

activity will be partially compensated by reduced daytime activity.

7) Examine whether more intense *Zugunruhe* is a characteristic of generally more active birds. We test whether activity levels of birds covaried between migratory and non-migratory contexts. We compare nocturnal activity levels of individuals during migration seasons (*Zugunruhe*) to a) nocturnal activity levels during 'neutral', non-migratory seasons, and to b) diurnal activity levels during non-migration seasons. We posit that a positive correlation between activity levels of these periods will weaken the assumption that individual variation in *Zugunruhe* uniquely represents individual variation in migratory propensity.

## Methods

### Birds and experimental setup

#### Origin and maintenance of birds

We present data from 976 migration periods (minimal duration 90 d) from 414 stonechats of the following four population groups: *S. rubicola rubicola* from Austria (hereafter referred to as 'Austrian' or by code A;  $n = 147$ ;  $48.0^{\circ}\text{N}$ ); *S. rubicola hibernans* from Ireland (hereafter 'Irish' or I;  $n = 83$ ;  $52.0^{\circ}\text{N}$ ); *S. torquatus axillaris* from Kenya (hereafter 'Kenyan' or K;  $n = 25$ ;  $0^{\circ}\text{N}$ ); and *S. maurus* from Kazakhstan (hereafter 'Siberian' or S;  $n = 53$ ;  $51.5^{\circ}\text{N}$ ) (Fig. 1A). We also included hybrid Austrian  $\times$  Kenyan stonechats ( $n = 16$ , all A  $\times$  K F1) and Austrian  $\times$  Siberian stonechats (A  $\times$  S;  $n = 80$ ). Austrian  $\times$  Siberian included F1 crosses ( $n = 56$ ) and backcrosses (A  $\times$  S with Austrian parent:  $n = 16$ ; A  $\times$  S with Siberian parent:  $n = 8$ ). Hereafter, we refer to the four populations and the hybrid groups simply as 'populations' (for details see Supplementary material Appendix 1, and Helm 2003, 2009).

For the birds in this study, the sex ratio was consistently nearly balanced in all groups (overall: 193 females, 221 males). The vast majority (330) were offspring of captive stonechats from our breeding scheme (i.e. at least 2nd generation in captivity), and were born between 1998 and 2006. Between 1997 and 2004, 84 birds were taken from the field, usually as nestlings, with the exception of two Irish stonechats that were collected as wintering adults in January 2003. After fledging, birds were housed individually indoors in recording cages ( $60 \times 40 \times 40$  cm) (Gwinner et al. 1995). Birds were kept under constant mild temperatures (ca  $20^{\circ}\text{C}$ ) and under light exposure of ca 300 lx during daytime and 0.01 lx at night, simulating natural photoperiodic change as described below. We assessed postjuvenile moult by inspection of wing and 19 defined body areas (Helm and Gwinner 1999). To focus on the main phase of moult, we defined its onset and end when birds crossed a threshold of at least 5 simultaneously moulting body areas.

#### Photoperiodic conditions

A main purpose of the breeding experiments were comparisons of the stonechat populations under identical conditions (i.e. 'common garden', Noordwijk et al. 2006). Birds were kept indoors under one of three photoperiods that all simulated naturally fluctuating photoperiods. The vast majority

( $n = 356$ ) were kept under conditions that simulated day length experienced by Austrian stonechats around the annual cycle; two Irish birds experienced summer day lengths mimicking those of their native location ( $52.5^{\circ}\text{N}$ ). A further 37 birds were exposed to simulated day length experienced by Siberian stonechats (Siberian and Austrian stonechats and their hybrids). Finally, 8 birds were exposed to both European and Irish day lengths during different years, and 11 were exposed to both European and Siberian day lengths during different years. In our analyses, if data were used from day length simulations other than those of Austrian stonechats, we included photoperiod as a covariate. The data reported are numbers of daily or nightly 10-min intervals during which activity was detected by passive infrared detectors.

### Data preparation and processing

#### Data preparation

For our primary *Zugunruhe* analysis, we only analysed nocturnal activity data after a bird had started postjuvenile moult (Fig. 2). Overall, missing data represented 1.0% of our dataset and were handled as explained in Supplementary material Appendix 1. We split the annual cycle into two halves to quantify spring and autumn migration periods separately. To do so, we determined population-specific cut-off dates as the mid-points of summer and winter periods when nocturnal activity was minimal (for details, see Supplementary material Appendix 1).

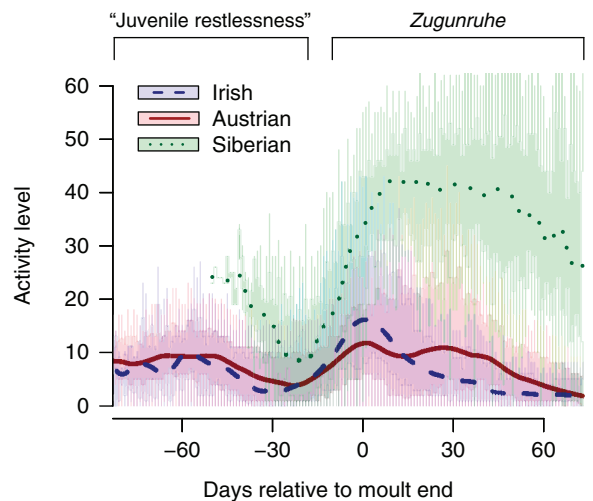


Figure 2. Nocturnal activity relative to moult completion in juvenile Irish, Austrian and Siberian stonechats. Although stonechats do not migrate until after the completion of postjuvenile moult, young birds showed 'juvenile restlessness' before this time, especially 50 or more days before moult completion (negative values along the x-axis). This activity typically reached a minimum 20–30 d before moult completion, after which *Zugunruhe* began. Activity level is defined as the number of active ten-minute periods during the night for an individual bird. For each day, curves show medians, and a boxplot describes the activity levels of birds in each population. Wide coloured bars corresponding to a given day represent the interquartile range (middle 50%) of activity values for stonechats on that day. Thin coloured lines extend outwards to the most extreme data point that is not an outlier, where an outlier is defined as exceeding a distance of 1.5 times the interquartile range from the bar. For clarity, outlier points are not shown.