer 1997). Because these measurements approach the asymptote at a much earlier age than weight, which reaches 90% of the asymptote at 38 days (Fig 1), they are even less suitable than weight for ageing old chicks. What is needed to age older chicks accurately is a measurement that changes rapidly with age until the chick is fully grown and shows modest variation about the fitted curve. Measurements of the developing primaries seem good candidates for this because they are very small until the chick is about 18 days old (Salzer & Schäffer 1997) and then emerge from their waxy sheaths and elongate rapidly from about 22 days old. However, the maximum chord wing length of captive-bred chicks starts to level off at about 30 days old (RE Green unpublished data), whereas the ratio of the length of the waxy sheath to wing length changes rapidly until wing feather growth is complete. The following sections evaluate the use of this measurement for ageing.

The relationship between 7th primary waxy sheath: wing length ratio and age

The use of the 7th primary waxy sheath: wing length ratio for ageing could not be evaluated for wild chicks of known age because they could only be readily caught while they were dependent on their radio-tagged mothers. Hence, too few were caught in the age range (over 22 days) in which the ratio can be measured. Therefore, the method was evaluated using measurements of captive-bred chicks. The waxy sheath diminished in length during development because of progressive loss of small fragments of sheath from its distal end (Fig 2). The estimates of the mean and standard deviation of the age at which the waxy sheath disappeared were m = 44.92 days (SE = 2.37) and s = 2.75 days (SE = 0.67). The daily rate of change b of *WAX / WNG* was estimated at -0.01518 day^{-1} (SE = 0.00202). It should be noted that the model used is not ideal because it assumes that *WAX / WNG* changes with age at the same rate for all chicks. This assumption is biologically unrealistic, but a more elaborate model with variation in rate among birds is more difficult to fit and is unlikely to give markedly different estimates of the main parameters of use for ageing, m and b. The alternative estimate of b based on rates of change of *WAX / WNG* of chicks measured twice was –0.01740 day^{-1} (SD = 0.00872, SE = 0.00218). The rates estimated by the two methods are not significantly different (small sample test with unknown variances not assumed equal (Bailey 1995); d = 0.25, P > 0.80).

Estimating the age of chicks from *WAX / WNG*

Rearranging the formula in Fig 2 to calculate age from *WAX / WNG* gives Eq 4:

$$AGE = 44.922 - 65.876 \times WAX / WNG \qquad \text{(Eq 4)}$$

Obviously, a chick with *WAX / WNG* = 0 cannot be aged, other than to say that it is most likely to be more than 45 days old. Applying this formula to the data from which it was obtained and excluding chicks with *WAX / WNG* = 0, the mean absolute error of estimated age was 2.1 days (maximum error 8.8 days). Although this indicates that the performance of the method would be satisfactory for ageing wild chicks, this might not actually be the case because it was developed using data from captive-bred chicks fed on a partly artificial diet and which might therefore grow differently from wild chicks. In addition, the captive-bred chicks were from a breeding stock that originated from Poland and Germany, whereas the current application of the method is for ageing wild chicks in Scotland and Ireland. Although using the ratio of the length of the waxy sheath to the wing length should allow for geographical differences in the asymptotic means of linear measurements, there might also be differences in growth rate between populations. For these reasons we devised a test of the *WAX / WNG* method on wild chicks from Coll.

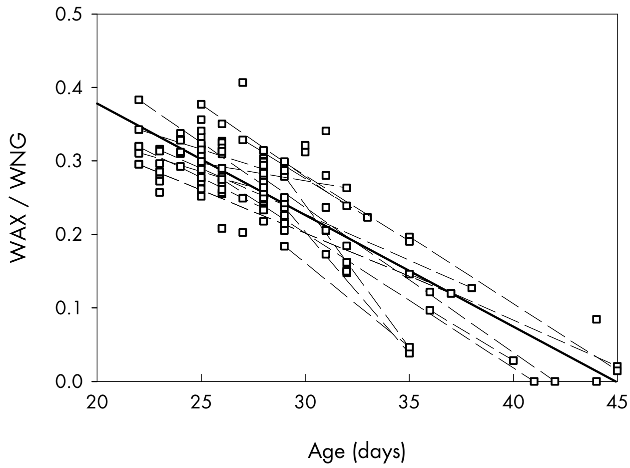

Figure 2. Relationship between the ratio of the length of the waxy sheath on the 7th primary to the maximum chord wing length and the age of 128 captive-bred corncrake chicks measured on 146 occasions. Dashed lines join pairs of measurements of the same bird. The solid line shows the fitted relationship *WAX / WNG* = 0.6819 – 0.01518 x *AGE*. See text for details of the statistical model.

Comparison of age estimates from the 7th primary waxy sheath: wing length ratio with estimates from weight for the same wild chicks

The test of the applicability of the *WAX / WNG* method on wild chicks exploits the fact that the ageing method based upon weight and developed using data from wild chicks of known age from Scotland (including one brood from Ireland) can be applied to chicks of unknown age up to about 140 g in weight with errors that are expected to be moderate (Fig 1). The *WAX / WNG* method can also be used on the same chicks if their primary feathers have begun to emerge from the sheath. In practice, this means that both methods can be used on chicks in an approximate age range of 22-32 days. Comparison of the two methods for 34 eligible wild chicks of unknown age captured on Coll in 1998-2003 showed that the means of the estimated ages given by the two methods were similar (*WAX / WNG* method mean = 28.9 days, SE = 0.9; weight method mean = 27.6 days, SE = 0.6). The difference between the two methods was not statistically significant (matched pairs *t* test, $t_{33} = 1.62$, $P = 0.12$). There was a highly significant correlation between the estimates given by the two methods ($r_{32} = 0.556$, $P = 0.001$). Although the correlation coefficient is not particularly high, it should be born in mind that typical errors in the age estimates based on weight for the older chicks in the sample are likely to have been about four days (Fig 1), which would reduce the strength of the correlation. The relationship between the two sets of estimates is close to that expected if the methods were essentially equivalent (Fig 3).

Recommendations

It is recommended that Corncrake chicks in Scotland and Ireland are aged using the relationship between weight and age derived from wild chicks of known age until their primaries have begun to emerge from the waxy sheaths. From this stage onwards, chicks should be aged using the 7th primary waxy sheath: wing length ratio. Birds with no waxy sheath on the primaries cannot be aged reliably by either method. For chicks of about 22-32 days old, an average of estimates from the two methods could be used, but this should probably be weighted to allow for the differences in precision between the two methods. The method based on the 7th primary waxy sheath: wing length ratio is expected not to be affected by geographical variation in size, but geographical differences should be allowed for when ageing chicks from their body weight. There is a general problem in ageing more than half-grown chicks of precocial bird species from measurements of dimensions that approach an asymptotic value slowly with increasing age. Therefore, methods based on the length of the waxy sheaths on remiges might be useful for a wide range of species.

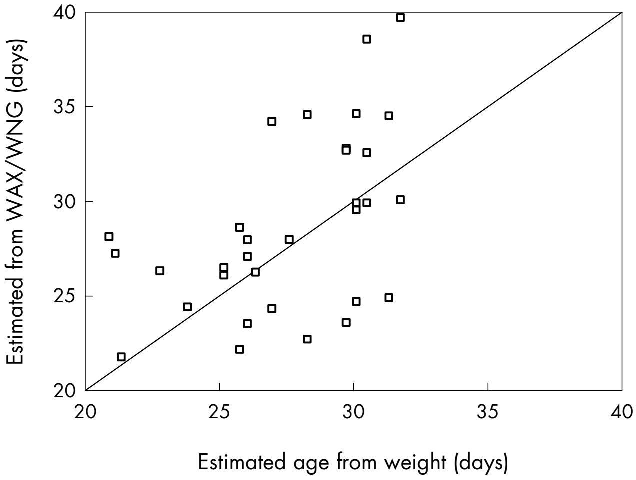

Figure 3. Comparison of two ageing methods for 34 wild Corncrake chicks of unknown age captured on the Isle of Coll, Argyll. Each chick was aged using both its weight and the ratio of the length of the waxy sheath on the 7th primary to the maximum chord wing length (*WAX / WNG*). Points show the two age estimates for each chick. The line shows the relationship expected if the two age estimates were the same.

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