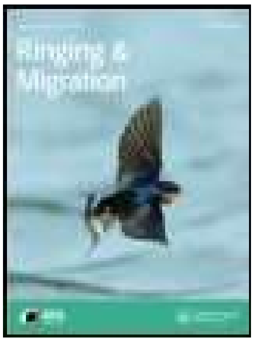

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Descriptive models for first-arrival dates of migrants in an inland UK county

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This forum article describes the analysis of first-arrival dates of migrant birds in Shropshire from the 1880s to 2010s. The process of analysis is described here in some detail, firstly to encourage similar data compilations for other areas and secondly to indicate features of data handling and analysis where special care must be directed; such manipulations are generally glossed over in write-ups!

The value of first-arrival dates has been debated, but Sparks *et al* (2001) concluded that trends in first-arrival dates over time constitute robust data that can be related to environmental changes. Shropshire is a landlocked county in the English Midlands, where the records are less affected by local weather events creating falls of migrant birds than would be the case in a coastal area. It is striking that we found simple trends for many species. We examined the data to look for periods of sustained change or trends. These are not investigated further here with regard to climatic or biological factors (as e.g. by Sparks & Braslavská 2001), but finding different patterns between species in our data might prompt such investigations. The timing of first arrivals will however be influenced by factors all along the migration route (Gordo 2007).

Methods

Compilation of the data set

In preparation for the Shropshire avifauna (*The Birds of Shropshire*: Smith 2019, here abbreviated to BoS), JJT compiled annual first-arrival dates for 32 species from county archives and other sources, as will be listed in BoS. The result is probably among the longest-running and most complete sets of such avian records, and has been made available online as the Shropshire's Migrant Arrival Database (SMAD: www.pgt7.uk/sos/general/index.php). Other studies (e.g. Rubolini *et al* 2007) describe 30-year sequences as 'long-term'.

The data will be described in BoS and its species accounts. They cover 130 years from the earliest record, a Cuckoo in 1871, to the end of 2017, for 29 species arriving in spring and three in autumn. The number of years for which a first-arrival date is known differs between species, and there are many gaps, but there are dates for over two dozen species in each year since 1899 (Figure 1a). The series for Blackcap and Chiffchaff (scientific names in Table 1) were truncated, in 1974 and 2005 respectively, when wintering birds became prominent.

JJT spent three months extracting and checking the data from the main sources and entering them onto a Microsoft Excel spreadsheet, which continues to be refined as further records come to light.

Preparing data for analysis

RAR analysed the sheet using the statistical software Stata, version 15 for Windows (StataCorp 2017). Various pitfalls can attend such an apparently simple operation. In general, one must be aware that features of a spreadsheet that make it versatile for data entry can create problems when the data are read by another program. What shows on screen may not reflect what is stored inside the file, especially for cells containing dates. Also, spreadsheets may assume a date is being entered and apply default rules for autocompletion, by adding the current year or treating the day and month in either American or British order. For example, 6/2/1952 might be interpreted either as 6 February or as 2 June of that year. Historical dates can be subject to some uncertainty, so it is best to enter all dates as three separate fields, for day, month and year, to allow for 'fuzzy' values. The month should ideally be entered as a name, to avoid any ambiguity. Alternatively, dates can be entered as character strings and the three fields extracted into new columns using spreadsheet functions.

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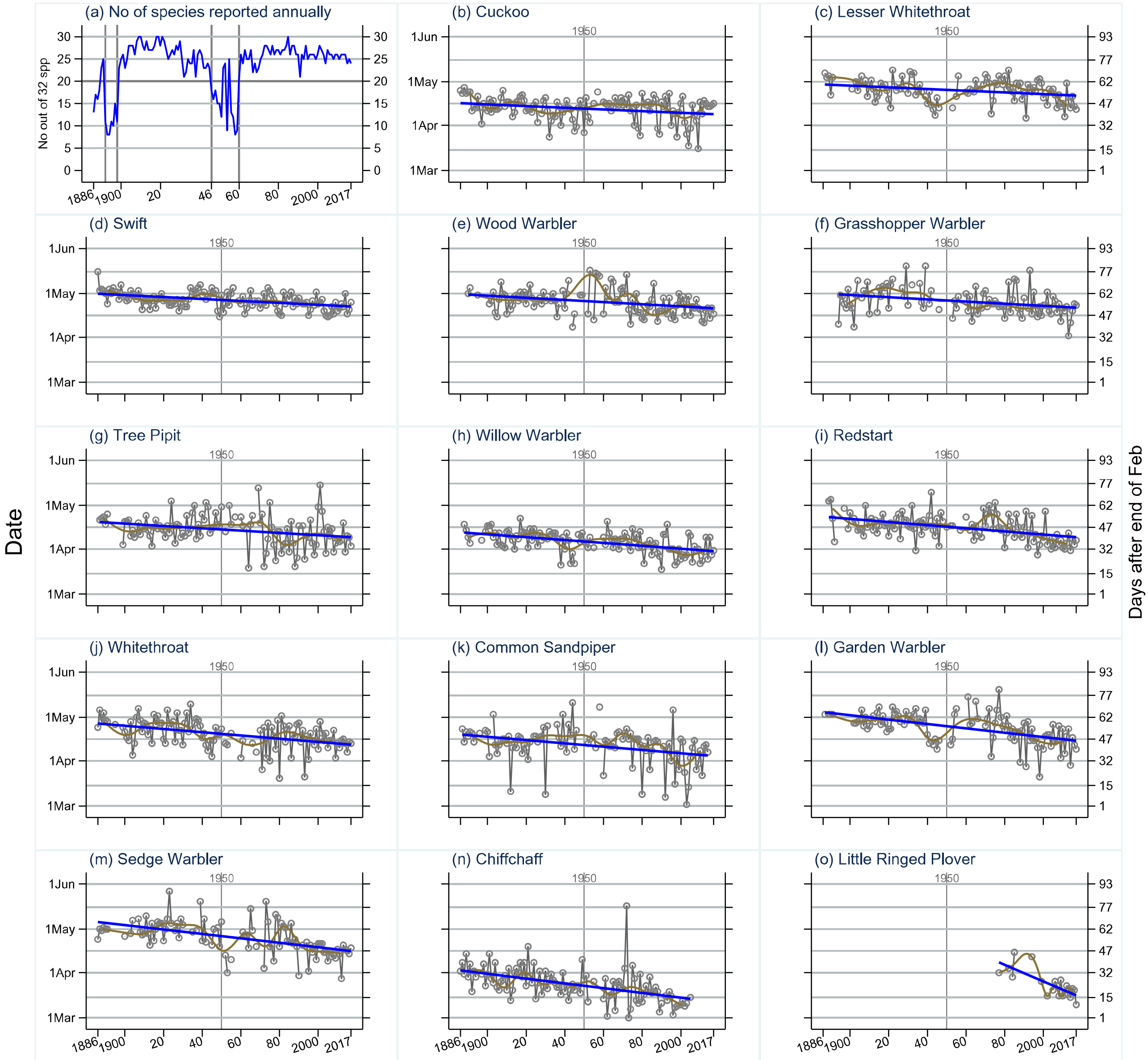

Figure 1. (a) Number of species for which data were available in each year; (b-o) species whose first arrivals have become progressively earlier, and therefore have negative linear trends.

Spreadsheet cells that appear empty may in fact contain non-printable characters and might be interpreted by statistical software in various ways. Cells have a format that can be defined individually, whereas statistical packages assign whole columns (or variables) to a single format. Spreadsheets lack the concept of missing values, which is integral to all statistical data analysis. It is helpful to enter a distinct, visible, but semantically impossible value as a flag for a missing value. In practice, it was convenient within a spreadsheet to create a pro forma data sheet with the species and years generated in sequence and the dates filled with missing values to be overwritten.

Spreadsheets are often used in a free and easy manner, for example to add notes or summary statistics, or split data into blocks. Such features underline the need for rigorous checking when data have been transferred to other software.

JJT also converted dates into numbered 'days into the year', beginning 1 January. Such values differ between leap and non-leap years for all dates after 28 February. This effect appears to have been ignored in many phenological analyses but is clearly unsatisfactory as it introduces artificial variance to all calendar dates after February. A pragmatic approach was to set 1 March as day 1 (as a variable we termed the 'bioday'). Since birds respond to factors such as the sun's ascendancy, it might be even better to relate the days to the spring equinox for its year, which can vary between years from 19 to 21 March.

Table 1. Statistics derived from fitted models, as described in the text, with species ordered by their average first-arrival dates around 1900. The series for Chiffchaff and Blackcap have been truncated, as described in the text.

Species	Letter code	Best-fit model	Average first-arrival date 1886–1915	Average first-arrival date 1986–2015	Days earlier over a century
Chiffchaff *Phylloscopus collybita*	CC	Linear	30 Mar	–	16
Sand Martin *Riparia riparia*	SM	Broken stick	1 Apr	17 Mar	16
Wheatear *Oenanthe oenanthe*	W	Broken stick	4 Apr	19 Mar	18
Swallow *Hirundo rustica*	SL	Broken stick	8 Apr	26 Mar	12
Willow Warbler *Phylloscopus trochilus*	WW	Linear	10 Apr	1 Apr	10
House Martin *Delichon urbica*	HM	Broken stick	11 Apr	2 Apr	10
Common Sandpiper *Actitis hypoleucos*	CS	Linear	15 Apr	4 Apr	11
Tree Pipit *Anthus trivialis*	TP	Linear	16 Apr	10 Apr	8
Cuckoo *Cuculus canorus*	CK	Linear	17 Apr	10 Apr	6
Wryneck *Jynx torquilla*	WY	Null	20 Apr	21 Apr	–
Redstart *Phoenicurus phoenicurus*	RT	Linear	20 Apr	10 Apr	11
Reed Warbler *Acrocephalus scirpaceus*	RW	Broken stick	21 Apr	24 Apr	27
Yellow Wagtail *Motacilla flava*	YW	Broken stick	21 Apr	9 Apr	12
Blackcap *Sylvia atricapilla*	BC	Null	22 Apr	–	
Whitethroat *S. communis*	WH	Linear	25 Apr	16 Apr	11
Nightingale *Luscinia megarhynchos*	N	Null	25 Apr	1 May	–
Whinchat *Saxicola rubetra*	WC	Null	26 Apr	24 Apr	–
Grasshopper Warbler *Locustella naevia*	GH	Linear	27 Apr	23 Apr	8
Wood Warbler *Phylloscopus sibilatrix*	WO	Linear	27 Apr	22 Apr	7
Corncrake *Crex crex*	CE	Null	28 Apr	29 Apr	–
Pied Flycatcher *Ficedula hypoleuca*	PF	Broken stick	28 Apr	15 Apr	17
Lesser Whitethroat *Sylvia curruca*	LW	Linear	29 Apr	23 Apr	6
Swift *Apus apus*	SI	Linear	30 Apr	24 Apr	7
Sedge Warbler *Acrocephalus schoenobaenus*	SW	Linear	30 Apr	16 Apr	15
Garden Warbler *Sylvia borin*	GW	Linear	1 May	15 Apr	15
Spotted Flycatcher *Muscicapa striata*	SF	Null	4 May	8 May	–
Turtle Dove *Streptopelia turtur*	TD	Null	6 May	2 May	–
Nightjar *Caprimulgus europaeus*	NJ	Null	13 May	8 May	–
Fieldfare *Turdus pilaris*	FF	Broken stick	11 Oct	5 Oct	16
Redwing *T. iliacus*	RE	Linear	18 Oct	3 Oct	18
Brambling *Fringilla montifringilla*	BL	Broken stick	26 Oct	19 Oct	13
Little Ringed Plover *Charadrius dubius*	LP	Linear	–	24 Mar	–

Analysis of the data

Our analyses used standard regression models, with bioday as the response and with normal errors. Four alternative models for each species were compared to find the best fit, as a description without implying causal links. The best-fitting model was selected for each species, based on Akaike's Information Criterion (AIC), in combination with finding the regression parameters significant after adjusting for multiple tests by a heuristic Bonferroni method (adjusted t test). Features of statistical methods that are named but not explained here are assumed to be documented in statistical textbooks or the software manuals.

The null model (1) is that the first-arrival day stayed constant on average over the 130-year period, with alternatives of (2) linear change at a constant rate over the whole period, (3) a variable rate of change, approximating to a polynomial up to cubic (allowing two points of inflexion), and (4) a 'broken stick' model with one constant rate of change up to 1950 and a different one since, forming two straight lines meeting at an angle. In a more general context, the point of inflexion of a 'broken stick' could be estimated as a parameter, but for the current study setting it as the midpoint year of the sequence appeared adequate. Also, the 1950s was a decade with sparser records (see Figure 1a) and the results suggested that to make the inflexion point a variable would be to over-fit the data.

Sequential annual observations within each species might be influenced by those of previous years, and therefore correlated with them. Such autocorrelations are less expected in county-level data as it is unlikely the same individual was seen each year, and annual first-arrival dates depend on many proximate factors. This differs, for example, from recording the arrival dates of a particular pair of Ospreys *Pandion haliaetus* at one nest. Short-term autocorrelations were tested for using ACF and PACF plots and Durbin–Watson statistics. Species that had no time trend in first-arrival dates also had no autocorrelation: this is reported here as a diagnostic rather than a result. More sophisticated time-series analysis (arima modelling) did detect serial effects in some model residuals. The optimal model for most species was the trend as described with ar(1) and ma(1) terms. The arima fits were used as diagnostic but indicated that ordinary least-squares (OLS) fits gave consistent estimates of slope.

Differences in AIC were sometimes marginal and the statistic is considered to be heuristic. The results must therefore be interpreted with regard to other information about each species. It was also possible for the model with the lowest AIC nevertheless to have a slope that was not significant, that is, with insufficient evidence that the slope was different from zero. Hence there cannot be an absolute divide between species that show a trend and those that do not.

As a visual aid to presentation, a local smoothing line was also computed for each series, using the Stata mspline command based on 13 bands, so that each band represents about ten years.

For species where the first-arrival date has become earlier over time, the question "by how much?" has been posed. There is no single answer to this. Taking the difference between predicted dates from the model at the end and start of the period is circular logic, and uses the regression model for inference rather than description. Multiplying the slope by any number of years gives an average precession, per century, say. Our preference is to calculate a mean date from the data for early and late periods (using ±15 years to centre on 1900 and 2002); one objection to this approach is that there are more missing values pre-1900, but there is little sense in estimating the precession more precisely than in units of whole days, and the bias can be ignored.

Results

Table 1 presents the summary statistics and the preferred model for each species. For the large majority of species, the initial finding was that a linear model (15 species) or the null model (nine species) was the best fit. A broken stick was the best fit for four species, although for Reed Warbler this result is influenced by the paucity of data before 1950. A quadratic curve was the best fit for House Martin and Yellow Wagtail, and a cubic one best for just Lesser Whitethroat and Fieldfare Table 1.

Looking at the polynomial fits on a graph, it is apparent that the quadratic fits reflected an upward, then downward pattern, with the maximum values (latest first-arrival dates) before the arbitrary 1950 breakpoint, say about 1930. For the cubic fits, Lesser Whitethroat had a cluster of early dates in the 1940s; Fieldfare first dates were extremely variable throughout. It was not apparent that these curves identified relevant features within these series, and the AIC improvements were marginal. Dropping the curve option and refitting resulted in 13 linear fits, 10 fits to the null hypothesis, and nine broken sticks. Lesser Whitethroat was deemed null, but the significance of the slope was so close to the adjusted critical value that this threshold was reset from 0.002 to 0.003. Refitting again found 15 linear, 8 null (Lesser Whitethroat and Tree Pipit both becoming linear) and nine broken-stick trends, including those for all three hirundines.

The models are presented on graphs (Figures 1–3), with species grouped according to the best-fit models. Each species graph plots arrival date against year. There are symbols for annual observations: observations in adjacent years are joined by line segments, thus showing the volume of data and gaps across missing years. This also helps visualise the variation around the trend line chosen as the best fit. The decadal smoothing lines indicate periods that deviated from the overall models. As a technical point, the decadal smoothing lines wiggle more wildly where data are scarce (this line therefore is omitted for Wryneck) and may run for periods above or below the trend lines. This reflects the nature of the data as time series, and the year-on-year autocorrelation within some species Figures 1–3.

Discussion

The analyses identified three types of pattern: species that have arrived progressively earlier over the whole study period (Figure 1); species for which arrival dates appear to have advanced since around 1950 (Figure 2); and species showing no change in first-arrival dates in Shropshire – if they now arrive at all (Figure 3).

It is well established that many phenological events now occur earlier in the year, but it was striking that almost half of the summer visitors examined showed a statistically significant trend over the whole time span (a continuous downward slope on the graph) and another seven species a trend in the second half. Trends for two species with non-significant slopes in the 2015 data analysis (Tree Pipit and Lesser Whitethroat) became clearer due to five extra dates from the 1880s unearthed for each and to the addition of the three most recent years. The linear fit for Little Ringed Plover is probably spurious, as this species colonised the area only in the 1980s. The winter visitors (Fieldfare, Redwing and Brambling) all show trends toward earlier autumn arrivals, though the decadal smoothing lines suggest more complex variation. It is less obvious why they would leave their breeding areas earlier, or what might be the advantages of earlier travel or arrival in the UK.

Eight species show little or no change: either the trend lines are horizontal, or the slopes are not statistically significant. The former group includes Spotted Flycatcher and Turtle Dove, both of which have suffered severe population declines across the UK but whose arrival dates have apparently not changed.

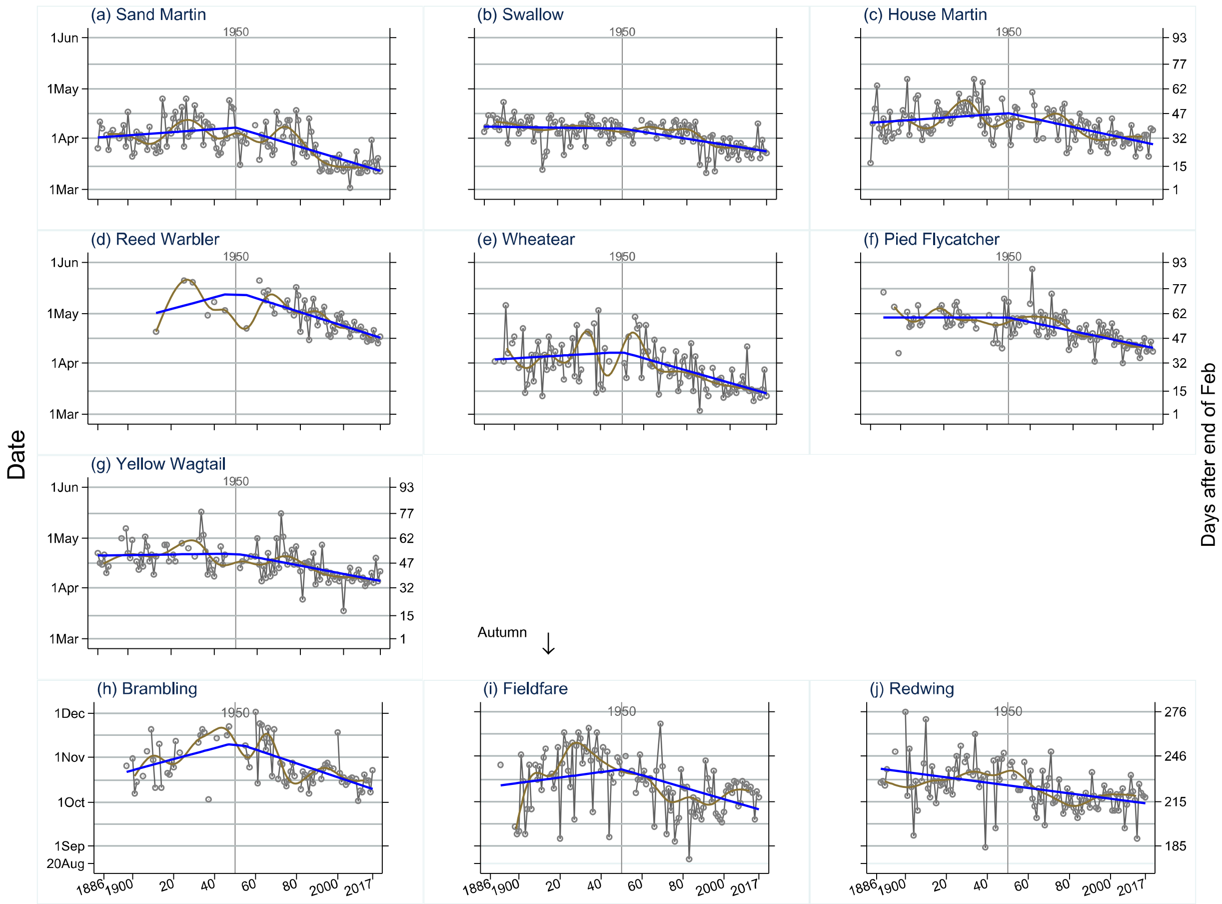

Figure 2. Species with first-arrival dates showing more complex changes over time, fitted as broken sticks. Autumn arrivals are included here (h-j), because the trends are modelled less well.

Other species, such as Nightingale and Corncrake, appear to be arriving later in the spring, but they have become so rare within Shropshire that the few modern records do not justify an inference of first arrivals becoming later. It is more surprising that Blackcap is in this grouping, but the data series was truncated when it was realised this species was also overwintering; visually there is an impression of earlier arrivals but after adjustment the slope was far from significant.

The seven summer visitors eventually fitted with a broken stick all had a non-significant regression slope pre-1950 and a significant downward slope after that year. As noted, the distinction from polynomial fits were marginal and may reflect 1950 not being the optimal break point. Nevertheless, the modelling has distinguished these species as having two periods of variation, and this invites a biological interpretation. There is a statistical aphorism, attributed to George Box: "All models are wrong but some are useful".

The regression slopes (including those deemed not significant) show a relationship with the average first-arrival dates (Figure 4, showing species labelled with their standard BTO two-letter codes; $P = 0.013$ for regression slope); species that were arriving earlier in spring at the start of the century were apparently able to adapt faster to a changing climate Figure 4.

In view of recent condemnation in the scientific press on the use of P values (Matthews *et al* 2017), it is worth pointing to the need for adjustment for multiple tests when analysing many species, and for interpretation over mere reporting. However, it is impossible to adopt a modelling approach without recourse to some measure of statistical significance.

First arrivals may be subject to sampling biases (Clark & Thompson 2011). We considered trying to model the effect of observer effort based on the numbers of observers submitting sightings: JJT estimated 15 reporters in the thirty years centred on 1900, 80 in the period centred on 1950, and 150 in the period centred on 2000. Greater effort in the field leading to earlier records would be analogous to the collector's curve.

The patterns of observation would also have changed, however. In Victorian times reports probably came from leisured gentry, but they would have been out and about perhaps every day and also received information from

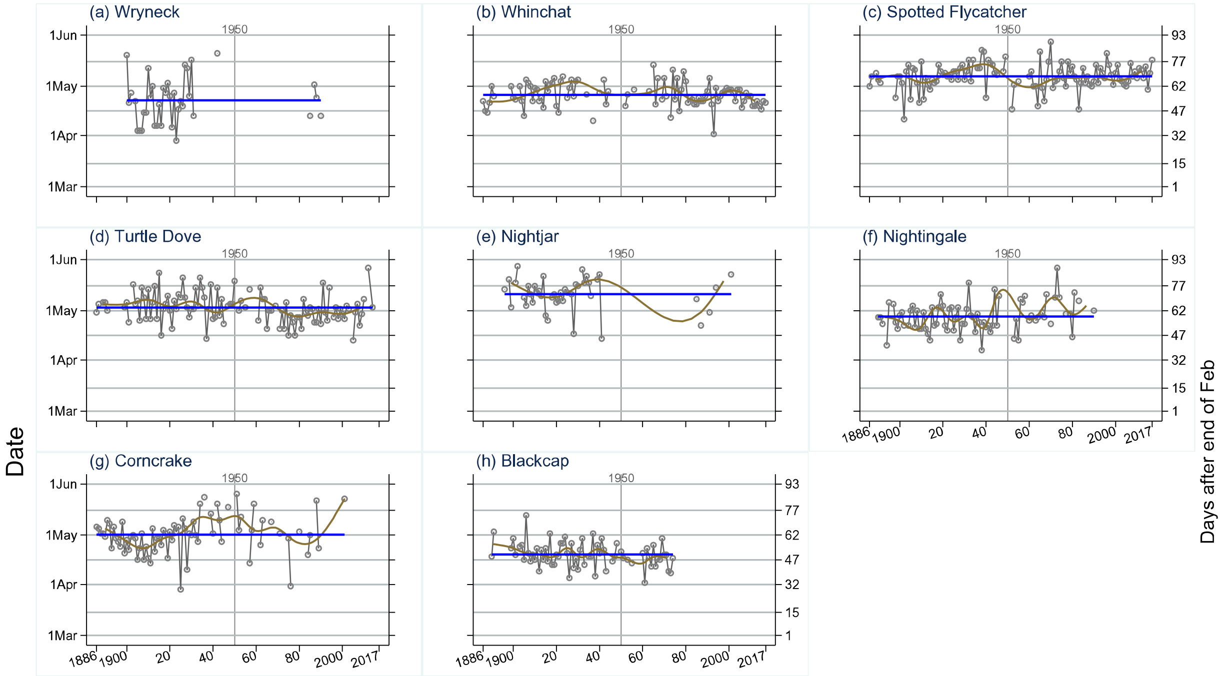

Figure 3. Species for which first-arrival dates appear to show no change over time.

farm workers and gamekeepers. More recently, self-identified bird-watchers are far more numerous and have better equipment. They have better information and communication, and are likely to travel more widely, but they may also be more restricted in the time they can spend in the field.

One factor reflecting these changes is an increase in weekend bias. In the first period, around 1900, 30% of 645 observations were on Saturday or Sunday, slightly above the expected proportion but far from significant (exact binomial test, $P = 0.23$). Around 1950, weekend records were 37% of 632, and around 2000 39% of 806 observations: both these excesses were highly significant ($P < 0.0000$), though less than the 44% of records reported by Sparkes *et al* (2008). This increase in weekend bias would not introduce any directional bias to first records, however, though it would increase the variance between years.

Any effect due to increased numbers or capacity of observers would be confounded with precession

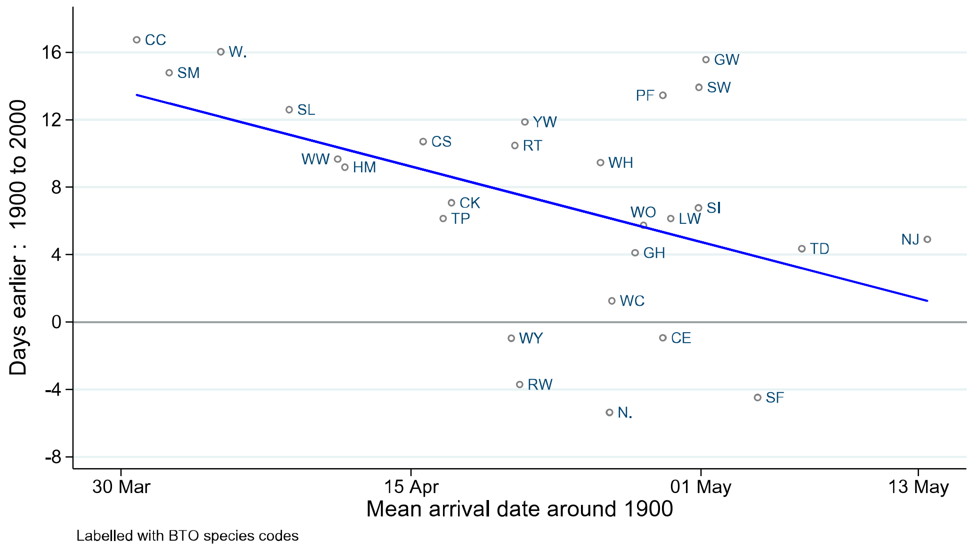

Figure 4. Slope from model fit for each species, regardless of whether this was the best fit or significant, plotted against average first-arrival date around 1900.

attributed to climatic change. However, finding similar patterns in species that are readily observed (e.g. Swift) and those that need a birder's knowledge (e.g. Lesser Whitethroat) suggests the early arrivals are a real effect.

Another proxy for effort might be the number of species reported each year. This varied between 20 and 30 except for periods in the 1880s, 1890s and between 1946 and 1960. The hypothesis might be that if fewer observers were active in the years of low recording, the first arrivals would be later. Testing this on the 21 species recorded in more than 90 years found positive parameter estimates for 15 species but negative ones for six. However, the effect was statistically significant only for Wood Warbler, whose decadal smoothing curve shows an upward lurch in the 1950s. There is thus at best very weak support for this hypothesis.

The conclusions from this study are that extensive historical data are worth accumulating and preserving, and can provide further robust evidence for changes in patterns of migration. Long-term data sets can be created only by locating and collating similar series from local records, newspapers and any historical journals. Descriptive statistical models provide an impetus to interpretation in respect of the natural history of each species but the many potential sources of influence or bias are difficult to incorporate. Nevertheless, interesting and stimulating results can be found.

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