Changepoint analysis for identifying and characterising periods of Zugunruhe

We applied changepoint analysis, developed to identify changes in the statistical properties of time series data, in the R package 'changepoint' (Killick and Eckley 2014). This algorithm assesses the mean and variance of time series data and identifies any changes in these properties (or absence thereof). Accordingly, we classified a migration period of a given bird as showing *Zugunruhe* if at least one changepoint was identified. A changepoint is identified if its addition to the model sufficiently improves the log-likelihood enough to overcome a penalty value used to prevent too many changepoints from being identified. Changepoint analysis of spring and autumn data provided us with one or more time segments for each migration period (Supplementary material Appendix 2, Fig. A1). When the analysis identified one or more changes, we classified a contiguous sequence of elevated segments as *Zugunruhe* (Supplementary material Appendix 2, Fig. A1).

Defining timing and intensity of Zugunruhe

For each migration period, we calculated several *Zugunruhe* timing metrics. Onset and end dates were given by the starting and ending dates of the contiguous elevated *Zugunruhe* period (Supplementary material Appendix 2, Fig. A1); duration was inferred as the number of days between start and end dates. We defined 'Mean day' as the average day from the elevated period, weighted by nightly activity levels. To derive a consistently defined measure of intensity, we first calculated the mean activity level during the contiguous 15-d period with highest overall activity (hereafter 'uncorrected peak intensity'). We then calculated 'corrected' peak intensity as the difference between uncorrected peak intensity and the mean of winter and summer baseline activity levels flanking the migration period. This correction accounts for consistent, year-round inter-individual differences in activity levels. We also calculated a bird's overall mean intensity as the average activity level over an entire elevated *Zugunruhe* period. Lastly, for comparability with the practice of some studies on *Zugunruhe*, we conducted a supplemental analysis in which we normalized our data according to the concurrent length of night (Owen and Moore 2008); we illustrate some comparative findings in Supplementary material Appendix 1.

Statistical analyses

Factors affecting occurrence of Zugunruhe

To identify which factors influence *Zugunruhe*, we modelled the proportion of spring and autumn migration periods with and without *Zugunruhe* by an analysis of deviance with binomial errors ('glm' function in the R base 'stats' package). The initial model comprised the categorical predictors of population (including hybrid groups), sex, age (first year or older), migratory season (spring or autumn), and all possible interactions. See Supplementary material Appendix 1 for details.

Consistent individual propensity to engage in Zugunruhe

We additionally examined intra-individual patterns of *Zugunruhe* for birds with activity data for more than two periods (spring or autumn). We analysed variation in the proportion of birds that always, sometimes, or never engaged in *Zugunruhe* during the periods for which they were monitored. We compared proportions using the 'pairwise.prop.test' function in R and corrected for multiple comparisons with the Holm–Bonferroni method (Holm 1979).

Variation in Zugunruhe timing and intensity

We examined overall variation in timing and intensity of *Zugunruhe* using linear mixed models (packages lme4 and lmerTest in R; Bates et al. 2015, Kuznetsova et al. 2015) as detailed in Supplementary material Appendix 1.

Population-wide nocturnal and diurnal activity during the migration periods

In addition to the procedure described above, we analysed overall nocturnal and diurnal activity levels during the migration periods of all individuals, regardless of the *Zugunruhe* status assigned to them by changepoint analysis, for compatibility with earlier analyses (e.g. blackcaps *Sylvia atricapilla*, Berthold 1988a). This required definitions of migration periods that were independent of changepoint analysis, as explained in Supplementary material Appendix 1. Diurnal activity of this data set was used to test for age-related changes in activity levels during the migration seasons. We also analysed these data by an approach that has sometimes been used in the literature, correcting the amount of nocturnal activity for the length of night. This follows the rationale that activity levels may be limited by night length, but it has the disadvantage of confounding activity level with time of year, which determines night length.

Covariation of diurnal and nocturnal activity levels

To examine how daytime activity varied relative to *Zugunruhe* (defined using changepoint analysis), we tested diurnal activity levels before, during, and after birds engaged in *Zugunruhe* with linear mixed models. We also studied the association between nocturnal and diurnal activity levels within individuals during both migration seasons and the 30-d neutral summer and winter periods (Supplementary material Appendix 1).

Covariation of activity between migratory and non-migratory contexts

We used two approaches to test whether high nocturnal activity levels during *Zugunruhe* periods were specific to a migration context, or, alternatively, reflected generally elevated activity levels of populations or individuals. First, we compared nocturnal activity during and outside of migration periods to test whether individuals with higher *Zugunruhe* activity were generally more active at night. Secondly, we compared *Zugunruhe* to diurnal activity during the non-migration seasons to test the hypothesis that individuals with high *Zugunruhe* were generally more active birds. We used linear mixed models (Supplementary material Appendix 1).

Data available from the Dryad Digital Repository: <http://dx.doi.org/10.5061/dryad.484m0> (Van Doren et al. 2016).