Silver spoon effect: Natal noise is associated with telomere dynamics in adult birds

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Abstract

Anthropogenic noise disturbance on wildlife is of growing concern. Environmental noise during incubation can negatively impact fitness in wild animal populations. Here, we hypothesised that chronic noise introduces stress through oxidative damage to wild bird embryos, resulting in short-term fitness reductions and long-term physiological changes. To test this hypothesis, we investigated the effects of chronic noise on chick body condition, fledging success, and adult telomere shortening in wild house sparrows *Passer domesticus,* using 13 years of data. We disentangled the effects of noise in the natal and rearing environments using cross-fostering. We found no evidence of an association between natal noise and chick mass, body condition at fledging, and fledging success. However, adults with shorter telomeres were underrepresented at older ages when they were incubated in chronic noise conditions. Such a silver spoon effect of early-life noise pollution has implications for the management of wild populations.

Introduction

Anthropogenic noise has profound impacts on wildlife, ranging from alterations in individual behaviours to changes in the structure of ecological communities (for an overview see Shannon et al., 2016). Importantly, chronic noise pollution experienced in early life can introduce a silver spoon effect to individuals, referring to lasting deficits due to an adverse developmental environment (Grafen, 1988). Long-term consequences associated with early-life noise include impaired body development (de Soto et al., 2013; Nedelec et al., 2015), accelerated reproductive schedules (Sun et al., 2025), and reduced lifetime reproductive output (Meillère et al., 2024; Sun et al., 2025). These lifetime fitness impacts could be introduced directly by stress effects through noise, even without any change of parental behaviour due to noise (Meillère et al., 2024).

The effects of noise during development can stem not only from the environment where the animal was reared but also from the maternal environment during pregnancy or *in ovo*. In mammals, such as humans (Vincens & Persson Waye, 2023), mice (Jafari et al., 2017) and rats (Kim et al., 2006), studies mainly focus on the consequences of prenatal environmental noise on auditory development, cognition or psychology, with a few studies finding associations with increased risks of congenital anomalies (e.g. Dzhambov et al., 2014; Ward et al., 1970). Yet, whether noise exposure during pregnancy is associated with perinatal mortality in mammals is unresolved (reviewed in Vincens & Persson Waye, 2023). In oviparous animals, noise in the pre-hatching environment can impair physiology (Meillère et al., 2024) and somatic development (Kesar, 2014; Meillère et al., 2024; Nedelec et al., 2014), and even lead to increased embryo mortality. The negative effect of noise in the pre-hatching environment on reproductive output can even be stronger than the effect of post-hatching noise (Meillère et al., 2024). These effects of natal noise can indirectly affect embryos through altered incubation behaviours of the parents induced by noise (Viigipuu et al., 2023) or directly affect the embryos (Kesar, 2014; Meillère et al., 2024).

Noise could introduce negative consequences by mediating the oxidative stress pathways (Manukyan, 2022; Münzel & Daiber, 2018). Telomere length is a biomarker that can reflect oxidative stress,

although there are mixed results on the association between oxidative stress and telomere dynamics (Armstrong & Boonekamp, 2023; Reichert & Stier, 2017). Telomeres are repeating DNA sequences (TTAGGG) capping the ends of linear chromosomes (Blackburn, 1991). They protect the linear chromosomes from shortening due to the end-replication problem during cell divisions or due to oxidative stress (Houben et al., 2008; Levy et al., 1992), with short telomeres associated with high mortality (Wilbourn et al., 2018). In some bird species, early-life anthropogenic noise is associated with accelerated telomere shortening (e.g. Dorado-Correa et al., 2018; Grunst et al., 2020; Injaian et al., 2019). However, previous studies have not disentangled the effects of noise exposure during incubation from those arising in the rearing environment, on telomere shortening (except that Meillère et al., 2024 tested for telomere length). Stages before and just after hatching could play a key role in telomere dynamics (Xiong et al., 2025).

Lifetime fitness consequences of natal noise exposure can be sex-specific. For example, female but not male house sparrows (*Passer domesticus*) hatched in a noisy environment had reduced lifetime reproductive output, controlling for the noise in their rearing environment (Sun et al. 2025). We hypothesise that noise in their natal environment leads to stress that negatively impacts the embryos. The stress has sex-specific long-term outcomes on reproduction, possibly because oocytes form at the embryo stage while sperm form after sexual maturity (Aire, 2014; Johnson, 2014). Additionally, although noise in the rearing environment reduced overall chick mass and fledging success due to reduced provisioning rates, whether noise in the natal environment affects chick mass and fledging success remains unexplored (Schroeder et al., 2012).

We investigated the short- and long-term effects of natal environmental noise in a wild bird population. We disentangled the effects of natal and rearing environments using a multi-year cross-fostering experiment. We tested short-term effects of natal noise on chick mass, body condition at fledging, and fledging success, predicting that these would be lower in noisy compared to quiet natal environments. We then tested long-term effects of natal noise on adult telomere shortening, predicting that noise would lead to faster telomere shortening in adulthood. We also tested whether the effect on telomere shortening differed between females and males.

Material and methods

Study population

We used data from wild house sparrows hatched between 2000-2012 on Lundy Island (51˚10'N, 4˚40'W). This population has been systematically monitored for breeding activities and survival since 2000. Nest boxes were placed in and near the village. During breeding seasons (April—August), all nest boxes and known natural nests have been checked routinely for nest-building activities. Once a nest was complete, it was checked every second day for eggs, and after the 12th day after laying, it was checked every day for hatchlings, and therefore precise hatching dates are known (Cleasby et al., 2010). Birds were typically ringed on the 12th day after hatching, each with a unique combination of three colour rings and a numbered metal ring from the British Trust for Ornithology, allowing individual identification upon sighting and recapture. The few birds that were not caught this way were ringed as first-year juveniles, captured with walk-in traps or mist nets during the breeding seasons and one or two weeks in the winter. More than 99% of birds were ringed within their first year and are therefore of known age (Schroeder et al., 2015). Sightings and recaptures were carried out throughout the breeding seasons and for the one or two weeks each winter, with an annual re-sighting rate of 0.96 (95% CI: 0.95-0.97, Simons et al., 2019).

Cross-fostering experiments were carried out routinely between same-aged broods during 2000–2012, except in 2008 and 2010, due to a low population size (Winney et al., 2015). Chicks were typically swapped when they were two days old, except that in 2000-2003, cross-fostering occurred at three days old (Cleasby et al., 2010). Broods were swapped entirely, or partially if that was required to maintain the original brood size. Depending on the location of the same-aged brood(s), cross-fostering occurred within or between noisy and quiet areas. Chicks remained in their foster broods until they fledged. There was no evidence for kin recognition, and parent birds did not alter their parental care behaviour to cross-fostered broods (Lattore et al., 2019).

Noise impact

Around a quarter of the nest boxes (29 in 2008, 28 in 2023) were impacted by chronic background noise from a set of power generators. These generators ran each day between 06:00-24:00 (Schroeder et al., 2012). The low-frequency noise produced by these generators reverberates in the surrounding area, a semi-open workshop with corrugated roofing and stone walls, with a permanently open gate and a louvered window allowing the birds access (Sun et al., 2025). The noise level in this area was at 68dB, and significantly higher than at other breeding sites (Schroeder, et al. 2012), and they are hereby defined as "noisy" and "quiet" areas, respectively (Fig. 1). Territory and parent quality did not significantly differ between noisy and quiet areas (Schroeder, et al. 2012). Sound insulation was added in 2013 to reduce the noise level in the workshop because provisioning behaviour of the house sparrow females was disturbed by the noise (Schroeder et al. 2012; Sun et al., 2025). Therefore, we only included birds hatched before 2013 to keep the natal noise at a constant level. All birds in this dataset died by the end of 2022.

Data collection

We weighed chicks at the ages of 2, 6 and 12 days with an electronic scale, but occasionally we weighed chicks one day earlier or later or on day 14, depending on their growth. We measured tarsus length at the last nest visit. Chicks that survived to the last nest visit were considered fledged. We measured relative telomere length (RTL) from blood samples collected from the birds upon subsequent captures. Sampling frequency for RTL per bird per year ranged between one to five (Chik et al., 2024). Detailed methods for quantifying RTL and the resulting dataset are provided in Chik et al. 2024. In summary, we used a monochrome multiplex quantitative polymerase chain reaction (MMqPCR) and RTL was expressed in a ratio of telomeric signals to that of a single-copy reference gene (GAPDH; Chik et al., 2024). The intra-plate, between-duplicate repeatability of RTL was 95.7% (s.e. = 0.2%); and the inter-plate repeatability was 97.7% (s.e. = 0.9%; Chik et al., 2024). In this

154 population, RTL declines linearly with age within an individual and its individual repeatability was
155 14.0% (95% CI: 9.1%-19.9%; Chik et al., 2025).

156

157 ***Statistical analyses***

158 We used Bayesian generalised linear mixed models (GLMMs) to test the effect of natal noise on chick
159 body mass, body condition at fledging, fledging success, and adult RTL, with *RStan* 2.32.7 (Stan
160 Development Team, 2025) and *brms* 2.21.0 (Bürkner, 2021) in R 4.4.3 (R Core Team, 2025). For
161 chick body mass and fledging success, we used a dataset that only contained cross-fostered chicks to
162 reduce collinearity between natal and rearing environments, which contained 4,143 mass measures
163 from 1,810 chicks. Body condition at fledging was a subset of this dataset, which only contained
164 individuals that survived to the last nest visit and had 1,170 measures from 1,170 individuals. Adult
165 RTL had a much smaller dataset, so we used all 1,236 adult RTL measures from 652 individuals,
166 including both cross-fostered and non-cross-fostered individuals, to ensure a sufficient sample size.

167

168 *Chick mass*

169 We fitted a GLMM with standardised chick mass as the response variable with a Gaussian residual
170 distribution, and the following variables as fixed effects: presence of noise in the natal environment (1
171 = present, 0 = absent), presence of noise in the rearing environment (1 = present, 0 = absent), age
172 (days), brood size (continuous). Brood size was included to control for the effect that chicks from
173 larger broods were lighter (Cleasby et al., 2011). Sex was not included because the sexes of chicks
174 that died before we blood sampled them were unknown. The model included the following random
175 effects: bird ID, to account for the nonindependence of the mass measured for the same chick at
176 different ages; natal brood ID, to account for the genetic factors that individuals hatched in the same
177 brood might share (Schroeder et al., 2012); cohort, to account for annual stochasticity. Rearing brood
178 ID was not included because only cross-fostered individuals were included in this dataset, and thus
179 rearing brood ID was perfectly correlated with natal brood ID and would explain the same variance.

Body condition at fledging

To ensure that the effect of noise was assessed on chick body condition rather than raw body mass, which could be confounded by skeletal size (Labocha & Hayes, 2012), we fitted a GLMM using a reduced dataset that included only the measurement taken right before fledging—prior to which tarsus length was not measured. This model used the same response variable, fixed and random structures as the chick mass model, except that tarsus length and sex (0 = female, 1 = male) were included as fixed effects to control for the effects of skeletal size and sex (Cleasby et al., 2011). The random effect bird ID was removed because each bird was measured only once.

Fledging success

We fitted fledging success as the response variable (1 = fledged, 0 = failed to fledge) with a Bernoulli distribution, and the same fixed and random structure as for the chick mass model. Brood size was kept in the model to account for the effect that chicks were less likely to fledge as brood size increased (Cleasby et al., 2010). Bird ID was not modelled as a random effect because there was one observation per bird.

Adult telomere shortening and sex-specific effect

Adult RTL was z-standardised (zRTL) for comparability with other studies (Verhulst, 2020). We modeled zRTL as the response variable, with a skew-normal distribution to account for the skewness of the data (Bürkner, 2021). We fitted the presence of noise in the natal environment (1 = present, 0 = absent) and age (in years) as fixed effects, and their interaction (natal environment * age) was fitted to test whether the change in zRTL with age was dependent on the noise presence in the natal environment. We included age^2 and natal environment * age^2 to allow the age effect to be non-linear. We also included the interaction between the natal environment and sex (0 = female, 1 = male) to test

whether the natal noise affected males and females differently. The GLMM also included the fixed effects of blood storage time (blood age, years) and its squared term (blood age^2), to control for the effect of the duration for which the samples were stored as whole blood (Chik et al., 2025; Sibma, 2021); DNA storage time (DNA age, years) and its squared term (DNA age^2), to control the effect of duration for which the samples were stored as extracted DNA (Chik et al., 2025; Sibma, 2021); technician identity (A = 0, B = 1), to control for the effect of technician performing the laboratory experiments; age of the genetic father (paternal age at conception, PAC), to control for the potential effect of PAC on RTL, which was previously found in other species (Eisenberg & Kuzawa, 2018; Sparks et al., 2022); the interaction between PAC and offspring sex, to account for sex-specific PAC effect (Bennett et al., 2022). Random effects included bird ID, to account for the nonindependence of the RTL measures from the same individual; plate, to account for the plate effect in the qPCR (Chik et al., 2024); year of sampling, to account for the variance introduced by year-dependent environmental factors (Simons et al., 2019); natal brood ID, to control for the effect that chicks hatched in the same brood had similar genetic backgrounds; and rearing brood ID, to control for the effect of the quality of parental care. We removed non-significant interactions from the zRTL model, least significant first based on the probability of direction, to facilitate interpretation of first-order effects. To account for the effect of maternal age at conception (MAC) on zRTL (Marasco et al., 2019), we built a separate model with PAC substituted with MAC, to avoid collinearity from age-assortative mating, and followed the same procedure to remove non-significant interactions. To account for the impacts of outliers on the model result, we carried out leave-one-out cross-validation (LOO) using *loo* 2.9.0 (Vehtari et al., 2015).

To examine whether the significant interaction of natal environment * age detected by the previous model was due to a between-individual effect or a within-individual effect, we decomposed age in the final zRTL model into two components: mean age (mean of the ages that each individual appeared in the dataset) and Δage (age – mean age) (van de Pol & Wright, 2009). This decomposition allowed mean age to capture between-individual differences—i.e., whether individuals that tend to live longer also differ in average RTL—while Δage captures the within-individual change in RTL with age. We

included both natal environment * mean age and natal environment * Δage in the model to identify which effect natal environment interacted with. We then removed natal environment * Δage because it was not significant, to facilitate interpretation of first-order effects.

We z-standardised all continuous predictors to facilitate model convergence and to ensure that predictions remained within a biologically interpretable range. We checked collinearity and ensured that the VIF for all continuous predictors was <3 (Zuur et al., 2009). We used weakly informative priors in all models (Table S1). We ran all models for four chains, each with 2,000 iterations after a warm-up of 2,000 iterations. For modelling body condition at fledging, we increased the drift rate parameter 'delta' to 0.95 to reduce divergent transitions after warm-up, which is within the recommended range of 0.8 to 1 (Bürkner, 2021). The R hat parameters for all predictors were 1.00, and the Monte Carlo standard errors (MCSE) for posterior means were <0.01, indicating stable estimates. The model fit was then checked by visually inspecting the density and trace plots generated by the plot function and the posterior predictive plot generated by the pp_check function in *brms*. All models showed satisfactory convergence and fit, except for the zRTL model, where the posterior predictive plot indicated a poor match to the skewed observed data (Fig. S1). Table S2 presents a summary of the posterior distribution of this model.

Results

Natal noise did not significantly affect chick mass, body condition at fledging, or fledging success (Table 1, Fig. 2). Noise in the rearing environment significantly reduced chick mass and body condition at fledging, and marginally reduced fledging success (Table 1, Fig. 2). The larger the brood was, the lighter the chicks were, but brood size did not predict body condition at fledging or fledging success (Table 1, Fig. 2). Chick mass increased with age (Table 1, Fig. 2a). Male chicks were heavier at fledging, when controlling for tarsus length (Table 1, Fig. 2b).

The age effect on adult RTL at old ages was significantly more positive for birds from a noisy natal environment than it was for birds from a quiet natal environment (Table 2, Fig. 3a). Although the

posterior predictive plot showed a suboptimal match to the observed data distribution (Fig. S1), the R hat parameters and MCSEs indicated stable posterior estimates, suggesting that the model captured the trend of the data, and parameter estimates and credible intervals can be interpreted with confidence regarding their direction and relative strength. The model using MAC instead of PAC led to the same conclusion (Table S4-5), confirming an environmental effect. The LOO identified two data points with the shape parameter $k > 1$, indicating outsized influence of these observations on the posterior distribution of the model (Vehtari et al., 2017). Removing these two observations let the credible interval (CrI) of the interaction natal environment * age border zero (CrI: [-0.00, 0.17]), but the trend persisted that the age effect was more positive for old birds from a noisy natal environment than it was for those from a quiet natal environment. We retained these data points in the model because they were real observations (Fig. S2).

The model decomposing age into mean age and Δage indicated that this effect was a between-individual age effect in response to natal noise: in birds from a noisy natal environment, telomere length was longer in long-lived birds than it was in short-lived birds, yet this was not the case for birds from a quiet natal environment (Table 3, Fig. 3b). The interaction between Δage and natal environment was not significant, indicating that natal noise did not affect the within-individual telomere shortening rate with age (Table 3). Adult zRTL changed quadratically as Δage increased (Table 3, Fig. S3).

Discussion

Natal noise exposure did not predict short-term fitness components, including chick mass, body condition at fledging, and fledging success. However, we observed a positive effect of the interaction between natal noise exposure and age on adult telomere length, which was accounted for by between-individual differences. This indicates selected disappearance—among individuals exposed to natal noise, those who lived longer tended to also have longer telomeres. We did not observe sex-specific effects of natal noise on adult telomere shortening.

Natal noise exposure did not affect chicks' short-term fitness in our study. Studies specifically testing the effect of pre-hatching noise on chicks are lacking (except for Kesar, 2014 and Meillère et al., 2024). Post-hatching or combined pre- and post-hatching environmental noise can affect corticosterone levels, growth, and body conditions in nestlings in some studies (Injaian et al., 2019; Injaian, Taff, & Patricelli, 2018; Injaian, Taff, Pearson, et al., 2018), but other studies also found no support for such effects (Angelier et al., 2016) or even effects contrary to expectations (Crino et al., 2013). In particular, a previous study in house sparrows measuring corticosterone stress response found no evidence that chicks exposed to noise during the breeding season (including pre- and post-hatching stages) suffered from chronic stress (Angelier et al., 2016). It was speculated that this resistance to noise disturbance might be a characteristic of house sparrows as urban exploiters (Angelier et al., 2016). Selective disappearance in embryos could also mask the negative effect of natal noise—i.e., low-quality embryos that died in the noisy environment before they could hatch. The deleteriousness of noise on embryonic development and survival has been reported in many species, including birds (Meillère et al., 2024; Potvin & MacDougall-Shackleton, 2015; Williams et al., 2021) and invertebrates (Nedelec et al., 2014). In our population, however, we do not have sufficient data on hatching success to test this hypothesis. There was no significant difference in the number of hatchlings per brood in quiet and noisy environments (t-test, $p = 0.44$), implying no effect of environmental noise on embryonic survival. However, further studies on whether natal noise is detrimental to embryonic development are needed to confirm this implication and to help us understand the mechanisms underlying the natal noise effect in this population.

Noise in the rearing environment, on the other hand, had a negative effect on chick mass and body condition at fledging, and a marginal negative effect on fledging success in our study. Together with the findings in the same population that noise in the rearing environment was associated with reduced fledging success, body mass at day 12, and recruitment rate (Schroeder et al., 2012), our study confirmed the negative short-term fitness consequences of rearing environmental noise in this population. This is because noise acoustically masked the parent-offspring communications, leading to reduced provisioning (Schroeder et al., 2012). In summary, the short-term fitness consequences

were attributed to the noise exposure in the rearing, rather than the natal environment, in our population.

Brood size was negatively associated with chick mass, in line with a previous study (Cleasby et al., 2011). However, brood size did not predict fledging success or body condition among fledglings. It is possible that chicks from larger broods were smaller in skeletal size, which has been observed in studies using brood size manipulation or food supplements (Cleasby et al., 2011; Hõrak, 2003; Smith et al., 1989), but not in a study using natural brood size variation (Howard, 1980). Alternatively, although fledging success did not differ by brood sizes, only chicks with good body condition might have survived in large broods. Future studies investigating the selective disappearance resulting from within-brood competition will help tackle this question.

We observed a positive interaction between the effects of natal noise and age on adult telomere length. We revealed that this was due to selective disappearance—i.e., birds that experienced natal noise and that had longer telomeres lived longer, rather than that telomeres lengthened as an individual aged (Fig. 3b & S3). As such, birds with shorter telomeres were more likely to disappear from the population if incubated in the noisy environment. Previous work in the study population showed that adults with shorter telomeres died earlier, leading to a bias for longer telomeres in older individuals (Sibma, 2021). Given that telomere length is a biomarker of oxidative stress (Reichert & Stier, 2017), our finding suggests that individuals from a noisy natal environment might be more likely to die under oxidative stress of the same intensity than those from a quiet natal environment. Together with the finding that natal noise was associated with reduced annual reproductive output (Sun et al. 2025), this suggests that natal exposure to noise is a cause of lifetime physiological consequences, aligning with the prediction of the silver spoon hypothesis. Our cross-fostering experiments were not conducted until the second day after hatching. It is possible that the disturbance of the parents' provisioning behaviour in the first two days played a critical role, as human studies have shown that provision of nutrition in a very early stage of life could be associated with growth and neurodevelopmental outcome on some occasions (Poindexter et al., 2006).

Adult telomere length first decreased and then slightly increased as an individual aged, and this within-individual age effect was not affected by the presence of natal environmental noise. Although a previous study in the same population found a linear relationship between adult RTL and within-individual-centred age (Chik et al., 2025), the quadratic term in our study was of small effect size (0.01, with the 95% CrI bordering 0), thus confirming the previous study (Fig. S3 in this study vs. Fig. 1 in Chik et al., 2025). As for whether pre-hatching environmental noise affects telomere dynamics, a study in Australian zebra finches *Taeniopygia guttata castanotis* found that adult telomeres were shorter in birds incubated in a noisy environment than in those incubated in a quiet environment, but the age effect and its interaction with noise were not investigated (Meillère et al., 2024). Although not on the effect of noise, another study in *Taeniopygia guttata* highlighted a determinant effect of telomere shortening rate before and just after hatching on post-hatching telomere length (Xiong et al., 2025). Other studies found negative effects of noise on telomere length, but they focused on nestling instead of adult telomere lengths and did not separate natal and rearing effects (Grunst et al., 2020; Injaian et al., 2019; Meillère et al., 2015). We propose two explanations regarding the absence of an effect of natal noise on within-individual telomere shortening in adulthood in our study. First, because telomere lengths are considered to reflect cumulative oxidative damage (Boonekamp et al., 2013; Houben et al., 2008), the effects of natal factors might be diluted as the birds get older. This could be resolved by measuring nestling telomere lengths. Second, unlike zebra finches, which inhabit grasslands and open or grassy woodlands with some proportion of inhabitation in cultivated areas (Payne, 2020), house sparrows are a successful human-commensal species (Ravinet et al., 2018) and may be more resistant to anthropogenic disturbance such as noise.

We did not detect a sex-specific effect of natal noise exposure on body condition at fledging or adult telomere length, even though natal noise exposure was associated with a significant reduction specifically in female lifetime reproductive output in this population (Sun et al., 2025). Our results suggest that the decline in female reproductive performance might not be mediated by a deterioration in somatic condition. A plausible explanation is that individuals allocated more resources to somatic maintenance at the cost of future reproductive success under noise stress during embryonic

development to maximise lifetime fitness (Kirkwood, 2002). A meta-analysis showed that the adverse effects of developmental environments were reflected by a faster decline in late-life reproduction instead of survival, presumably due to the same reason (Cooper & Kruuk, 2018). Male reproduction is less energetically demanding than female reproduction, which may explain why it was not detectably affected by natal noise exposure. This life history plasticity to maintain body condition and survival in response to noise stress during development at the expense of adult reproductive output might again be one of the manifestations of the superiority of house sparrows to adapt to human-commensal niches. This might be a direction for future studies to explore.

In conclusion, we found that natal noise altered the age-telomere relationship in adulthood, indicating its potential long-lasting physiological effects. Future studies on the direct effect of noise disturbance on development, as well as studies on long-term consequences of other natal stressors, will be valuable for understanding the nature of these long-lasting effects and the mechanisms underlying them. We also note that the absence of a detectable effect of natal noise on somatic condition in house sparrows may be attributable to their characteristics as a successful human-commensal.

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Tables

Table 1. Fixed and random effect estimates with [95% CrI] from the GLMMs testing the effect of the natal environmental noise on z-standardised chick mass, body condition at fledging, and fledging success in Lundy house sparrows. Significant fixed effects are in bold; fixed effects whose 95% CrI borders zero are in italics. Number of levels for random effects is in brackets. CrI: credible intervals.

Response variable:			**Chick mass**	**Body condition at fledging**	**Fledging success**
Fixed effects	(Intercept)	(Level)	0.05 [-0.03, 0.13]	0.03 [-0.14, 0.21]	-1.12 [-1.63, -0.63]
	Natal environment	Noisy	-0.03 [-0.06, 0.01]	0.00 [-0.11, 0.12]	0.11 [-0.24, 0.44]
	Rearing environment	Noisy	**-0.04 [-0.08, -0.00]**	**-0.11 [-0.22, -0.01]**	*-0.32 [-0.65, 0.00]*
	Age		**0.92**	-0.02	

			[0.91, 0.93]	[-0.05, 0.01]	
	Brood size		**-0.03**	-0.01	-0.09
			[-0.05, -0.02]	[-0.05, 0.04]	[-0.24, 0.05]
	Tarsus length			**0.80**	
				[0.77, 0.84]	
	Sex	Male		**0.10**	
				[0.04, 0.16]	
Random effects (number of levels)	Bird ID		0.13		
			[0.12, 0.15]		
			(1810)		
	Cohort		0.13	0.27	0.744
			[0.07, 0.22]	[0.15, 0.46]	[0.36, 1.31]
			(11)	(11)	(11)

	Rearing brood			
	Natal brood	0.15	0.42	0.97
		[0.13, 0.16]	[0.38, 0.46]	[0.72, 1.22]
		(608)	(462)	(613)

592

593 Table 2. Fixed and random effect estimates with [95% CrI] from the GLMM testing the effect of the
594 natal environmental noise on adult z-standardised relative telomere length (zRTL) in Lundy house
595 sparrows. Significant fixed effects are in bold. Number of levels for random effects is in brackets. CrI:
596 credible intervals. PAC: paternal age at conception. For results of the full model, see Table S3.

Fixed effects	**Level**	**Estimates**
(Intercept)		-0.13 [-0.42, 0.15]
Natal environment	Noisy	0.01 [-0.10, 0.11]
Rearing environment	Noisy	-0.00 [-0.10, 0.09]
Age		-0.02 [-0.07, 0.03]
Age^2		0.01 [-0.02, 0.03]
DNA age		**-0.24 [-0.46, -0.01]**
DNA age^2		0.01 [-0.08, 0.10]
Blood age		**-0.27 [-0.48, -0.02]**
Blood age^2		-0.01 [-0.13, 0.12]
PAC		0.01 [-0.02, 0.05]
Sex	Male	0.04 [-0.03, 0.10]
Technician	B	-0.03 [-0.20, 0.14]
Natal environment * age	Noisy	**0.09 [0.00, 0.18]**
Random effects		**Estimates (number of levels)**
Bird ID		0.07 [0.00, 0.17]

		(652)
Rearing brood		0.09 [0.00, 0.17]
		(446)
Natal brood		0.09 [0.00, 0.18]
		(444)
Capture Year		0.30 [0.17, 0.54]
		(13)
Plate		0.22 [0.16, 0.28]
		(82)

Table 3. Fixed and random effect estimates with [95% CrI] from the GLMM testing the effect of the natal environmental noise on adult z-standardised relative telomere length (zRTL), with age decomposed into mean age and within-individual-centred age (Δage). Significant fixed effects are in bold; fixed effects whose credible interval (CrI) borders zero are in italics. PAC: paternal age at conception. For output of the reduced model where the non-significant interaction natal environment * Δage was removed, see Table S6.

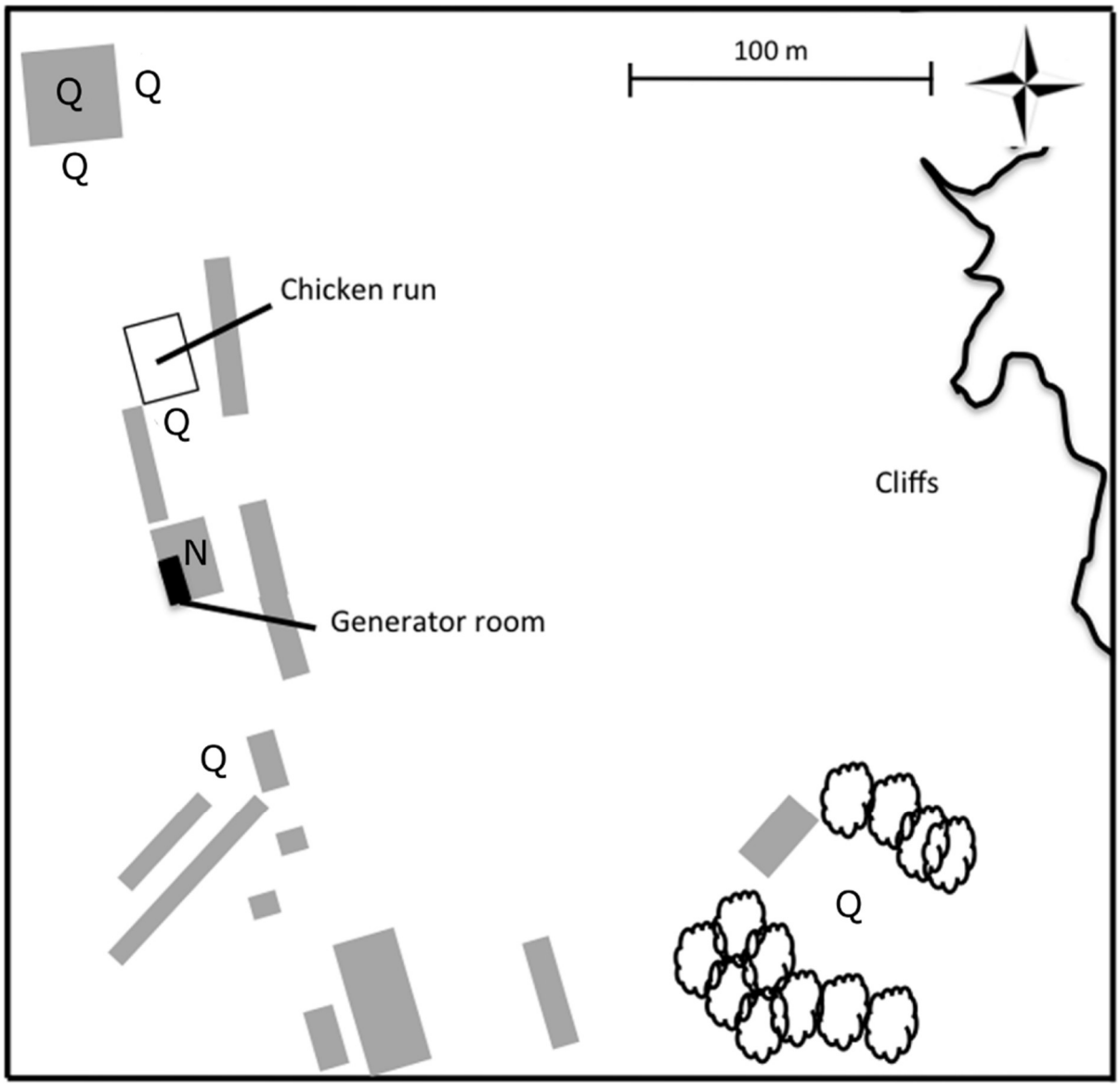
Fixed effects	**Level**	**Estimates**
(Intercept)		-0.14 [-0.43, 0.16]
Natal environment	Noisy	0.02 [-0.09, 0.12]
Rearing environment	Noisy	-0.01 [-0.11, 0.09]
Δage		-0.01 [-0.05, 0.02]

Δage²		*0.01 [-0.00, 0.03]*
Mean age		-0.01 [-0.06, 0.03]
DNA age		**-0.24 [-0.46, -0.01]**
DNA age²		0.01 [-0.08, 0.10]
Blood age		**-0.26 [-0.47, -0.02]**
Blood age²		-0.01 [-0.14, 0.11]
PAC		0.01 [-0.02, 0.05]
Sex	Male	0.04 [-0.03, 0.10]
Technician	B	-0.03 [-0.19, 0.13]
Natal environment * Δage	Noisy	0.02 [-0.06, 0.10]
Natal environment * mean age	Noisy	**0.10 [0.01, 0.19]**
Random effects		**Estimates**
		(number of levels)
Bird ID		0.08 [0.00, 0.17]
		(652)
Rearing brood		0.09 [0.00, 0.18]
		(446)
Natal brood		0.09 [0.01, 0.18]
		(444)
Capture Year		0.30 [0.17, 0.53]

		(13)
Plate		0.21 [0.16, 0.28]
		(82)

605

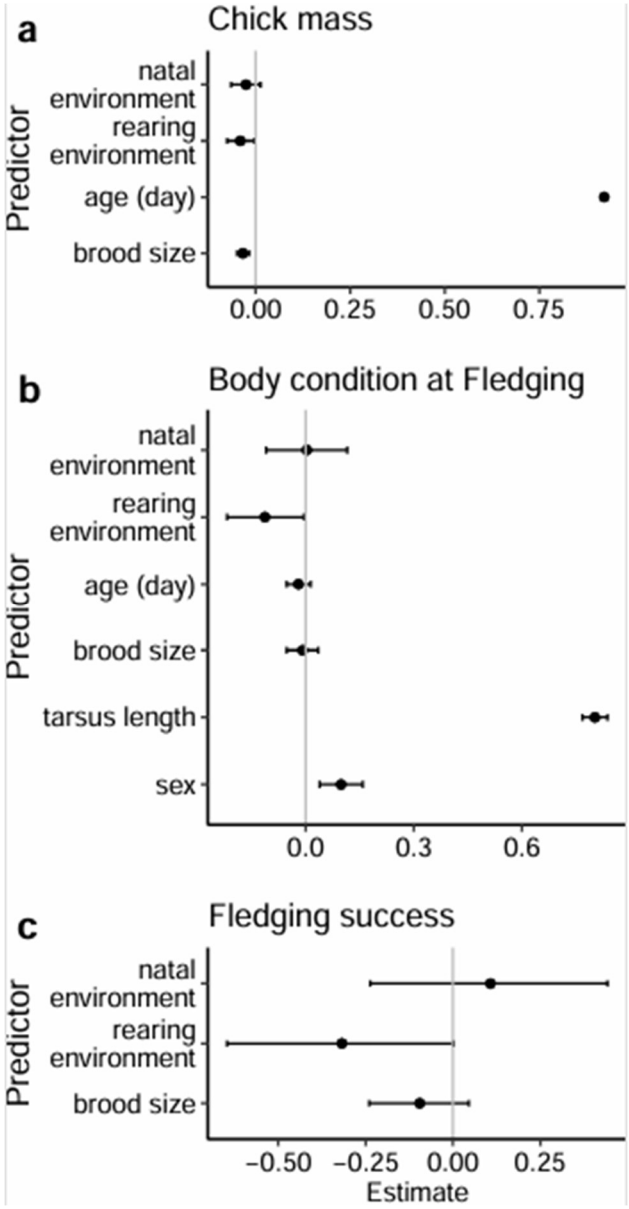
606 **Figures**



607

608 Figure 1. Locations of quiet (Q) and noisy (N) house sparrow breeding sites on Lundy Island. The
609 chicken run was the main feeding site of the house sparrows. Adopted from Sun et al. (2025).

610

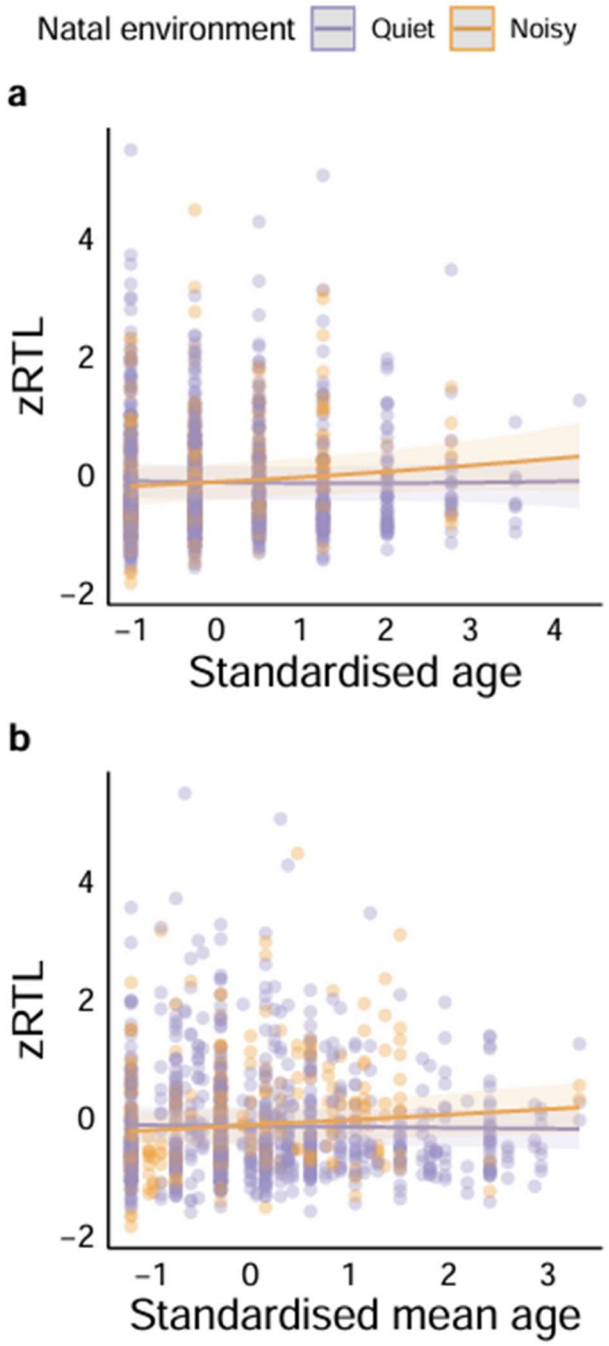


611

612 Figure 2. Effect sizes with 95% credible intervals of the fixed effects predicting (a) chick mass, (b)

613 body condition at fledging and (c) fledging success.

614



615

616 Figure 3. Adult zRTL (z-standardised relative telomere length) in relationship to (a) z-standardised
617 age and (b) z-standardised mean age (mean of the ages that each individual appeared in the dataset) in
618 Lundy house sparrows. Each dot represents an observation; lines are predicted zRTL; shaded areas
619 represent 95% credible intervals.

620

621