ONLINE APPENDICES

APPENDIX I: model construction

A random-walk model was constructed in Visual Basic 6. Each step of the random walk represents a single daily movement, the direction of which is chosen at random (0-360º) since no directional biases in daily movement were detected in the mark-recapture data (figure 1a). The distance of each daily movement is randomly selected according to a gamma probability distribution that is derived as a function of temperature (see below). The model is based solely upon the adult life of the species since only adults can fly and the dispersal of nymphs is found to be very limited (Richards and Waloff 1954). Random-walks were conducted for 37 days, the mean adult life-span recorded in the field of the closely related species *C. brunneus* (Richards and Waloff 1954).

To choose an appropriate probability distribution (PD) for within-individual variability in daily movement we firstly plotted the standardised residuals of relative daily movement among individuals regressed against maximum daily temperature within the grass sward. The frequencies of these residuals showed a right-skewed distribution similar to a three-parameter PD. To confirm that a standard two-parameter PD such as the exponential or standard lognormal distribution would not be a more parsimonious choice the coefficients of variation (CoV) for relative movement were calculated for each day and were compared with the predicted CoV values calculated using the observed means. An exponential distribution is characterised as having a constant CoV of 100% which is significantly different to the observed value of 76.8% ± 4.2 (mean ± 1SE: one sample t-test: $t_{18} = 5.497$, $P < 0.001$). Similarly the predicted CoV values (of ln-transformed values) calculated using observed means on a given day assuming a standard log-normal distribution were significantly greater than that observed (mean ± 1SE: 125.9 ± 16.5 versus 23.1 ± 1.8, paired t-test, t_{18} = 6.713, $P < 0.001$). A three-parameter PD was therefore necessary. The inherent flexibility of three-parameter PDs in general mean that the probability distribution of within-individual variation with temperature can justifiably be modelled using a number of different PDs. However, as the CoV of relative movement among days was neither related to mean relative movement on a given day (figure 2b) nor to maximum daily temperature within the grass sward a gamma distribution was chosen as the most parsimonious choice. This is because the transformation of the gamma PD with temperature is achieved through a change in a single parameter, since the other parameters will be fixed (see below).

The gamma distribution has the probability density function:

$$f(x;\beta,\gamma) = \frac{\left(\frac{x-\mu}{\beta}\right)^{\gamma-1} \exp\left(-\frac{x-\mu}{\beta}\right)}{\beta\,\Gamma(\gamma)}, \quad x \geq \mu; \beta, \gamma > 0 \qquad (1)$$

where, x is a continuous random variable (relative daily movement), μ is the location parameter, γ is the shape parameter, β is the scale parameter and $\Gamma(\gamma)$ is the gamma function, which has the formula:

$$\Gamma(\gamma) = \int_0^\infty x^{\gamma-1} e^{-x}\, dx \qquad (2)$$

Because we will generate probability distributions which have an area under the curve ($\Gamma(\gamma)$) equal to 1 and a location parameter equal to 0 (an individual's net daily movement is assumed to vary from 0 to positive infinity) the probability density function can be simplified to:

$$f(x) = \frac{\left(\frac{x}{\beta}\right)^{\gamma - 1} \exp\left(-\frac{x}{\beta}\right)}{\beta}, \qquad (3)$$

where, the γ and β parameters can be estimated as a function of the sample mean and standard deviation as:

$$\gamma = \left(\frac{x}{s}\right)^2 \qquad (4)$$

$$\beta = \frac{s^2}{x} \qquad (5)$$

As the CoV of relative movement among individuals was not found to be significantly related to mean movement or temperature, the parameters γ and β were calculated assuming a constant CoV of 76.8%. Note that as CoV = 100*standard deviation/mean there is predicted to be no change in the shape parameter γ with temperature (eq. 4). Changes in the scale parameter β in the model are dependent upon changes in mean relative daily movement which we show to vary between individuals (figure 1b) and to be a function of temperature (figure 2a).

As maximum temperature varies between days a seasonal probability distribution was created from a composite of daily probability distributions. The relative contribution of a daily probability distribution derived as a function of a given maximum daily temperature to seasonal movement was determined by the relevant frequency of maximum daily temperatures recorded on-site. Daily movements of both sexes were highly related to maximum daily temperature recorded within the grass sward (y) but in order to relate these movements to long-term climate data sets, these temperatures were converted to maximum daily temperatures recorded by the on-site meteorological station (x) over this time period ($y = 1.171x + 2.461$; $R^2 = 0.64$, $F_{19} = 31.79$, $P < 0.001$).

Data were available from the British Atmospheric Data Centre (BADC) for the period 1963-2001. Frequency distributions of maximum daily temperatures recorded during the months of July and August were produced for two separate periods: 1963-1990 and 1991-2000. On days on which recorded maximum temperatures exceeded that which occurred during the study period, the relative response of individuals was limited to the maximum temperature recorded during the field-study. The frequency distributions of maximum daily temperatures for these respective periods were found to conform to a Normal distribution; the 1991-2000 period showed a 1.7°C increase in maximum daily temperature relative to the 1963-1990 period, which had mean maximum daily temperatures of 21.1°C and 22.8°C respectively. To model potential increases in temperature, such as that predicted under climate change, we assumed a shift to the right of the Normal distribution for the 1963-1990 period of 3ºC and 5ºC. This was to simulate increases in temperature that are currently predicted for the given geographical area by 2070-2099 under two greenhouse gas emission scenarios: a medium-low B2 SRES scenario and a medium-high A2 SRES scenario, respectively (Hulme *et al.* 2002).

Appendix II: testing of model

Table 1. Sensitivity analyses of the dispersal model based on 1 S.E. deviation. The effects of calculated errors of regression coefficients associated with measuring daily movements were tested on the mean, standard deviation, skewness and kurtosis of the dispersal function predicted by simulations of female dispersal under 1963-1990 thermal conditions. Numbers in parentheses indicate percentage change.

Source of error. Regression coefficients (mean ± 1 S.E).		Properties of the dispersal function							
		Mean		SD		Skewness		Kurtosis	
		Min	Max	Min	Max	Min	Max	Min	Max
ln(mean relative daily movement) regressed against maximum daily temperature within the grass sward.									
slope	0.095 ± 0.024	7.2 (-54.3)	31.3 (98.9)	5.4 (-54.6)	23.3 (96.4)	1.64 (2.4)	1.58 (-1.3)	3.54 (9.9)	3.09 (-4.1)
constant	1.562 ± 0.728	15.7 (-0.3)	53.0 (236.8)	11.7 (-1.6)	38.5 (224.5)	1.59 (-0.6)	1.49 (-6.9)	3.30 (2.7)	2.72 (-15.5)
Standard deviation of relative daily movements regressed against the mean of relative daily movements recorded on a given day.									
slope	0.733 ± 0.114	14.6 (-7.3)	17.0 (8.0)	11.0 (-7.7)	12.8 (8.1)	1.63 (2.1)	1.61 (0.6)	3.55 (10.3)	3.33 (3.4)
constant	4.198 ± 11.872	15.0 (-4.7)	16.6 (5.3)	11.2 (-5.6)	12.5 (5.2)	1.56 (-2.4)	1.61 (0.9)	3.02 (-6.2)	3.29 (2.1)

Table 2. Elasticity analyses of the dispersal model based on a proportional increase in a given parameter. The effects of a given 10% increase in regression coefficient values and a 10% increase in the range among individuals in mean daily movement were tested on the mean, standard deviation, skewness and kurtosis of the dispersal function predicted by simulations of female dispersal under 1963-1990 thermal conditions. Rank indicates relative sensitivity to parameter from one (highest) to five (lowest). Numbers in parentheses indicate percentage change.

Source of	Mean		SD		Skewness		Kurtosis	
variability	Change	Rank	Change	Rank	Change	Rank	Change	Rank
ln(mean relative daily movement) regressed against maximum daily temperature within the grass sward.								
Slope	18.3 (+16.5)	2	13.8 (+16.3)	2	1.63 (+2.0)	3	3.42 (+6.3)	2
Constant	39.9 (+153.3)	1	29.3 (+146.9)	1	1.54 (-3.6)	2	3.02 (-6.2)	3
Standard deviation of relative daily movements regressed against the mean of relative daily movements recorded on a given day.								
Slope	15.7 (-0.4)	5	11.8 (-0.6)	5	1.60 (+0.1)	5	3.23 (+0.4)	5
constant	16.4 (+3.9)	4	12.4 (+4.5)	4	1.66 (+3.9)	1	3.68 (+14.4)	1
Between-individual variation	16.5 (+4.75)	3	12.5 (+5.3)	3	1.61 (+0.8)	4	3.17 (-1.5)	4

REFERENCES

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