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# First spring arrival response to climate warming in birds

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The present period of our history is characterized by the distinct global climate change most likely due to man-induced gas emissions accompanied by the so-called "greenhouse" effects, particularly, the global warming tendency [8,9]. As a result, even several years of the 1990s (1990, 1995, 1998, and 2000) were the warmest throughout the 20th century [7]. The trends of climate change observed in the Baltic region, including Lithuania, have been described in a number of special editions and articles. Since the 1970s winters and springs have begun to get apparently warmer in Lithuania. Since the end of the 18th century the average annual weather temperature has increased about 1° and during the 20th century – 0.4–0.5°. During the latter winters and springs warmed up in particular ($\sim$1.7–2.0°), whereas summer and autumn temperatures changed less. In the last decade of the 20th century a unique climatic phenomenon was recorded with several warm winters (1988/1989–1994/1995) in turn. The Baltic region has not faced such a long series of anomalously warm winters for the past two hundred years [3]. In Lithuania, air temperatures were higher than the mean annual ones on average 0.5° in 1998, 1.7° in 1999, and 1.9° in 2000.

The impact of global climate warming on birds is obvious and has been reported by many authors [4,2], including the authors of this paper. By different researchers it is indicated that weather conditions of a particular spring have a significant impact on bird spring arrival timing. The shift of first spring arrival dates towards earlier migration in short/medium- and long-distance migrants over the past decades has been reported in a number of publications [2,5,6,1].

This paper reviews the results of the long-term investigation into dates of bird spring arrival. We use the data on the first spring arrival day (*FSAD* – it is numbered from 1 (January 1) to the 151th day of a year) of 30 short/medium-distance migrants and 16 long-distance migrants collected by experienced professionals during 35 years (1966–2000) by daily routes in the environs of Žuvintas Biosphere Reserve.

In Fig. 1, one can see two typical graphs for both the short/medium-distance migrant (*Sturnus vulgaris* Starling) and long-distance migrant (*Ciconia ciconia* White Stork). Every graph contains raw data accompanied by the fitted lines of the following regression models:

$$\begin{aligned}
&FSAD = \beta_0 + \beta_Y \cdot Year && \text{(model } I\text{)},\\
&FSAD = \beta_0 + \beta_T \cdot Temp && \text{(model } II\text{)},\\
&FSAD = \beta_0 + (\beta_{Y1} + \beta_{Y2} \cdot Temp) \cdot Year && \text{(model } III\text{)}.
\end{aligned}$$

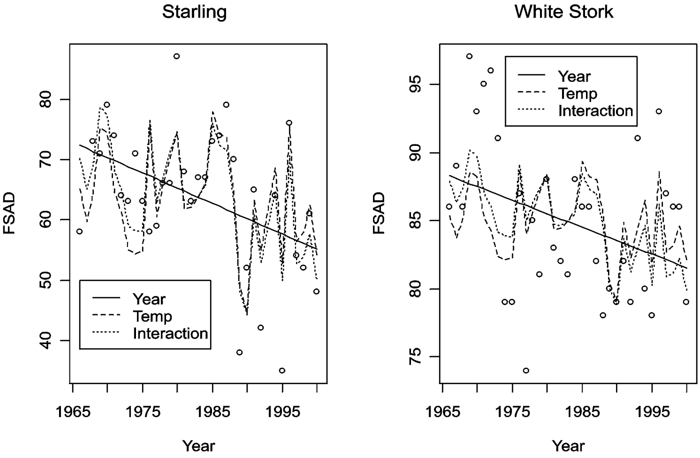


Fig. 1. Both scatter diagrams are accompanied by fitted lines of the three regression models.

The variable $Year$ serves as a proxy to the global climate warming effect and $Temp$ stands for the mean February–March temperature in the vicinity of Žuvintas Biosphere Reserve. The most interesting model *III* (model with interaction) allows a varying coefficient at $Year$, which takes into account not only the global warming effect but also adjusts $FSAD$ for the mean temperature of the given year. The model *III* equations for Starling and White Stork are, respectively,

$$\begin{array}{ll} FSAD = 676,8 + (\underset{(-2,25)}{-0,316} \; - \underset{(-5,64)}{0,001} \cdot Temp) \cdot Year & , \quad R^2 = 0.6059, \end{array}$$

and

$$\begin{array}{ll} FSAD = 381,6 + (\underset{(-1,73)}{-0,1503} \; - \underset{(-2,50)}{0,0004} \cdot Temp) \cdot Year & , \quad R^2 = 0.2677, \end{array}$$

where the Student statistics in parentheses show that the interaction terms are significant at 5% level. In both equations, the terms $Year$ and $Temp \cdot Year$ enter with the “right” (negative) sign which means that when, say, $Year$ increases, $FSAD$ decreases (i.e., the bird arrives earlier).

As can be seen in Table 1, only 5 (out of 30 short/medium range migrants) have the wrong sign for the $Year$ variable (and only 1 for the variable $Temp.Year$) what once again evidences the $Temp \cdot Year$ climate warming hypothesis. Clearly, it is less probable that $FSAD$ for the long distance migrants will be affected by the local temperature (indeed, 5 out of 16 migrants have the wrong $Temp \cdot Year$ sign) but, as we see in Table 2, all 16 $Year$ term signs are correct (and most of them are significant at 10% level).

The analysis presented so far was more or less traditional. Now we would like to describe another approach based on the survival analysis which is used in many biomedical (as well in the economic) sciences and also in engineering (reliability and

Table 1. Summary of model *III* (short/medium range migrants)

| No | Bird | Signs | $p$-value $Year$ | $p$-value $Temp \cdot Year$ | $R^2$ |
|---|---|---|---|---|---|
| 1 | Bean Goose | − − | 0.019* | 3.2e-09* | 0.748 |
| 2 | Coot | − − | 0.001* | 5.88e-10* | 0.776 |
| 3 | Curlew | − − | 0.007* | 0.849 | 0.225 |
| 4 | Greylag Goose | − − | 3.77e-08* | 2.31e-09* | 0.86 |
| 5 | Lapwing | − − | 0.13 | 6.11e-07* | 0.598 |
| 6 | Pochard | − − | 0.076* | 1.75e-05* | 0.545 |
| 7 | Reed Bunting | − − | 0.297 | 0.000* | 0.591 |
| 8 | Robin | − − | 0.103 | 0.050* | 0.307 |
| 9 | Skylark | − − | 0.068* | 5.83e-07* | 0.609 |
| 10 | Smew | − − | 9.30e-05* | 2.08e-05* | 0.727 |
| 11 | Starling | − − | 0.032* | 3.82e-06* | 0.606 |
| 12 | Tufted Duck | − − | 0.000* | 1.22e-08* | 0.777 |
| 13 | White-fronted Goose | − − | 0.000* | 0.002* | 0.613 |
| 14 | Wigeon | − − | 0.013* | 1.17e-08* | 0.724 |
| 15 | Woodpigeon | − − | 0.001* | 0.14 | 0.434 |
| 16 | Song Thrush | − − | 0.036* | 0.036* | 0.001 |
| 17 | Bittern | − − | 0.306 | 0.002* | 0.342 |
| 18 | Black-tailed Godwit | + − | 0.895 | 0.078* | 0.096 |
| 19 | Chaffinch | + − | 0.204 | 0.004* | 0.293 |
| 20 | Cormorant | − − | 0.284 | 0.857 | 0.065 |
| 21 | Linnet | − − | 0.629 | 0.001* | 0.464 |
| 22 | Penduline Tit | − − | 0.626 | 0.7 | 0.025 |
| 23 | Pintail | + − | 0.548 | 0.027* | 0.181 |
| 24 | Redshank | − − | 0.535 | 0.002* | 0.298 |
| 25 | Ruff | + − | 0.78 | 0.335 | 0.033 |
| 26 | Teal | + − | 0.626 | 2.90e-05* | 0.544 |
| 27 | Whinchat | − + | 0.106 | 0.972 | 0.141 |
| 28 | Gadwall | − − | 0.737 | 0.427 | 0.065 |
| 29 | Meadow Pipit | − − | 0.177 | 0.007* | 0.384 |
| 30 | Water Rail | − − | 0.384 | 0.373 | 0.126 |

failure time analysis) or sociology (event-history analysis). In all these applications the primary endpoint of interest is time to a certain event (death, radioactive decay, or $FSAD$) and we would like to model the relationship of "time to event" to other prognostic factors or predictors. We treat $FSAD$ as a random variable and describe its distribution via the hazard function $h(t)$ which assesses the instantaneous risk of "demise" at time $t$:

$$h(t) = \lim_{\Delta t \to 0} \Pr\big(t \leqslant FSAD < t + \Delta t \,|\, FSAD > t\big)/\Delta t.$$

The Cox proportional-hazards model assumes that $h(t) = h_0(t) \cdot e^{(\beta_1 x_1 + \dots \beta_k x_k)}$ and allows to estimate both the parameters $\beta$ and the unspecified base line hazard $h_0(t)$ . We begin with the simple model $h(t) = h_0(t) \cdot e^{(\beta_Y \cdot Year)}$ for Starling. In Fig. 2, left, we see that arrival function (we use this term instead of a more common term of survival function) at the mean value of $Year$ (=1983) is steadily decreasing in time and ends

Table 2. Summary of model *III* (long range migrants)

| No | Bird | Signs | $p$-value $Year$ | $p$-value $Temp\cdot Year$ | $R^2$ |
|---|---|---|---|---|---|
| 1 | Black Tern | $-\ +$ | 0.054* | 0.188 | 0.143 |
| 2 | Common Tern | $-\ -$ | 0.023* | 0.444 | 0.195 |
| 3 | Crane | $-\ -$ | 4.76e-09* | 0.004* | 0.745 |
| 4 | Cuckoo | $-\ +$ | 0.079* | 0.66 | 0.099 |
| 5 | Garganey | $-\ -$ | 0.081* | 0.001* | 0.399 |
| 6 | Golden Oriole | $-\ -$ | 0.687 | 0.085* | 0.162 |
| 7 | Great Reed Warbler | $-\ -$ | 0.663 | 0.57 | 0.05 |
| 8 | Grey Heron | $-\ -$ | 9.18e-08* | 0.003* | 0.708 |
| 9 | House Martin | $-\ +$ | 0.001* | 0.11 | 0.313 |
| 10 | Marsh Harrier | $-\ -$ | 0.076* | 0.000* | 0.426 |
| 11 | Savi's Warbler | $-\ -$ | 0.008* | 0.888 | 0.259 |
| 12 | Spotted Crake | $-\ +$ | 0.144 | 0.254 | 0.112 |
| 13 | Swift | $-\ +$ | 0.002* | 0.034* | 0.39 |
| 14 | White Stork | $-\ -$ | 0.094* | 0.018* | 0.268 |
| 15 | White Wagtail | $-\ -$ | 0.035* | 0.070* | 0.284 |
| 16 | Yellow Wagtail | $-\ -$ | 0.96 | 0.169 | 0.073 |

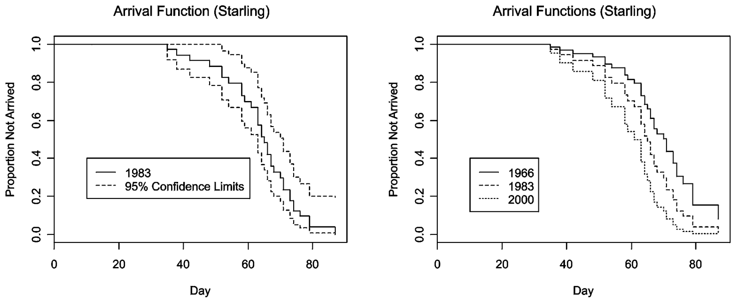
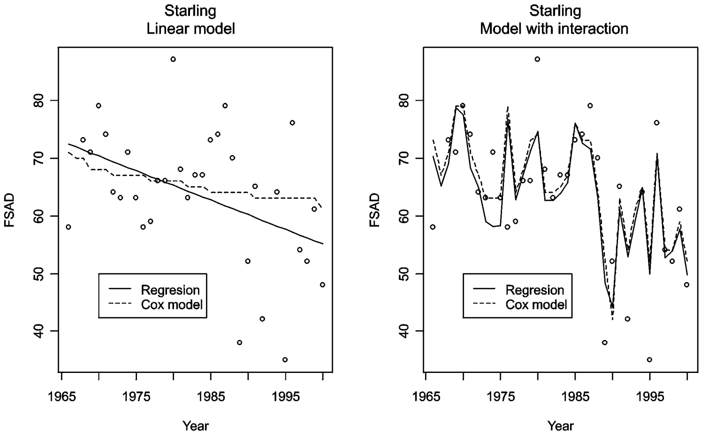


Fig. 2. Arrival (survival) functions for Starling.

at day 87. More interesting is the right graph which depicts the $Year$ impact on the arrival pattern and where one can easily see that every year Starling is arriving earlier. For example, the median day of arrival (it corresponds to a day when the proportion of not arrived equals 0.5) for the years 1966, 1983 and 2000 equals, respectively, 71, 65, and 61, i.e., we register a 10-day advance effect in 35 years. Note that similar analysis for White Stork discloses a 7-day effect (lowers from 88 to 81).

Another model is the model with interaction $h(t) = h_0(t)\cdot e^{(\beta_{Y1}\cdot Year+\beta_{Y2}\cdot Temp\cdot Year)}$ (below we present the output for Starling):

| | coef | exp(coef) | se(coef) | $z$ | $p$ |
|---|---|---|---|---|---|
| Year | 0.063592 | 1.07 | 2.33e-02 | 2.73 | 6.4e-03 |
| Temp*Year | 0.000238 | 1.00 | 4.83e-05 | 4.91 | 8.9e-07 |


Starling
Linear model

Starling
Model with interaction

Fig. 3. Regression model and Cox proportional-hazards model.

The two coefficients are highly significant ($p$-value $p$ is clearly less than any sensible significance level) and have the right (now positive) signs which once again supports the climate warming hypothesis.

In Fig. 3, one can compare a traditional regression model with the median fit of the Cox proportional-hazards model – both curves demonstrate quite similar behavior.

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REZIUMĖ

***F. Ivanauskas, R. Lapinskas, M. Žalakevičius. Klimato šiltėjimo įtaka pirmojo pavasarinio paukščio atskridimo datai***

Gerai žinoma, kad migruojantys paukščiai į Lietuvą grįžta vis anksčiau. Remdamiesi klasikiniais regresiniais, o taip pat išgyvenamumo teorijos metodais, įrodome, kad globalus klimato šiltėjimo efektas yra statistiškai reikšmingas.