Oikos

OIK-06468

Eichhorn, G., Enstipp, M. R., Georges, J.-Y., Hasselquist, D. and Nolet, B. A. 2019. Resting metabolic rate in migratory and non-migratory geese following range expansion; go south, go low. – Oikos doi: 10.1111/oik.06468

Appendix 1

Statistical method details

We modelled variation in ln($\dot{V}_{O2}$) separately for growing juvenile and wing-moulting adult barnacle geese by fitting linear mixed-effect models using maximum likelihood estimation. Starting with a full model containing the explanatory variables and interactions of interest, non-significant ($p > 0.05$) terms were removed from the model one by one in decreasing order of p-value until only significant terms remained in a final model (random effects were kept in final model regardless of statistical significance). As a control, non-significant terms were re-entered to the final model one by one to avoid non-significance due to over-parameterisation, but results remained consistent. The full ln($\dot{V}_{O2}$ [ml min^{-1}]) model for juvenile geese included the fixed main effects of ln(*M* [kg]), colony, sex, time since capture [h], chamber temperature during respirometry, and the interactions of ln(*M*)*colony and ln(*M*)*sex to allow the allometric scaling exponent to vary with colony or sex. The full ln($\dot{V}_{O2}$) model for adult geese included the same explanatory variables as the model for the juvenile geese and, additionally, also the length of the 9th primary feather (P9 [mm]) and its square ($P9^2$) to account for a non-linear effect of moult stage. Residuals of final models proved normally distributed (Shapiro-Wilk p = 0.2 and 0.8) with equal variance across model predictions.

Simple uncorrected back-transformation of logarithmically transformed data can introduce bias to estimates on the original scale (White and Kearney 2014). To counter such potential bias, consistent I estimators of $\dot{V}_{O2}$ were calculated (following Hayes and Shonkwiler 2006) as *e* raised to the power ln($\dot{V}_{O2}$) + $s^2/2$, where ln($\dot{V}_{O2}$) are the log model estimates, and s^2 represents the mean square error (error variance) of the log model calculated as the sum of residuals divided by the degree of freedoms. Final models' s^2 were 0.0042 (goslings) and 0.0045 (adult geese) yielding small correction factors of 1.0021 and 1.0022 relative to uncorrected back-transformation. We constructed 95% confidence intervals about consistent I estimators using Cox's method (Hayes and Shonkwiler 2006; Shonkwiler pers. comm.) as *e* raised to the power $\ln(\dot{V}_{O2}) + s^2/2 \pm 1.96\,(SEP^2 + s^4/[2(n\text{-}1)])^{0.5}$, where *SEP* are the standard errors of the predictions on the log scale, and *n* is the sample size. We followed Kennedy (1981) to counter bias in the estimation of the mean percentage impact of our dummy variable 'colony' on $\dot{V}_{O2}$, which was derived as 100 [$e^{Col - 0.5SEsquare(Col)}$ -1], where *Col* is the parameter for 'colony' estimated from the log model, and *SEsquare*(*Col*) is the square of the standard error for *Col*.

References

Hayes, J. P. and Shonkwiler, J. S. 2006. Allometry, antilog transformations, and the perils of prediction on the original scale. – Physiol. Biochem. Zool. 79: 665–674.

Kennedy, P. E. 1981. Estimation with correctly interpreted dummy variables in semilogarithmic equations. – Am. Econ. Rev. 71: 801–801.

White, C. R. and Kearney, M. R. 2014. Metabolic scaling in animals: methods, empirical results, and theoretical explanations. – Comprehensive Physiol. 4: 231–256.

Table A1. Sample sizes of n_i individual barnacle geese sampled at n_j capture events (random effect) as used to model resting rate of oxygen consumption ($\dot{V}_{O2}$) in juveniles and adults from the Netherlands and Russia (sex: F - female, M - male; sex of 5 goslings unknown).

	Netherlands		Russia		Total	
	n_i (F+M+unknown)	n_j (catches)	n_i (F+M+unknown)	n_j (catches)	n_i (F+M+unknown)	n_j (catches)
Juvenile	33 (15F+16M+2)	19	29 (12F+14M+3)	6	62 (27F+30M+5)	25
Adult	12 (6F+6M)	4	27 (14F+13M)	8	39 (20F+19M)	12

Table A2. Summary statistics of variables used to model resting rate of oxygen consumption ($\dot{V}_{O2}$) in juvenile and adult barnacle geese from the Netherlands and Russia.

	Netherlands				Russia				Total	
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Juvenile geese										
$\dot{V}_{O2}$ (ml min^{-1})	10.3	5.5	3.8	22.8	16.0	4.9	6.2	27.1	13.0	6.0
Body mass (kg)	0.536	0.363	0.122	1.315	0.836	0.349	0.220	1.555	0.677	0.385
t $catch$-V_{O2} (h)	15	9	4	41	20	6	8	32	17	8
Adult geese										
$\dot{V}_{O2}$ (ml min^{-1})	21.2	3.0	17.4	26.8	26.7	2.9	22.7	32.5	25.0	3.8
Body mass (kg)	1.678	0.280	1.270	2.250	1.827	0.184	1.490	2.145	1.781	0.225
t $catch$-V_{O2} (h)	21	6	11	31	18	6	8	29	19	6
P9 (mm)	93	63	0	162	92	58	0	192	92	59

Table S3. Parameter estimates for modelling the growth in body size (PC1 of length of wing, head, tarsus and body mass) with age [days] of juvenile barnacle geese from a migratory and a sedentary colony (*Col*) in arctic Russia (RU, reference level, n=152) and the Netherlands (NL, n=64), respectively. Percentage difference in growth rate between colonies can be calculated from parameter estimates, yielding -0.031 / 0.086 * 100 = -36.2% slower rate in Netherlands goslings.

Parameter	Estimate	SE	*t*	p
Intercept (= RU)	-2.156	0.060	-35.673	<0.001
Col (Δ RU-NL)	-0.135	0.091	-1.489	0.138
Age (= RU)	0.086	0.002	40.975	<0.001
Col × Age (Δ RU-NL)	-0.031	0.003	-11.482	<0.001

Table A4. Parameter estimates for modelling the development of body mass [kg] during wing moult (length of P9 [mm]) in adult barnacle geese from a migratory and a sedentary colony (*Col*) in arctic Russia (RU, reference level, n=115) and the Netherlands (NL, n=105), respectively, while accounting for body size (PC1 of tarsus and head length).

Parameter	Estimate	SE	*t*	p
Intercept (= RU)	1.784	0.021	85.336	<0.001
Col (Δ RU-NL)	-0.028	0.028	-0.998	0.319
PC1	0.152	0.009	17.79	<0.001
P9 (= RU) †	0.00013	0.00021	0.639	0.524
Col × *P9* (Δ RU-NL) ††	-0.00095	0.00033	-2.867	0.005

† Tests slope for RU against a value of zero.

†† Tests slope for NL against slope for RU. The estimate for slope of body mass with P9 for NL (and test against zero slope) from a model including only NL data is -0.00078 ± 0.00028, *t* = -2.765, p = 0.007.

Table A5. Parameter estimates for modelling the growth in body size (PC1 of length of wing, head, tarsus and body mass) with accumulated daylight hours (divided by 24) experienced during growth (from individual hatch date to body size measurement) of juvenile barnacle geese from a migratory and a sedentary colony (*Col*) in arctic Russia (RU, reference level, n = 152) and the Netherlands (NL, n = 64), respectively. Data and general model structure are as in Table A3 but with "daylight" replacing variable "age" in present model. Percentage difference in growth rate between colonies yields -0.013 / 0.087 × 100 = -15.3% slower rate in Netherlands goslings.

Parameter	Estimate	SE	*t*	p
Intercept (= RU)	-2.169	0.060	-36.215	<0.001
Col (Δ RU-NL)	-0.116	0.090	-1.291	0.198
Daylight (= RU)	0.087	0.002	41.556	<0.001
Col × Daylight (Δ RU-NL)	-0.013	0.003	-4.308	<0.001

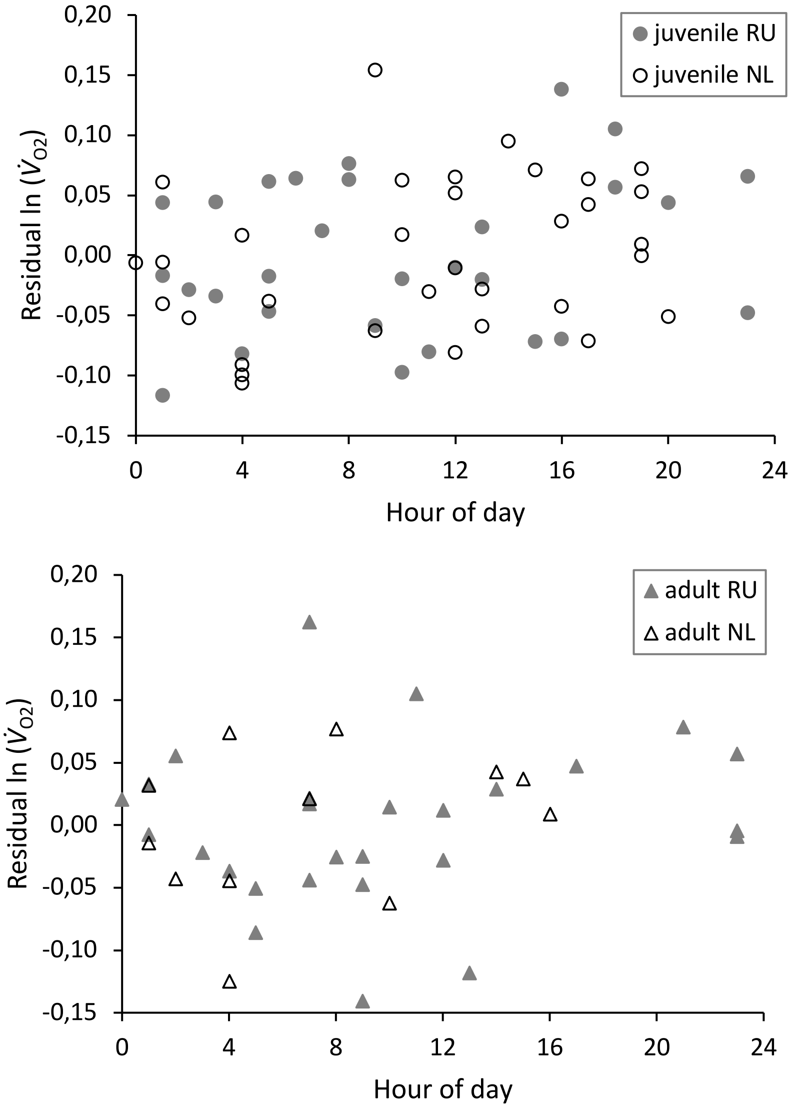

Figure A1. Residuals of the final ln($\dot{V}_{O2}$) model for juvenile (upper panel) and adult (lower panel) barnacle geese from a migratory and a sedentary colony in the Russian Arctic and the Netherlands, respectively, versus daytime of $\dot{V}_{O2}$ measurement.

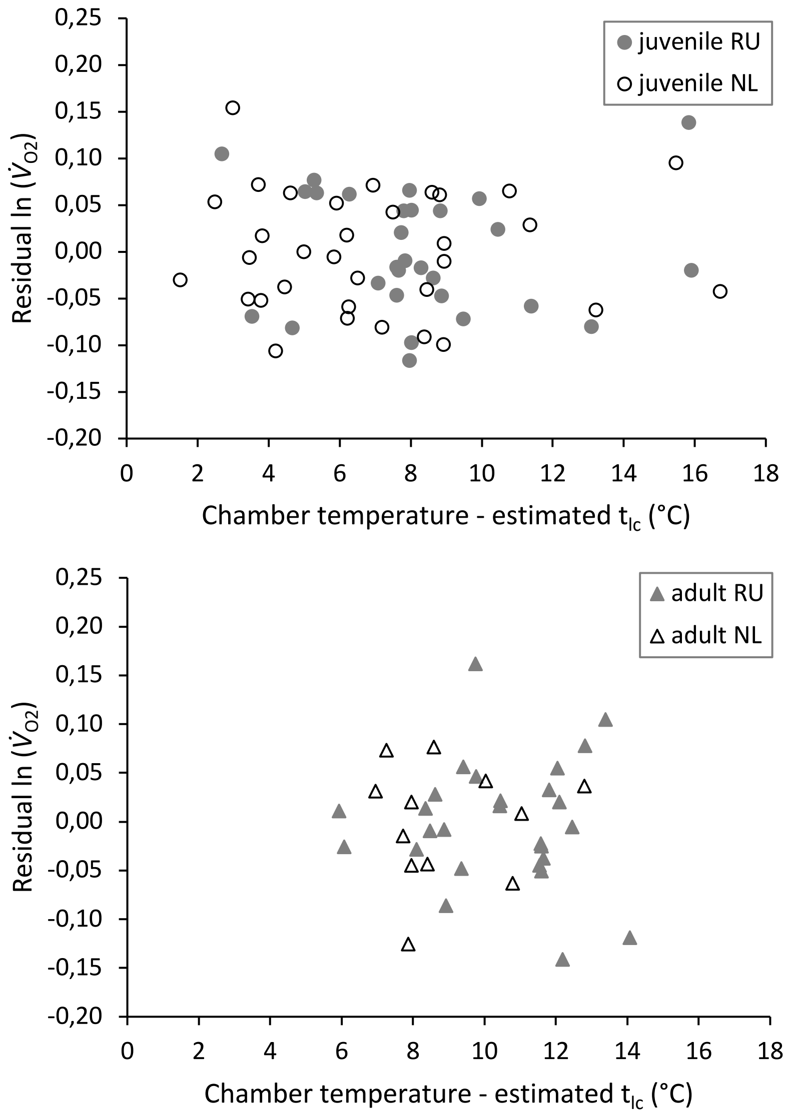

Figure A2. Residuals of the final ln($\dot{V}_{O2}$) model for juvenile (upper panel) and adult (lower panel) barnacle geese from a migratory and a sedentary colony in the Russian Arctic and the Netherlands, respectively, versus ambient (chamber) temperature minus estimated lower critical temperature (t_{lc}). See methods section for calculation of t_{lc} estimates.

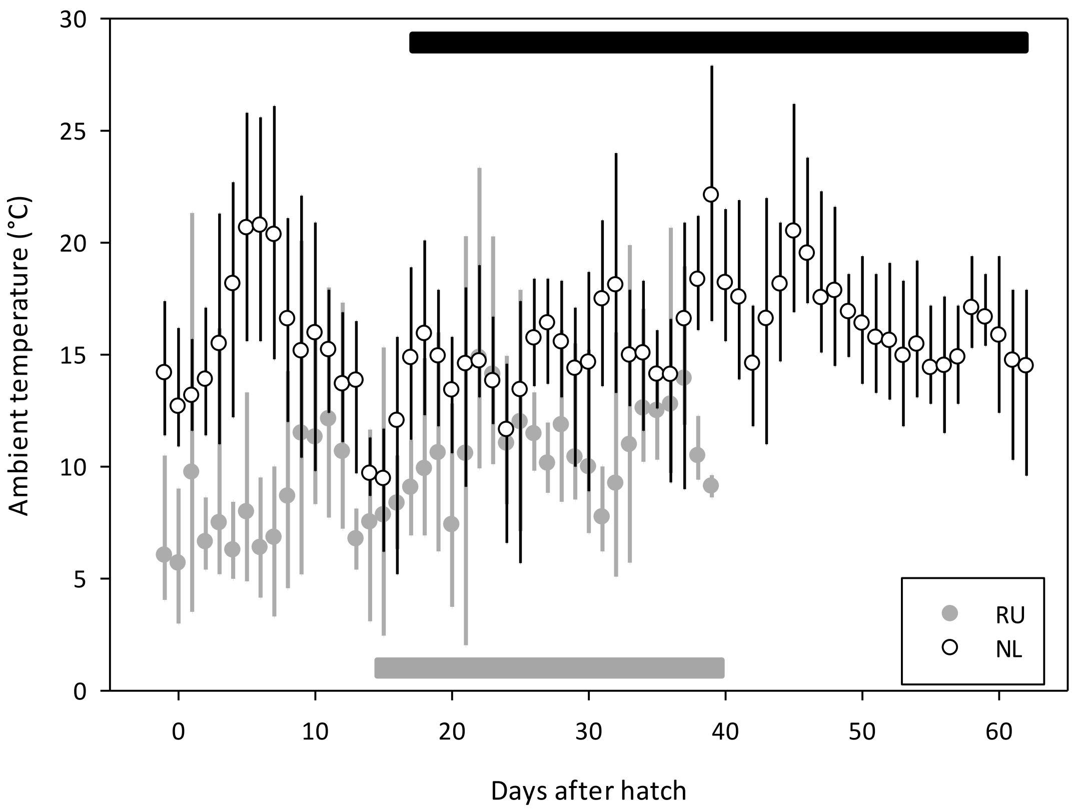

Figure A3. Daily mean (circles), maximum and minimum (vertical bars) ambient temperature during juvenile growth as measured by us in the Russian study colony in 2014 and by the Royal Netherlands Meteorological Institute (KNMI) in their station 'Wilhelminadorp' at 33 km distance from our Dutch study colony in 2012. Time is expressed as days relative to mean hatch date in each colony and year, which occurred on 10 July 2014 (RU, n = 388) and 20 May 2012 (NL, n = 210). Horizontal bars mark the age range of goslings used for $\dot{V}_{O2}$ measurements.

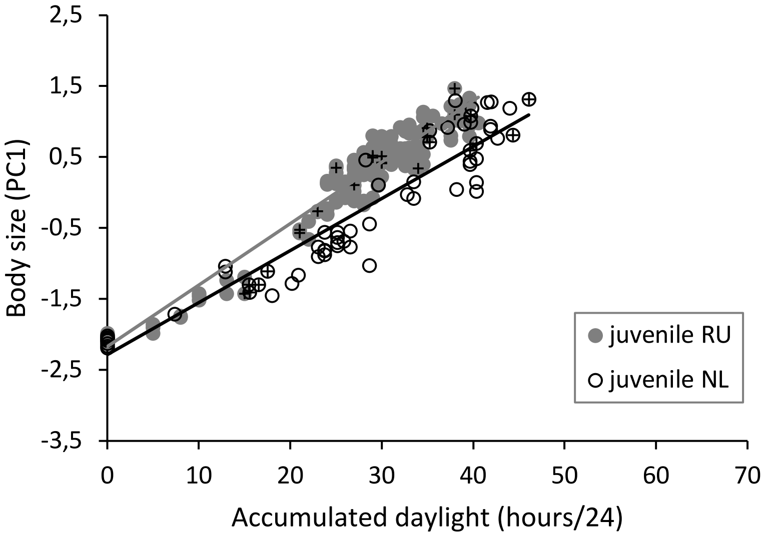

Figure A4. Body size (PC1 of wing, head and tarsus length, and body mass) development in juvenile barnacle geese from a migratory and a sedentary colony in the Russian Arctic and the Netherlands, respectively, when related to accumulated daylight hours experienced during growth (from individual hatch date to date of body size measurement) instead of days of age as in main Fig. 4. Daylight hours were calculated from the time between start and end of daily civil twilight times, and values accumulated during growth were divided by 24 to facilitate comparison with 24 hours daylight conditions as experienced by Russian juvenile geese. Data were collected during same seasons when $\dot{V}_{O2}$ was measured, and cross symbols mark subjects that were also measured for $\dot{V}_{O2}$ in this study. See Supporting Information Table A5 for details of the statistical model.