Table 1. Formulae for estimating days to hatching (D) from W/LB^2 measurements (in g and mm).

Species	Formula	r	Error S.D. (days)	Mean error (days)	N (nests)
Common Snipe	$D = 325945\ W/LB^2 - 145$	0.821	3.23	2.54	82
Redshank	$D = 446508\ W/LB^2 - 197$	0.821	3.92	3.13	48
Black-tailed Godwit	$D = 382819\ W/LB^2 - 165$	0.829	4.18	3.24	8
Lapwing	$D = 321337\ W/LB^2 - 133$	0.924	3.21	2.18	25

Nomograms

Simple nomograms are diagrams for carrying out addition and subtraction. They are drawn in such a way that joining values on two parallel scales with a straight line gives the required quantity where the line crosses a third scale midway between the first two. If the scales are logarithmic they can be used for multiplication and division. For estimating the stage of incubation I used two overlapping logarithmic nomograms. The first nomogram calculates LB^2 and the second uses this result and W to calculate D. Fig. 1 gives instructions for using the nomograms and Figs 2–5 show nomograms for Snipe, Redshank, Lapwing and Black-tailed Godwit. A copy of the nomograms can be covered with adhesive-backed transparent plastic film and inserted into a field notebook. The diagram can then be marked with a water-soluble overhead projector pen and wiped clean after each use. Nomograms used over 100 times are still in good condition. Estimating D from measurements on nest record cards (four egg clutches) took me an average of 41 second per clutch (range 34–48 N=10) using a nomogram, compared with 40 second per clutch (range 38–42, N=10) using a micro-computer.

A good alternative method for estimating the incubation stage of wader eggs, which can give an instant result in the field, is to judge the degree of flotation of eggs in water in a transparent container (see Paassen *et al.* 1984). This method is accurate and quick in experienced hands, but if eggs are being weighed and measured for other reasons then the use of the W/LB^2 nomogram will probably save time and inconvenience.

Acknowledgements

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The prediction of hatching dates of Lapwing clutches

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Introduction

In breeding studies of precocial species where the young leave the nest soon after hatching, and may become difficult to find, it is useful to be able to predict hatching dates from egg measurements. Furness & Furness (1981) developed a technique based on the reduction in egg density resulting from water loss during incubation, and showed that the hatching dates of Great and Arctic Skuas (*Catharacta skua* and *Stercorarius parasiticus*) could be predicted with respective mean errors of only 1.4 and 1.9 days. Again using change in egg density, Green (1984) presented nomograms intended for use in the field to predict the hatching dates of Redshank *Tringa totanus,* Snipe *Gallinago gallinago*, Lapwing *Vanellus vanellus* and Black-tailed Godwit *Limosa lapponica* clutches. He also showed that an index of egg density was similarly related to time to hatching in three widely separated Redshank populations. This note demonstrates, however, that inter-population differences in patterns of egg weight loss may restrict the applicability of Green's Lapwing nomograms.

Methods

Data was gathered from three sites and in two different years: Cambridgeshire in 1982 (the data used for the construction of Green's nomogram, with the addition of five reweighings), and two separate Stirlingshire populations in 1984. The Cambridgeshire study area lies at sea level and comprised poorly drained meadow land. One Stirlingshire site comprised arable farmland at 15 m above sea level whilst the other was an area of poorly drained rough grazing at 180 m (hereafter referred to as the arable and rough grazing sites respectively).

Egg lengths and breadths were measured to the nearest

0.1 mm using vernier calipers and weights were recorded to the nearest 0.1 g using Pesola spring balances (which were regularly calibrated throughout the study period). An index of mean egg density was calculated for each clutch from: (mean weight/mean length × mean breadth (W/LB^2) × 10^2. Nests were checked at 5–7 day intervals and those with known hatching dates (for criteria see Green (1984)) chosen for analysis.

Results

A regression of mean egg density against days till hatching revealed differences between populations in patterns of weight loss (Fig. 1). Covariance analysis showed that, whereas there were no significant differences between the Stirlingshire arable and Cambridgeshire clutches in either slope ($F = 0.224$) or elevation ($F = 2.669$), the Stirlingshire rough grazing clutches differed significantly from both the arable ($F_{slope} = 4.966$, $p < 0.05$; $F_{elevation} = 2.878$, n.s.) and the Cambridgeshire clutches ($F_{slope} = 3.847$, $p < 0.1$ (n.s.); $F_{elevation} = 8.204$, $p < 0.01$).

Although statistically correct, the similarity in slope and difference in elevation obtained in the last result is misleading because when the lines are plotted (Fig. 1) it is obvious that all populations are similar in the value of $(W/LB^2)10^2$ at 28 days from hatching but the clutches from rough grazing lose weight more slowly than the others. The reason for the misleading result of the ANCOVA is that an elevation can be estimated more precisely than a slope from a given body of data.

Fig. 1 shows that close to hatching a prediction of hatch date based on the Cambridgeshire data (from which the nomogram in Green (1984) is derived) would give a reasonable estimate for the arable clutches but would over-estimate by approximately 8 days for the rough grazing clutches.

A more generally applicable predictor of hatch dates might be obtained by regressing the days till hatch (y-axis) against density. This is statistically more valid than rearranging the regression of density on days till hatch. However, when the former is carried out and the deviation from the regression is calculated for each clutch it is found that the predictor is an under-estimate in recently completed clutches and an overestimate closer to hatching (Fig. 2). When density (y-axis) is plotted against days till hatch there is no significant correlation between deviations from the combined regression and days till hatch ($r = -0.03$, $p < 0.05$). Density plotted against days till hatch gives, therefore, a more accurate prediction at all stages of incubation. Green (1984) found that this was also the case for Snipe and Redshank.

By manipulating the combined regression equation of density against days till hatch we obtain the predictor equation: days till hatch = $374532W/LB^2 = 161$ with an overall mean deviation of 3.3 days.

Discussion

It seems that differences exist between populations and the nomogram in Green (1984) is inadequate for predicting hatching dates in the clutches on rough grazing (except nests found soon after clutch completion). Its general applicability must be questioned.

Van Paassen *et al.* (1984) found that, in the Netherlands, Lapwing eggs attained neutral buoyancy in water (specific gravity 1) eight days after the start of incubation. Assuming an initial specific gravity for Lapwing eggs of 1.059. (Paganelli *et al.* 1974) the day of incubation on which neutral buoyancy is attained can be predicted from the regression given in Fig. 1 as: Cambridgeshire 9.7 days, Stirlingshire

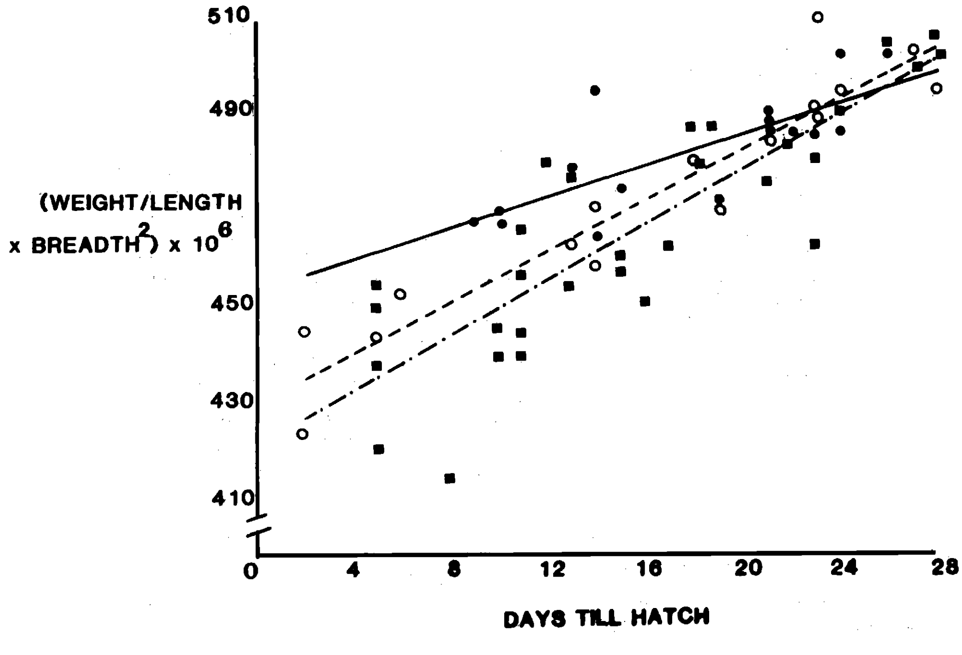

Figure 1. Reduction in mean egg density during incubation.
●—— = Stirlingshire rough grazing clutches (n = 16, $W/LB^2 \times 10^2 = 1.682D = 453.9$)
O – – – = Stirlingshire arable clutches (n = 16, W/LB2 × 102 = 2.634D = 432.0)
■ –·–·– = Cambridgeshire clutches (n = 30, $W/LB^2 \times 10^2 = 2.852D = 422.7$).
Combining regression equation: n = 62, $W/LB^2 \times 10^2 = 2.670D + 429.5$ where D is days to hatching.

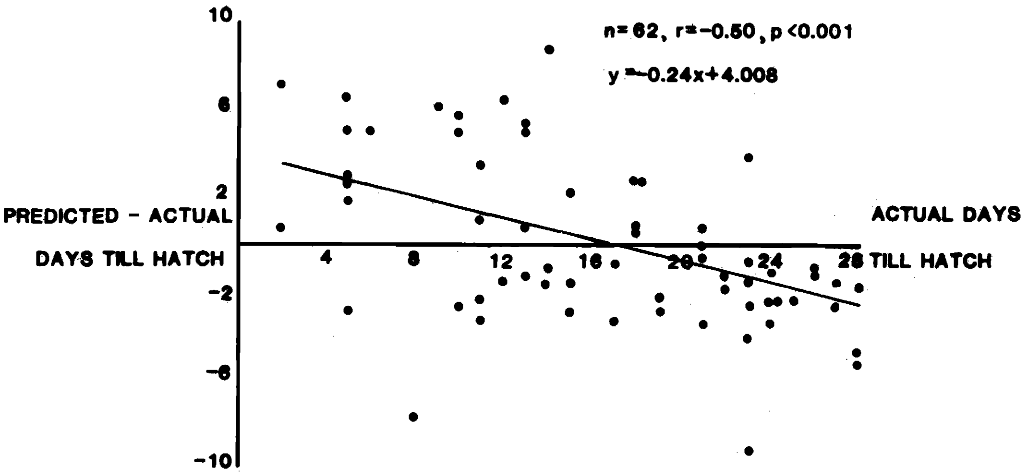

Figure 2. Difference between actual days till hatch and value predicted by regressing days till hatch against W/LB^2 × 10^2.

arable 10.6 days, and Stirlingshire rough grazing 16.5 days.

Hence the results for Stirlingshire rough grazing appear to be markedly different than those from lowland areas. It is worth noting that by applying the same procedure to the data on Black-tailed Godwit clutches in Table 1 of Green (1984) it is predicted that the eggs of this species should attain neutral buoyancy 10.9 days after the start of incubation, which is close to the 11 days reported by Van Paassen *et al.* (1984).

A new nomogram based on the equation $D = 374532\ W/LB^2 - 161$ is likely to be a more generally applicable predictor of hatching dates than the previously published Lapwing nomogram. Caution should, however, be exercised in its use for two reasons. First, if inter-population differences in egg weight loss patterns are widespread then there is no assurance that the equation will give unbiased estimates for any given population. Second, even if the populations being investigated do conform to the equation, any estimate of days till hatching will be, on average, three days out. For this second reason it may be advisable to visit each nest at least three–four days before the predicted hatch date and base the timing of further visits on whether or not the eggs show any signs of hatching (eggs which are "starred" will normally hatch within two–three days). In this way, precise hatching dates should be obtained for most broods.

Why should the rough grazing clutches lose weight more slowly than the arable or Cambridgeshire clutches? Possible answers include explanations based on the 160 m difference in altitude (with associated differences in climate) or the incubation behaviour of the adults. On seven occasions during February–late April 1984 air temperatures were recorded to the nearest 1.0°C within 20 minutes of each other at the arable and rough grazing sites. The rough grazing site was, on average, 2.1°C colder (s.d. = 1.463), and it is likely that wind-strengths and rainfall were higher. The possibility of ambient temperature and rainfall affecting egg weight loss was investigated for the Cambridgeshire and Stirlingshire arable sites, from which there were daily temperature and rainfall records. A model in which daily weight loss was a linear function of maximum day temperature and daily rainfall was fitted by least squares but indicated no significant effect of temperature ($t_{39} = 0.20$) or rainfall ($t_{39} = 0.46$). Neither was there any significant effect when these two variables were assumed to operate alone. This analysis does not however, rule out the possible effects of micro-climatic differences in the immediate area of the nest.

Similar analyses for other sites and species would be useful in establishing the extent and causes of inter-population variation.

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