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Supplementary material

Supplementary online material

Appendix 1. Details of study areas and adult capture methods

Coordinates of the approximate centres of the study areas were as follows: Magadino: 46°09' N, 8°55' E, Piedmont: 45°33' N, 8°44' E, Lombardy: 45°19'N, 9°40'E. All three areas consist mainly of farmland, dominated by maize and hayfields (see Ambrosini et al. 2012; CS, unpubl. data).

In all years, we intensively captured all the adults breeding in selected farms by placing mist-nests before dawn at every exit of the buildings (mainly cowsheds and stables) where breeding individuals spend the night. We carried out 2-3 capture sessions per farm throughout the nesting season. Repeated capture sessions ensured that the vast majority of breeding individuals were captured, as confirmed by subsequent observations of birds attending the nests. We can therefore reasonably assume that the return rate of breeding adults is equal or very close to the actual survival rate of individuals at a given farm, and we will refer to survival rates hereafter (see Saino et al. 2011, 2012; see also Turner 2006 and Møller 1994 for documentation of strong breeding philopatry in the barn swallow). Moreover, since capture sessions were targeting all birds spending the night inside buildings, irrespective of whether they were equipped with geolocators or not, this ensured that recaptures were not biased towards birds wearing geolocators. Laying date and clutch size of geolocator and control subjects in the year of geolocator deployment did not differ significantly [mixed models with treatment, year, sex as fixed effect factors, and study area and farm as random effects; laying date: treatment, $F_{1,379} = 1.48$, $p = 0.23$; year, $F_{1,154} = 16.01$, $p < 0.001$; sex, $F_{1,686} = 0.68$, $p = 0.41$; year × treatment, $F_{1,378} = 2.14$, $p = 0.14$; clutch size: treatment, $F_{1,381} = 0.14$, $p = 0.71$; year, $F_{1,176} = 1.52$, $p = 0.22$; sex, $F_{1,678} = 0.14$, $p = 0.70$; year × treatment, $F_{1,381} = 1.53$, $p = 0.22$; the 2011 Magadino data were excluded because no data for controls were collected].

In addition, for the 508 birds of known age (either because they were initially ringed as nestlings/yearlings or because they were unringed immigrants in farms where all breeding adults had been ringed in the year before; see Saino et al. 2004) that were included in the study (age ranging between 1 and 5 years), mean age did not differ significantly between geolocator and control subjects [mixed model with treatment, year, sex as fixed effect factors, and study area and farm as random effects; treatment, $F_{1,502} = 0.52$, $p = 0.47$; year, $F_{1,503} = 31.93$, $p < 0.001$; sex, $F_{1,501} = 0.06$, $p = 0.81$; year × treatment, $F_{1,502} = 0.68$, $p = 0.41$].

Appendix 2. Geolocator design and variation in absolute and relative geolocator weight

In 2010, we aimed at testing the efficacy of different harness configurations, in terms of harness thickness (1.00 or 1.25 mm thick) and leg-loop diameter (27 or 28 mm) on geolocator loss rate and survival. The choice of leg-loop diameters was based on Naef-Danzer's (2007) allometric equation relating harness size and body size among bird species. The number of geolocators deployed for each combination of thickness and diameter was as follows: 1.00-27 mm, n = 62; 1.25-27 mm, n = 181; 1.00-28 mm, n = 15; 1.25-28, n = 52.

Individual geolocators were weighted on an electronic balance (to the nearest 0.01 g) before deployment. Minor variations in device mass could arise because they were handcrafted and differed in specific harness characteristics. The overall weight of 2010 geolocators including harness (model SOI-GDL2.10) was 0.77 g (0.05 s.d., n = 310), while that of 2011 geolocators (model SOI-GDL2.11) was 0.68 g (0.03 s.d., n = 330). In 2010, geolocator weight varied according to harness thickness (thickness 1.00 mm: 0.71 g (0.03 s.d., n = 77); thickness 1.25 mm: 0.79 g (0.04 s.d., n = 233); $t_{308} = 17.0$, $p < 0.001$) but not diameter ($t_{308} = 0.21$, $p = 0.84$). The 2011 geolocators (harness diameter 27 mm and thickness 1.00 mm) were also significantly lighter (0.04 g on average) than those with the corresponding design deployed in 2010 [0.72 g (0.03 s.d.), n = 62] ($t_{390} = 8.47$, $p < 0.001$). The latter difference was partly due to a reduction in the length of the light stalk in model SOI-GDL2.11 compared to the previous model (from 10 mm, forming an angle of ca. 60° with the body axis when pointing the stalk towards the tail of the bird, to 5 mm with an angle of 90°, see Fig. 1). A reduction of the light stalk was accomplished in order to minimize geolocator drag, because wind tunnel studies suggested that a reduction of the drag of externally attached devices could be as important in affecting migration performance as reducing their size (Bowlin et al. 2010).

Relative weight of geolocators was on average 3.93% (0.43 s.d.) of swallow body mass upon capture. Only two subjects (out of 640) received a geolocator weighting > 5% of their body mass at capture (5.03% and 5.12%): notably, the one equipped with the relatively heaviest geolocator returned with the device in the subsequent year. In a two-way analysis of variance, the relative weight of geolocators varied significantly according to year and sex [year, $F_{1,624} = 205.9$, $p < 0.001$; sex, $F_{1,624} = 65.2$, $p < 0.001$; year × sex, $F_{1,624} = 3.06$, $p = 0.08$), with geolocators being relatively heavier in 2010 and for male subjects [2010, males: 4.23% (0.34 s.d., n = 157); females: 4.05% (0.45 s.d., n = 144); 2011, males: 3.87% (0.31 s.d., n = 181); females: 3.58% (0.34 s.d., n = 146). The sex effect was due to the fact that female barn swallows, though being structurally smaller (shorter wings and tail compared to males) are heavier than males during the breeding season (Møller 1994, our unpubl. data).

Appendix 3. Analysis of factors affecting geolocator loss rate and of the effects of geolocators on survival

For the 2010 data, we investigated whether different geolocator configurations affected the odds of losing the geolocator (0 = subject survived and returned with geolocator; 1 = subject survived and returned without geolocator) in a binomial mixed model with sex, harness thickness, diameter and their interactions (up to three-ways) as predictors. Geolocator weight and harness thickness were strictly correlated (r = 0.70), and we therefore included in the analyses of loss rate harness thickness only, since it is this latter characteristic that determines geolocator weight.

Binomial mixed models were run to test whether geolocator weight affected survival of geolocator subjects, with sex and geolocator characteristics as predictors (results reported in Appendix 6). In addition, for 2010 we ran separate analyses testing the effect of harness diameter and thickness or of harness diameter and weight (either absolute or relative) on survival (we could not include geolocator weight and thickness in the same model because the variables are strictly collinear; see above; results reported in Appendix 6).

Appendix 4. Evaluating the short-term effects of geolocator deployment on parents on nestling growth and fledging success

We investigated whether equipping parents with geolocators while they were attending their brood affected nestling body mass or fledging success. Parents not equipped with geolocators, acting as controls, were captured in the same capture sessions as geolocator parents, at least 6 days before nestling measurement, but were only handled and measured. Replacement broods were excluded from these analyses. The effect of parental treatment on nestling body mass was analysed in a mixed model with male parent treatment (0 = without geolocator, 1 = with geolocator), female parent treatment and their interaction as fixed predictors, while controlling for nestling age (covariate), brood size (covariate; number of nestlings in the nest at the time of measurement), brood order (3-level factor; first, second or third) and nestling sex (covariate). Nest and farm identity were included as a random intercept effects. Farm identity was included as a random effect. Sampe size (number of nests) was as follows: geolocator on the male only, n = 20 nests; on the female only, n = 18 nests; on both parents, n = 14 nests; both parents withouth the geolocator: n = 11 nests.

To investigate the effects on fledging success, nests were included in the analysis with similar constraints as for the analyses of nestling body mass (parents had to be equipped or not with the geolocator before hatching or during chick rearing, up to a nestling age of 4 days). However, sample size was larger since we also included additional nests for which we did not record body mass (geolocator on the male only, n = 20 nests; on the female only, n = 20; on both parents, n = 18; both parents without geolocator, n = 14).

Appendix 5. Effects of geolocator deployment, wing length and age on survival

We tested whether geolocator individuals with longer wings of each sex were more likely to survive to the subsequent breeding season. We expected larger survival of geolocator birds with longer wings, which may better sustain the additional load. Analyses were carried out separately for each sex because of morphological differences between males and females (e.g. Møller 1994). To this end, we ran binomial mixed models with wing length, treatment and their interaction as fixed effects. Wing length did not differentialy affect survival probability of control and geolocator subjects in either sex (analyses carried out by excluding birds that lost the geolocator, tests performed on centred variables; 2010, males: wing length, $z = 0.05$, $p = 0.95$; treatment, $z = 3.03$, $p = 0.005$; wing length × treatment, $z = 1.08$, $p = 0.28$; females: wing length, $z = 0.15$, $p = 0.88$; treatment, $z = 5.29$, $p < 0.001$; wing length × treatment, $z = 1.55$, $p = 0.12$; 2011, males: wing length, $z = 0.01$, $p = 0.99$; treatment, $z = 2.39$, $p = 0.018$; wing length × treatment, $z = 1.71$, $p = 0.09$; females: wing length, $z = 0.13$, $p = 0.90$; treatment, $z = 2.03$, $p = 0.044$; wing length × treatment, $z = 1.55$, $p = 0.12$).

We also tested, for the sample of known-age control and geolocator birds that returned with the geolocator ($n = 192$ in 2010 and $n = 300$ in 2011) whether the survival probability of geolocator and control birds was differentially affected by age in binomial mixed models with treatment, age, sex and their two-way interactions as predictors. The treatment × age interaction was not statistically significant in either year (both $p > 0.95$), as was the main effect of age (both $p > 0.08$) (other model details not shown for brevity).

Appendix 6. Effect of variation in harness design and geolocator weight on survival

For the 2010 data, we investigated whether geolocator harness design affected survival of geolocator subjects in binomial mixed models with sex, harness thickness and diameter as predictors. Two-way interactions were included in initial models. When we excluded birds that lost the geolocator, we found a significant effect of harness thickness on survival ($z = 2.52$, $p = 0.011$), with birds bearing thinner harnesses being more likely to survive [model-predicted survival probabilities (s.e.): 1.00 mm, 0.35 (0.06); 1.25 mm, 0.20 (0.03)]. Though the effect of diameter was not significant ($z = 1.46$, $p = 0.14$), birds bearing smaller harnesses tended to be more likely to survive [model-predicted survival probabilities (s.e.): 27 mm, 0.32 (0.04); 28 mm, 0.22 (0.06)]. Two-way interactions were not significant (all $p > 0.14$) and were removed from the model (other model details not shown for brevity). However, the statistically significant effect of harness thickness disappeared ($z = 1.33$, $p = 0.18$; other model details not shown for brevity) when analyses were carried out on the entire set of surviving birds, irrespective of geolocator loss, suggesting that any effect of harness thickness on survival was confounded by non-random geolocator loss rate with respect to geolocator characteristics (see Table 2). Conclusions were similar if we included in the models harness diameter and absolute geolocator weight (instead of thickness) (details not shown), while relative geolocator weight did not significantly affect survival either if birds that lost the geolocator were included or excluded (all $p > 0.34$).

For the 2011 data, we tested whether geolocator weight (both absolute and relative) predicted survival in binomial mixed models with geolocator weight, sex and their interaction as predictors (birds that lost the geolocator were excluded). Geolocator weight did not significantly predict survival (absolute weight, $z = 1.45$, $p = 0.15$; sex, $z = 2.89$, $p = 0.004$, weight × sex, $z = 0.16$, $p = 0.87$; relative weight, $z = 1.43$, $p = 0.15$; sex, $z = 2.92$, $p = 0.004$, weight × sex, $z = 0.42$, $p = 0.67$).

Supplementary references

Ambrosini, R., Rubolini, D., Trovò, P., Liberini, G., Bandini, M., Romano, A., Sicurella, B., Scandolara, C., Romano, M. and Saino, N. 2012. Maintenance of livestock farming may buffer population decline of the Barn Swallow *Hirundo rustica*. – Bird Conserv. Int. 22: 411–428.

Bowlin, M. S., Henningsson, P., Muijres, F. T., Vlegels, R. H. E., Liechti, F. and Hedenström, A. 2010. The effects of geolocator drag and weight on the flight ranges of small migrants. – Methods Ecol. Evol. 1: 398-402.

Møller, A. P. 1994. Sexual selection and the barn swallow. Oxford University Press.

Naef-Daenzer, B. 2007. An allometric function to fig leg-loop harness to terrestrial birds. – J. Avian Biol. 38: 404-407.

Saino, N., Szép, T., Romano, M., Rubolini, D., Spina, F. and Møller, A. P. 2004. Ecological conditions during winter predict arrival date at the breeding quarters in a trans-Saharan migratory bird. – Ecol. Lett. 7: 21-25.

Saino, N., Caprioli, M., Romano, M., Boncoraglio, G., Rubolini, D., Ambrosini, R., Bonisoli-Alquati, A. and Romano, A. 2011. Antioxidant defenses predict long-term survival in a passerine bird. – PLoS ONE 6: e19593.

Saino, N., Romano, M., Ambrosini, R., Rubolini, D., Boncoraglio, G., Caprioli, M. and Romano, A. 2012. Longevity and lifetime reproductive success of barn swallow offspring are predicted by their hatching date and phenotypic quality. – J. Anim. Ecol. 81: 1004–1012.

Turner, A. 2006. The Barn Swallow. London, UK: T & A D Poyser.

Table A1. Effects of geolocator design and sex on geolocator loss rate. Results from a binomial mixed model with loss rate (0 = subject survived and returned with geolocator; 1 = subject survived and returned without geolocator) as the binary dependent variable and sex, harness thickness and diameter as predictors (see footnotes for coding), while study area and farm were included as random effects. Results for main effects are from a model excluding the non-significant interaction terms.

Predictors	Estimate (s.e.)	z	p	Odds ratio (c.l.)
Sex[a]	-1.53 (0.58)	2.66	0.008	4.61 (1.47-14.46)[d]
Thickness[b]	1.68 (0.69)	2.44	0.015	5.33 (1.36-2.87)
Diameter[c]	2.31 (0.63)	3.69	< 0.001	10.12 (2.90-35.24)
Sex × thickness	-0.63 (1.44)	0.44	0.67	-
Sex × diameter	0.89 (1.40)	0.63	0.53	-

a: 0 = female; 1 = male
b: harness thickness: 0 = 1.00 mm; 1 = 1.25 mm
c: harness diameter: 0 = 27 mm; 1 = 28 mm
d: males as reference category

Table A2. Mixed models testing the effects of geolocator deployment (treatment: 0 = control birds; 1 = geolocator birds), sex (0 = female; 1 = male) and their interaction on laying date and clutch size. Dependent variables are expressed as within-individual differences in each trait between year (i + 1) and year i. Estimates from predictors that were centred around their mean value are shown. Sample sizes for each treatment by sex combination are shown in Fig. 2, as well as *post hoc* tests for the statistically significant treatment × sex interaction on the 2010 clutch size difference. No data from the Magadino study area were included in this analysis (see Methods). Geolocator birds that returned without the device were excluded.

	Year 2010				Year 2011			
	Estimate (s.e.)	F	d.f.	p	Estimate (s.e.)	F	d.f.	p
Laying date (days)								
Treatment	11.93 (4.57)	6.81	1, 69	0.011	3.11 (6.89)	0.20	1, 40	0.65
Sex	4.85 (4.53)	1.14	1, 69	0.29	1.03 (6.84)	0.02	1, 52	0.88
Treatment × sex	-1.11 (9.29)	0.01	1, 69	0.91	-6.45 (13.37)	0.23	1, 49	0.63
Clutch size (eggs)								
Treatment	-0.76 (0.28)	7.12	1, 67	0.010	0.24 (0.43)	0.31	1, 44	0.58
Sex	0.09 (0.28)	0.10	1, 65	0.75	-0.47 (0.43)	1.16	1, 53	0.29
Treatment × sex[a]	1.25 (0.57)	4.86	1, 65	0.031	0.58 (0.85)	0.46	1, 51	0.50

a: least-square means (s.e.):
control males = 0.06 (0.29)
geolocaotor males = -0.15 (0.28)
control females = 0.51 (0.27)
geolocator females = -0.95 (0.40)

Table A3. Mixed models of nestling body mass and fledging success analysing the effects of geolocator application to the male parent (male parent treatment: 0 = without geolocator; 1 = with geolocator) and/or the female parent (female parent treatment) (data collected in the Magadino study area, year 2010). In models of body mass, we controlled for the confounding effects of nestling age, brood size (number of nestlings), brood order (3-level factor: first, second or third brood), and nestling sex (0 = female; 1 = male), while in models of fledgling success we controlled for the confounding effects of brood. Estimates for main effects refer to models excluding the non-significant interaction terms.

Predictors	F	d.f.	p	Estimate (s.e.)
Nestling body mass (g) (n = 203 nestlings, 63 nests)				
Nestling age	4.97	1, 52.4	0.030	0.34 (0.15)
Brood size	3.70	1, 52.6	0.06	-0.53 (0.28)
Brood order	1.97	2, 56.3	0.15	-
Nestling sex	3.11	1, 167	0.08	0.58 (0.33)
Male parent treatment (MT)	0.00	1, 50.7	0.99	-0.01 (0.61)
Female parent treatment (FT)	0.86	1, 53.5	0.36	-0.52 (0.56)
MT × FT	0.05	1, 44.9	0.83	-0.25 (1.16)
Fledging success (brood size at fledging) (n = 72 nests)				
Brood order	0.45	2, 61.9	0.64	-
Male parent treatment (MT)	2.26	1, 62.4	0.14	0.44 (0.29)
Female parent treatment (FT)	0.71	1, 59.7	0.40	-0.23 (0.28)
MT × FT	1.40	1, 60.2	0.24	0.67 (0.56)

Figure A1. Nestling body mass (open bars, left axis) and fledging success (black bars, right axis) of barn swallow nests in relation to parental geolocator treatment. Values are least-square means (s.e.) obtained from the models listed in Table A3 (including the male parent treatment × female parent treatment interaction term). Numbers above bars show sample size (number of nests) for each treatment category.