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Source: Folia Zoologica, 66(4) : 227-230

Published By: Institute of Vertebrate Biology, Czech Academy of Sciences

URL: https://doi.org/10.25225/fozo.v66.i4.a3.2017

Folia Zool. – 66 (4): 227–230 (2017)

How sunrise and weather affect timing of rooks' (*Corvus frugilegus*) morning departure from the winter communal roost

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Received 3 October 2017; Accepted 19 January 2018

Abstract. The pattern of morning departure of rooks (*Corvus frugilegus*) from large communal roosts in winter is regular though it is affected by several environmental (weather) variables. A total of 151 records of the morning departure of rooks (and associated jackdaws, *Corvus monedula*) from two large communal roosts in the Czech Republic during the years 1966 to 1974 were analyzed. On average, the birds departed 36 min before local sunrise and 1.5 min after beginning of local civil twilight. Light intensity was the leading factor that explained 60 % of variability of the departure time. Cloud cover 30 min before sunrise, being interrelated with the light intensity at local sunrise, explained 52 % of the variability. Less important but significant factors were several weather variables such as precipitation, relative humidity of the air, horizontal visibility (fog), snow cover, and air temperature. Two best predictive multivariate regression models for timing of the birds' departure involved factors: light intensity (that accelerated the departure) or inter-related cloud cover before sunrise (it delayed the departure), precipitation (delaying the departure), snow cover (accelerating the departure due to increased food demand), and horizontal visibility (fog delayed the departure). The two predictive multivariate models explained together 75 % of variability of the birds' departure in relation to beginning of local civil twilight.

Key words: animal behaviour, chronobiology, circadian rhythms, environmental variables

Introduction

Rooks, *Corvus frugilegus*, and associated jackdaws, *Corvus monedula*, wintering in central and western Europe, use communal roosts. From the roosting sites, they carry out regular morning flights to the feeding grounds (distanced up to 20 to 40 km), and return movements to their roosts in the late afternoon. These circadian movements of rooks have been described in many countries: Germany (Pflugbeil 1936/39, Porath 1964, Heitkamp 1970), France (Gramet 1956, Rappe 1965), U.K. (Watson 1967, Munro 1975, Swingland 1976, 1977, Francis 1998), Poland (Grodziński 1971, 1980, Jadczyk 1994, Jadczyk & Jakubiec 1995, Winiecki 2000), Austria (Grüll 1981, Krenn et al. 1993), Czechland (Zdobnitzky 1907, Hubálek 1980, Hubálek & Kubík 1983) or Slovakia (Hubálek & Kubík 1983).

Timing of the morning departure of corvids (and many other birds as well) from communal roosts is a regular and stable phenomenon, but it still remains out of scope of most ornithologists. To analyze the clues influencing the start of morning dispersal of birds was the aim of this study.

Material and Methods

The study is based on 151 observations by the author of the morning dispersal of rooks and associated jackdaws at two large (used by thousands of birds) winter (November to February) basic communal roosts in the Czech Republic between 1966 and 1974. Site A was a floodplain forest at Nosislav near Židlochovice (49°01′ N, 16°39′ E; 180 m a.s.l.; 95 observations) in southern Moravia; site B was a mixed forest at Vraclav near Vysoké Mýto (49°58′ N, 16°08′ E; 310 m a.s.l.; 56 observations) in eastern Bohemia. Both communal roosts were described and characterized by Hubálek & Kubík (1983) as the communal roosts BV 5 (site A) and UO 1 (site B).

In the morning, about 50 min before local sunrise time, the roosting sites were approached at a distance 300 to 1500 m, closely to the main dispersal flight line of the birds, and time of the departure from the roost (i.e. first group of departing birds) was recorded.

Astronomical yearbooks (Bouška et al. 1967-1974) were used for estimation of local sunrise time (T_S) with a correction for solar declination. The beginning of local civil twilight (CT_B – civil twilight is the instant when the true geocentric zenith distance of the solar disk is 96°, i.e. the solar depression is 6°) was also estimated. Total duration of the civil twilight was extrapolated from astronomical ephemeris for individual localities and days, and subtracted from the local T_S. During winter season (November to February), the difference between CT_B and T_S (i.e. the length of civil twilight), ranged from 33 to 39 min at the roosting sites. The following weather variables were recorded 30 min (unless otherwise indicated) before T_S:

X_0, light intensity at local T_S, measured and expressed as exposimeter "Lunex" relative values (directed towards the zenith); calibration of the exposimeter was carried out by light-meter Metra (Prague, Czech Republic), and corresponding values in lux (given in parentheses) were: 1.0 (42), 2.0 (65), 3.0 (115), 4.0 (200), 5.0 (365), 6.0 (740), 7.0 (1750).

X_1, cloud cover in scores 0 to 12: the scores 0 to 9 correspond to the standard scale (tenths of the sky covered); 10, overcast with the cloud layer relatively thin; 11, overcast with the cloud layer moderate; 12, overcast with the cloud layer thick.

X_2, snow cover, in scores: 0, absent; 1, discontinuous; 2, continuous, less than 10 cm high; 3, continuous, 10 cm or more.

X_3, precipitation, in scores 0 to 4: 0, nil; 1, light snowfall; 2, moderate snowfall or drizzle; 3, dense snowfall or moderate rainfall; 4, dense rainfall.

X_4, relative humidity of the air (%).

X_5, horizontal visibility, in scores 0 to 6: 0, visibility below 100 m; 1, 100 to 200 m; 2, 200 to 500 m; 3, 500 to 1000 m; 4, 1000 to 3000 m; 5, 3000 to 5000 m; 6, more than 5000 m.

X_6, air temperature (°C).

X_7, trend of barometric pressure overnight (*vs.* 9 p.m. yesterday), in torr.

X_8, wind direction (at wind speeds 1° Beaufort or more), in scores: 0, NNE to E; 1, W to N; 2, SEE to S; 3, SSW to WSW.

X_9, length of the day (the interval between local T_S and local sunset), in min.

Timing of the birds' dispersal from the roost was described and defined as: $Y = T_D - CT_B$, i.e. the difference (in min) between the time of birds' departure (T_D) and beginning of local civil twilight. Positive values of Y mean the departure delays in relation to CT_B (in min), negative values show the departure accelerated in relation to CT_B.

Descriptive statistics, correlation and regression (including linear, and stepwise and backwards multiple regression) were calculated using statistical program Costat. Statistical significance was considered at the level $P < 0.05$.

Results

It was found that the roost location (sites A and B) did not affect significantly timing of the dispersal of the birds (Y values from both roosting sites were compared with t-test); data sets from both roosts were therefore merged and further treated jointly.

Simple linear regression and correlation

The birds departed from the winter communal roost on average 36.1 min before local sunrise (T_S), and 1.5 min after beginning of local civil twilight (CT_B). The temporal association of birds' departure time with CT_B was obvious but it was affected by several environmental variables (Table 1): significant Pearson correlation coefficient values were found for light intensity (−0.78), cloud cover (+0.72), precipitation (+0.54), relative humidity of the air (+0.24), horizontal visibility (−0.31), air temperature (+0.34), snow cover (+0.30), and marginally with wind direction (+0.28). The two other variables (barometric pressure trend overnight, and day length) did not correlate significantly with the departure time of the birds.

However, interpretation of causality in the significant factors is not trivial because some of these environmental variables were interrelated (r values are given in parentheses): light intensity correlated significantly with cloud cover (−0.93), precipitation (−0.42), and air temperature (−0.36); cloud cover also correlated with precipitation (+0.36), and air temperature (+0.32); precipitation correlated with

Table 1. Descriptive statistics (AVG, arithmetic average; SD, standard deviation), and correlation (Pearson r) between birds' departure timing in relation to beginning of civil twilight (Y) and environmental variables X_0 to X_9. Values printed in bold are significant at $P < 0.05$.

Variable	AVG	SD	r
$Y = T_D - CT_B$	1.50	8.080	-
X_0 light intensity	4.94	1.350	**−0.78**
X_1 cloud cover	7.41	3.975	**+0.72**
X_2 snow cover	0.83	1.106	−0.14
X_3 precipitation	0.29	0.724	**+0.54**
X_4 rel. humidity of the air	88.9	7.326	**+0.24**
X_5 horizontal visibility (fog)	3.95	1.418	**−0.31**
X_6 air temperature	–0.98	3.747	**+0.34**
X_7 barometric pressure trend	–0.22	3.188	**−0.19**
X_8 wind direction	1.43	0.965	**+0.28**
X_9 day length	551.8	60.264	+0.09

relative humidity of the air (+0.24); and relative humidity with horizontal visibility (−0.55).

The most significant is linear regression of T_D on light intensity, presenting as: $Y = 24.46 - 4.6448\,X_0$ (Y being the difference between the time of birds' departure T_D and beginning of local civil twilight). This equation explains as much as 60 % of variability in T_D ($R^2 = 0.602$). Similar linear regression equation for cloud cover is $Y = -9.37 + 1.4662\,X_1$ ($R^2 = 0.520$). Other significant but less pronounced linear regressions of the departure were on precipitation $Y = -0.25 + 6.0163\,X_3$; relative humidity of the air $Y = -21.94 + 0.2627\,X_4$; horizontal visibility $Y = 8.48 - 1.7851\,X_5$; air temperature $Y = 2.22 + 0.7346\,X_6$; and wind direction $Y = -1.95 + 2.2818\,X_8$.

Multivariate regression

Best subsets of environmental variables were defined as those which minimized sufficiently the residual sum of squares (this is equivalent to maximizing the multiple correlation coefficient and R^2); only those descriptors contributing significantly to the explanation of variability were included in the best subsets. In all cases, results of both stepwise and backwards multiple regression algorithms were identical. In the following pair of the best predictive models, analysis of residuals (i.e. differences between the Y values observed and predicted) is also presented for the arithmetic mean (AVG), standard deviation (SD), and minimum (Min) and maximum (Max) difference values:

(1) $Y = 21.89 - 3.6305\,X_0 + 3.1541\,X_3 - 1.3180\,X_2 - 0.9862\,X_5 + 1.0693\,X_8$

($R^2 = 0.761$)

Residuals: AVG = 0.03, SD = 3.97, Min = –9.4, Max =16.8

(2) $Y = -4.69 + 1.1617\,X_1 + 3.7237\,X_3 - 1.6839\,X_2 - 1.0168\,X_5 + 1.3279\,X_8$

($R^2 = 0.752$)

Residuals: AVG = 0.09, SD = 4.04, Min = –9.0, Max =16.4.

The high proportion of variance explained by these two models (75-76 %) indicates that the extraction of variables in the subsets was effective. In general, equation (1) based on light intensity is slightly better in prediction than equation (2) based on cloud cover, but the former variable X_0 in the equation (1) is, in fact, determined *ex post* (i.e. after departure of most birds from the roost).

Discussion

The analysis demonstrated that following variables can be regarded as factors affecting departure timing of rooks (and associated jackdaws) from the winter communal roost: light intensity at sunrise (accelerating the departure) and with it the interrelated cloud cover 30 min before sunrise (delaying the departure) as leading (primary) factor, precipitation (delaying the departure), snow cover (accelerating the departure due to reduced food availability), and horizontal visibility (fog – delaying the departure) as secondary factors.

Zdobnitzky (1907) and Gramet (1956) also observed that high cloud cover, fog and rain delayed departure of rooks (and associated jackdaws) from winter communal roosts in southern Moravia and France, respectively. Aschoff & Holst (1960) found the association between dispersal of jackdaws from winter roosts near Heidelberg (Germany) and beginning of civil twilight, which was also confirmed in Finnish jackdaws (Tast & Rassi 1973), English rooks (Swingland 1976), and in rooks (and jackdaws) in this study as well. The German ornithologists also found that light intensity is a primary factor, a "Zeitgeber" for the birds' dispersal and their circadian activity. Leading role of light intensity in timing the morning departure of rooks from a communal roost was confirmed by Swingland (1976), too. In North America, *Corvus caurinus* crows departed later on rainy mornings from roosting sites (Khadraoui & Toews 2015).

Possibility of prediction of departure times of corvids from large communal roosts (as well as return arrival times of the birds in late afternoon) suggested in this study may have application in air traffic schedules of nearby located airfields by decreasing the risk of aircraft collisions with the birds at the time of their departure (or arrival).

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