

Article

Dynamics of Sex and Age Correlation of Eurasian Woodcock (*Scolopax rusticola* L.) During Spring Migration in Hungary

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Simple Summary: Our research provides detailed insights into the migratory patterns of the Eurasian Woodcock. By focusing on the dynamics of sex- and age-dependent migration of the species, our study adds valuable knowledge to understanding the ecological needs and conservation priorities for this species during critical periods of their annual life cycle. We used data of 24,167 individuals collected during spring migration in Central Europe, Hungary. This manuscript details statistical analyses and methodologies employed to discern variations in migration patterns, contributing to a broader understanding of avian ecology under the influence of climatic and geographical variables.

Abstract: Based on samples collected in the framework of the Eurasian Woodcock Bagging Program in Hungary between 2010 and 2019, we investigated the spring migration of Eurasian Woodcock by age class and sex. The dynamical properties of each year's trajectory are represented using Gaussian smoothing. The models were used to determine the peak of the migration by sex and age in each year. In the comparative analysis by sex, an ARIMA regression model was used as a time-series analysis, which showed that there was a strong positive correlation between the migration of females and males in each year, which indicates that there is no statistically verifiable time difference in the migration pattern of each sex. We found a positive correlation in the same ARIMA model for each year of migration, which indicates that there is no statistically verifiable difference in the spring migration of males and females of the same age groups in Hungary. This study also demonstrates that there is a sharp ratio shift in the spring migration in favour of males. This significant imbalance can be explained by the selective hunting during spring roding, which is of particular importance for the sustainable utilisation of the species.

Keywords: sex-specific migration; age-specific migration; spring hunting; sustainable use; gamebird management



Academic Editor: Jukka Jokimäki

Received: 30 April 2025

Revised: 13 June 2025

Accepted: 13 June 2025

Published: 16 June 2025

Citation: Bende, A.; Faragó, S.; László, R.; Csanády, V.; Fekete, I.; Pecsics, T.; Bozó, L. Dynamics of Sex and Age Correlation of Eurasian Woodcock (*Scolopax rusticola* L.) During Spring Migration in Hungary. *Birds* **2025**, *6*, 30. <https://doi.org/10.3390/birds6020030>

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1. Introduction

With the exception of a few countries (e.g., Slovenia, the Netherlands, and the Czech Republic [1]) and geographical regions (Flanders (Belgium) and the Canary Islands (Spain) [2])

the Eurasian Woodcock is a huntable species throughout Europe [3,4], with a European population estimated at 13.8–17.4 million adults and considered stable [5,6]. In Hungary, only occasional breeding records of Eurasian Woodcock are known, so the size of the nesting population does not exceed a few tens of specimens per year [7–9]. In the Carpathian Basin, the species is found in larger numbers only during its spring and autumn migration. It has a wide frontal migration [10]; its main migration route is north of the Carpathian Basin [11]. The majority of birds arriving in Hungary winter in France, with a smaller proportion wintering in Italy [9,10,12], from where they move on to nesting areas in western Siberia [13–17], as confirmed by ringed specimens found in Hungary [10,18] and by data from birds equipped with transmitters [19]. It is possible that birds migrating through Hungary may also breed further east, as shown by the data from birds fitted with transmitters in Spain [20].

There is no precise data on the extent of utilisation at the European level. Based on known data, the bag of the species in the 2000s was around 2–4 million individuals [2]. According to recent data, including 50–60,000 specimens caught annually in European areas of Russia [21], the annual utilisation is estimated at 2.3–3.4 million specimens [22]. The majority of them come from a few Western European countries. The highest hunting utilisation is in France (1.2 million specimens per year) [23] and Greece (1 million specimens), which accounts for about 70% of the total European bag. In addition to these two countries, Italy and Portugal limit the annual quantity that can be bagged [2], as does Hungary, where a maximum of 5500 Eurasian Woodcocks can be bagged under quota [9].

Nowadays, Eurasian Woodcock hunting during spring roding has been almost completely side-lined, and the species is typically hunted during the autumn–winter season by dog tracking [3,22–24]. Traditional spring hunting is now only permitted in Russia [21] and Hungary [9]. As a consequence, little information is available on the age and sex ratios during spring migration [4,25–28]. It is known, however, that the winter survival of first-year birds is significantly lower than that of adults [29–31].

In many bird species, both sex-specific and age-specific migration are known [32–35]. In spring, protandric migration is usually the dominant pattern, i.e., males precede females [36–42]. Protandric migration is driven by the need to occupy territories of the highest quality [43] and to maximise mating success [44]. In the autumn, on the other hand, females very often leave earlier (protoginia), including wader species, such as the Ruff (*Philomachus pugnax*) [45]. One of the main reasons for this might be that males mark and occupy territories for the following year [33]. Age-dependent migration is also a feature of many species, but in this case the situation is not so obvious. There may be significant interspecific differences in the timing of migration of adults and juveniles in both spring and autumn [46,47]. Studies in NE Poland showed that the second-year individuals of Wood Sandpipers (*Tringa glareola*) migrated significantly later than adult birds [40]. Different migration strategies between specimens should also be considered, as has been shown in recent studies of the Black-tailed Godwit (*Limosa limosa*) [48] and the Whimbrels (*Numenius phaeopus*) [49].

The latest knowledge on the spring migration of Eurasian Woodcock in Hungary was summarised by [50]. Their work was based on the bagging data collected within the Hungarian Woodcock Bag Monitoring programme (1990–1999). The results on the age and sex ratios of the Eurasian Woodcock bags from 2000 to 2008 and 2010 to 2014 were published by [51–58]. These studies, however, focused only on the annual evolution of age and sex ratios, leaving the dynamics of sex- and age-specific migration unexplored. This is important, as if the departure of wintering areas occurs at different times, then there must be a temporal shift in the arrival of the sexes during the migration to the nesting area [9]. On the other hand, this is important in the case of the utilisation of the species, since the

different arrivals of the sexes (possibly by sex and age) can also have an impact on the distribution of the bags; therefore, the timing of the migration also affects judgement of the spring hunting utilisation.

The sample collection module of the Woodcock Bag Monitoring programme started in 2010, which was initiated by the implementation of Article 4 (2) of the European Union Birds Directive (79/409 EEC) [59], as after this international convention was implemented in the Hungarian hunting regulations, no hunting season was established for Eurasian Woodcock in Hungary from 2009. However, the hunting of Eurasian Woodcock during the spring roding is an integral part of the Hungarian hunting culture [60], so Hungary has taken the opportunity to derogate from the Directive. As a result, a nationwide survey of the bags of this species was launched, coordinated by the Hungarian Hunters' National Association. This large-sample, time-series study, in addition to revealing migratory patterns, will also contribute greatly to a better understanding of the extent to which and how hunting habits in different countries affect Eurasian Woodcock populations. Although estimates suggest that European populations of the species are stable [5], hunting is the most significant threat to the species, in addition to weather extremes [61], and the knowledge gained from examining the bagging data collected during the autumn/winter and spring hunting seasons can greatly contribute to meeting the requirements of international conventions on hunting sustainability in the utilisation of the species.

In the present study, we used the ARIMA model, which is suitable for analysing and evaluating age- and sex-specific features of migration dynamics. The following hypotheses were formulated: (I) Our aim was to investigate whether there is any difference regarding age group and sex on the spring migration route in order to reveal the possible timing differences between age groups of each sex during spring migration. (II) We examined the sex distribution of the bags in order to assess the impact of the utilisation during spring migration on the Eurasian Woodcock population. Whether there is any difference an important question; it can be a result of the different migration timings of the different age groups (adult and juvenile) by sex or due to the fact that females and males are bagged with different probabilities during spring spot hunts. Therefore, it emerges from the selectivity by sex of the hunting method.

2. Materials and Methods

2.1. Hungarian Woodcock Bag Monitoring Programme

Our work was based on data from the spring monitoring of Eurasian Woodcocks ($n = 24,167$ specimens) collected between 2010 and 2019 (Table 1). During the monitoring, hunting permit holders participated in the data collection each year, with more than 800 sampling points. Countrywide, up to 5500 Eurasian Woodcocks per year (mean = 2417 SD = 546.8) could be bagged by the data providers under a quota system. During the sampling, the place where the birds were bagged (municipality, gamekeeper), the exact time of sampling (month, day) and the sex of the birds were recorded. For age determination purposes, all data providers were required to send in at least 25%, and from 2011 onwards 40%, of one of the wings of the Eurasian Woodcocks they had killed, stretched at 130 degrees and prepared. Age determination was carried out at the Institute of Wildlife Biology and Management of the University of Sopron. Age determination was performed according to the conventional ornithological methods, i.e., age determination was based on the state and degree of moulting and the characteristic marks of each feather group, moulted or unmoulted [13,14,50,62–64]. During the monitoring we determined the age of 16,907 individuals in total. Sex determination was performed using a destructive method. Data providers recorded sex ($n = 23,882$ individuals) based on the gonads of birds bagged after capture. Since the Eurasian Woodcocks are already preparing for the mating period

in March, the sexes can be distinguished based on the hyperplasia of the testes and the small-sized ovaries that include developing follicles [65].

Table 1. Eurasian Woodcock samples of specified sex (males (σ) and females (φ)) and age collected in Hungary between 2010 and 2019.

Year	Bagged Specimens	Known Sex (Specimens)	Known Age (Specimens)	Sex		Age		Sex and Age			
				σ	φ	Ad.	Juv.	Ad. σ	Juv. σ	Ad. φ	Juv. φ
2010	2389	2385	2386	1988	397	1511	875	1278	709	230	166
2011	3402	3392	1913	2844	548	997	916	844	767	150	147
2012	1941	1925	1162	1671	354	476	686	370	573	105	112
2013	2913	2901	1738	2411	490	939	799	777	666	156	132
2014	2727	2705	1639	2250	455	766	873	646	727	120	143
2015	2787	2751	1661	2367	384	755	906	618	795	128	94
2016	2215	2192	1257	1784	408	605	652	469	539	127	104
2017	1683	1661	1325	1255	406	661	664	482	517	174	138
2018	2349	2267	2132	1876	391	1117	1015	891	811	182	174
2019	1761	1703	1694	1397	306	793	901	619	722	146	151
Sum.	24,167	23,882	16,907	19,843	4139	8620	8287	6994	6826	1518	1361

2.2. Statistical Analysis

For the statistical analysis, we processed annual bagging data recorded in the sampling periods between 1 March and 10 April (41 days) between 2010 and 2019. The sample size required for statistical representativeness was determined using the Cochran formula [66] for an annual migratory bird population of at least 1.5 million individuals. The approximate minimum of 1.5 million individuals for the annual migratory bird population under study helps determine the total population size (N). In this regard, our calculations reinforce that the sampling strategy achieves representative results despite the generalisation derived from sampling error. A confidence interval (CI) of 99% and margin of error (E) of 3% were selected in order to achieve precision and accuracy in estimating population metrics. A stringent CI of 99% was chosen to minimise the chances of committing a Type I error, especially in an ecological and conservational context. A margin of error of 3% was deemed reasonable in measuring significant population change while still maintaining a realistic sample size. Utilising these conditions within Cochran's formula provides a reliable minimum sample size while ensuring logistical practicality. A Z-score of 2.576 was used with the 99% CI for this study, which represents a very strict criterion meant to reduce Type I error risk in population estimation. The estimated proportion (p) was set to 0.5, which is standard practice. This approach maximises the product of p and q (where $q = 1 - p$), thereby providing the largest possible sample size. Adopting this approach guarantees that the resulting sample size will be more than adequate for providing reliable, robust, and generalizable estimates, even in high-variability conditions. This approach resulted in a sample size estimated at approximately 1844 specimens per year, which is considered to be a sufficient number of samples for statistical representativeness. Hence, statistical representativeness was met in each of the years of the ten-year period we examined.

Edited Gaussian smoothing was performed to represent the spring migration process by plotting a set of coordinates for each sampling day, matched to the characteristics of the point set of the catch numbers per sex and age. The criteria for the smoothing used were as follows: boundedness, the existence of one or more extreme values, and differ-

entiability. These requirements were met by a linear combination of two Gaussian functions:

$$y = \frac{b_6}{e^{(b_5(x-b_4))^2}} + \frac{b_3}{e^{(b_2(x-b_1))^2}} + b_0$$

The model is characterised by seven parameters—different stretching and offsets—which ensure sufficient flexibility of the function, so that a model with appropriate fitting accuracy to the asymmetry of the data series is created.

The initial values of model (a) are determined from the values of the data series as follows:

$$b_6 = \text{var}_2 \text{ first max.} - \text{var}_{2\text{min.}} \text{ or } b_6 = \text{var}_2 \text{ first min.} - \text{var}_{2\text{max.}}$$

$$b_3 = \text{var}_2 \text{ sec. max.} - \text{var}_{2\text{min.}} \text{ or } b_3 = \text{var}_2 \text{ sec. min.} - \text{var}_{2 \text{ max.}}$$

$$b_4 = \text{var}_1 \text{ first max.} \text{ or } \text{var}_1 \text{ first min.}$$

$$b_1 = \text{var}_1 \text{ sec. max.} \text{ or } \text{var}_1 \text{ sec. min.}$$

$$b_0 = \text{var}_{2\text{min.}}$$

$$b_5 = b_2 \sim 0.05$$

The initial values of the model can be determined from the values of the test data set as indicated above, based on the interval boundaries of the independent (var_1) and dependent (var_2) variables, and the maximum and minimum values of the dependent variable within the point set and their locations [67,68]. The coordinates of the extreme values were determined using WinPlot 10.7 [69]. Gaussian smoothing was created in Statistica 13.0 [70]. Spearman's rank correlation was used to test whether there was a significant temporal shift in the spring migration by age within each sex. Further statistical analyses were conducted in R-Studio [71].

To verify our first hypothesis (I.), the count of individuals, i.e., the dependent variable, was first log-transformed because of skewness occurring between the sexes. Then, the variables "Year", "Month", and "Day" were merged to create a single time-series variable. We also observed significant imbalance in the two independent variables, "Proportion of sex" (hen and cock) and "Proportion of age" (adult and juvenile). Handling imbalances was performed by replacing missing values in the variables mentioned above with the median values. The ARIMA (1, 0, 1) default model was fitted with "Sex", "Age", and their interaction as exogenous variables. The key results can be seen in Table 3 below in Section 3.

Subsequently, we performed an Augmented Dickey–Fuller (ADF) test on the log-transformed dependent variable with the following critical values: 1% level: -3.45 , 5% level: -2.87 , 10% level: -2.57 . Mean Absolute Error (MAE) and the Root Mean Squared Error (RMSE) were also computed. MAE, which is less sensitive to outliers, is the average of the absolute differences between the predicted and actual values, providing a measure of the average magnitude of the errors without considering their direction. Similarly to MAE, RMSE is the square root of the average of the squared differences between the predicted and actual values. RMSE penalises larger errors more heavily, making it more sensitive to outliers and particularly useful in case of large errors.

We ran an ARIMA time-series model, with the constant representing the baseline level of the log-transformed dependent variable of "Count_of_Individuals", when all other variables are zero. Two more terms were in the model. (i) The autoregressive coefficient reflects the impact of the previous period's value of the dependent variable on the given period. (ii) The moving average coefficient term reflects the impact of the lagged forecast errors on the current value. Sigma^2 represents the variance of the residuals or the model's error term. Consequently, a higher value indicates more variability in the model's predictions.

We employed the Ljung–Box Test to assess autocorrelation in the residuals. To check the normality of residuals, we used a Q–Q plot to visually assess the normality of the residuals. Additionally, the Jarque–Bera Test was used to evaluate if the residuals followed a normal distribution. In the case of homoscedasticity, if plots of residuals vs. fitted values show no clear pattern, this indicates homoscedasticity (constant variance). The Breusch–Pagan Test was used to test heteroscedasticity in the residuals. The AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) were employed to assess model fit.

Regarding forecasting accuracy, the model's fit was assessed using in-sample residuals. MAE, RMSE, and Mean Absolute Percentage Error (MAPE) were assessed. These values indicate that the model's errors are small or large. A holdout sample was used to validate the model's forecasting ability. The RMSE for out-of-sample data was calculated.

The CUSUM and CUSUM of Squares tests were applied to check for structural stability of the model coefficients over time. A Variance Inflation Factor (VIF) analysis was performed for the independent variables with a very strict threshold of 5 for VIF. Overall, the ARIMA (1, 0, 1) model is suitable for time-series forecasting of the log-transformed count of individuals.

As earlier mentioned, there is a conspicuously strong imbalance between females and males in the variable "Sex". Hence, to show the imbalance between females and males for every year, we performed binomial tests. Since there are multiple years and, consequently, multiple comparisons, we employed the binomial tests with the Benjamini–Hochberg correction for multiple comparisons to control the false discovery rate (FDR). This test will compare the observed proportions of females and males to an expected proportion of 50%, which represents a balanced population. If the p -value is significant, it indicates a significant imbalance in the given year.

3. Results

In the sample collected during 10 years of sampling in Hungary, there is no statistically verifiable temporal shift in the spring migration. We present the modelled migration characteristics of spring migration by sex using data from 2012 ($n = 1925$ specimens). The point sets of cumulative sampling frequencies of males and females follow each other closely (Figure 1), and it was assumed that there is no difference in the course of the temporal pattern between different sexes.

No temporal shifts were observed in the spring migration dynamics of males and females in Hungary, illustrated by the example of the year 2012. The time of sampling and the closely co-moving point set of cumulative sampling frequencies plotted using sex and age data also show no temporal variation (Figure 2).

In the case of the Gaussian function, which provides a double representation of the temporal variation in the number of Eurasian Woodcocks during spring migration, it can be seen that despite the significant shift in the proportions between the sexes, there is no difference in the temporal course of the process (Figure 3). The model peak dates of the migration data series by sex fell on sampling days 18 and 23 for males and on days 17 and 24 for females. For both sexes, the model follows the same pattern, with a small decline after the first local maximum, followed by an increase until the absolute peak of migration, followed by a declining phase indicating the end of migration. In terms of proportions, the sampling dynamics for females closely reflect the trends of the overall migratory flock.

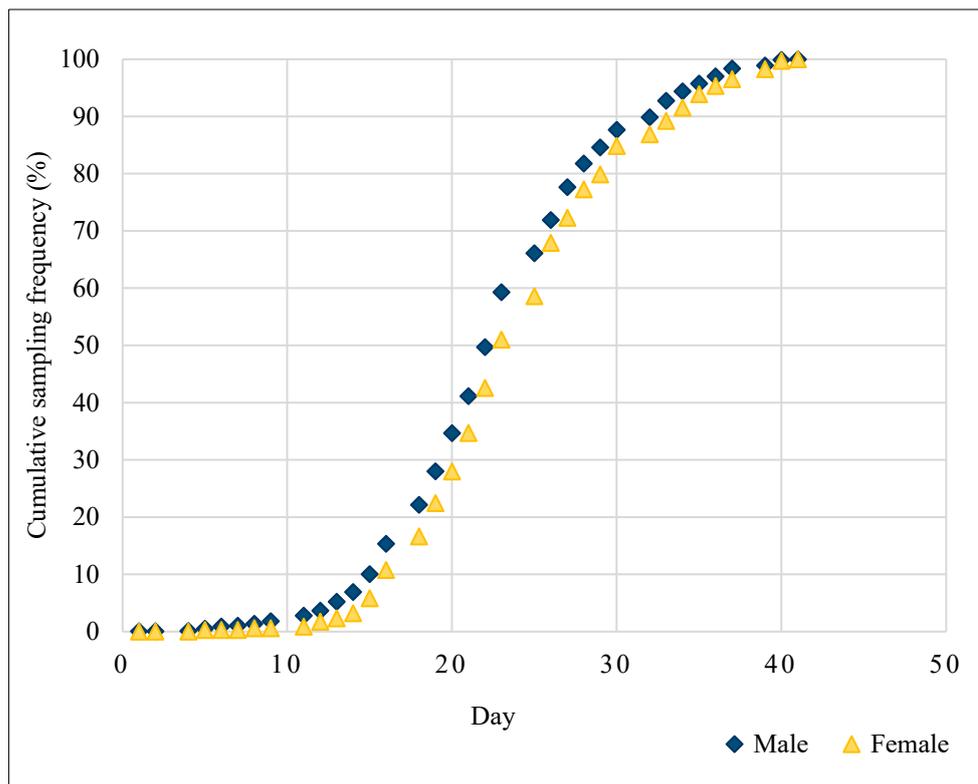


Figure 1. Cumulative spring sampling frequency of Eurasian Woodcock by sex in 2012. Days were counted from the first day of the sampling period (1 March).

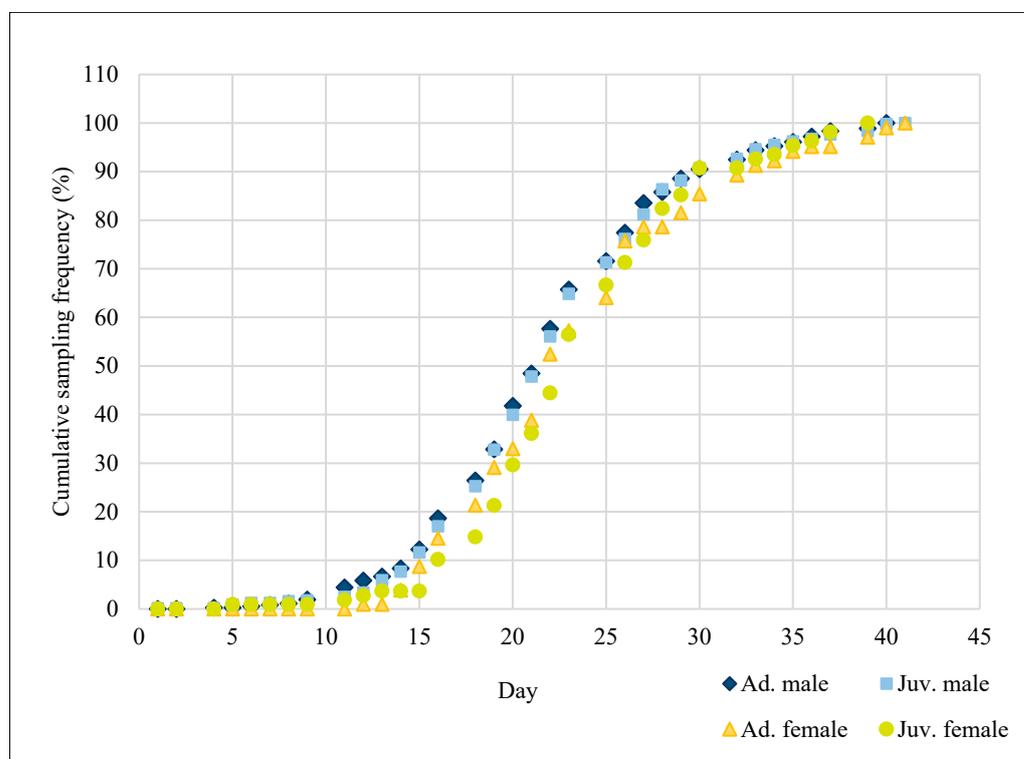


Figure 2. Cumulative spring sampling frequency of Eurasian Woodcock by sex and age in 2012. Days were counted from the first day of the sampling period (1 March).

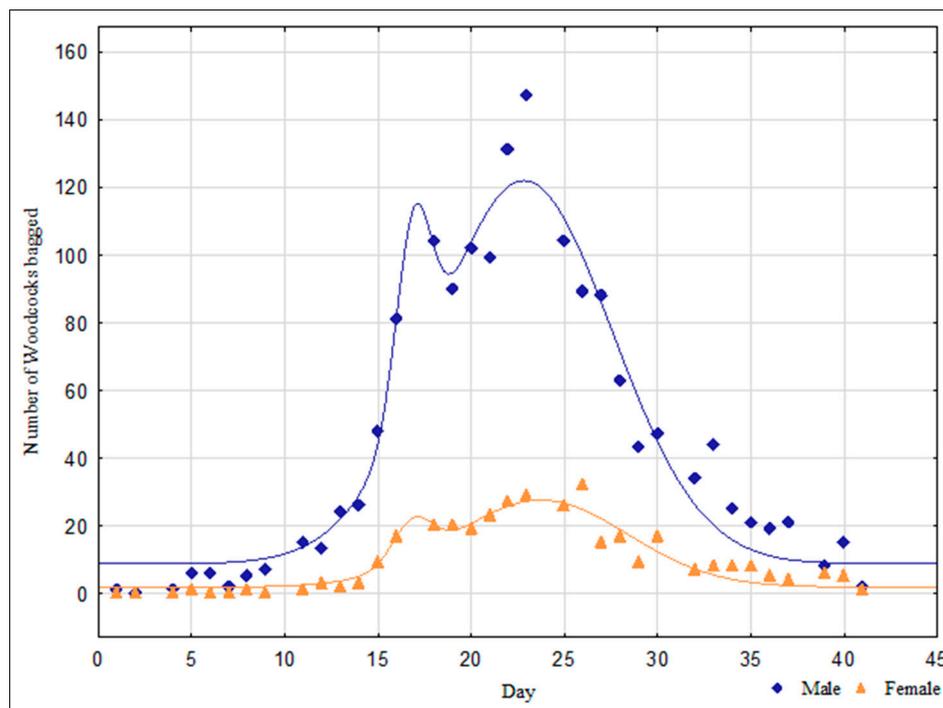


Figure 3. Spring migration dynamics models of the Eurasian Woodcock by sex in 2012. Days were counted from the first day of the sampling period (1 March).

We also modelled the spring migration pattern by age and sex, also using Gaussian functions (Table 2). There was a difference of only two days between the absolute maximum of the functions modelling the migration of males with a higher number of samples in both ages (ad. ♂: 370 individuals; juv. ♂: 573 individuals) (ad. ♂: sampling day 21, juv. ♂: sampling day 19). According to the models of spring migration of females, the absolute maximum for both adult (105 individuals) and juvenile (112 individuals) ages was on sampling day 23, so there was no difference in the peak of migration between the female ages (Figure 4).

Table 2. Double Gaussian extreme value data, regression coefficient, and monotonicity coefficient of variation values for migration by sex and age in 2012.

Sex	Extreme Value Coordinates		Regression Coefficient (R)
	T Max.	N Max.	
♂	18	115	0.9768
	23	121	
♀	17	23	0.9539
	24	28	
Sex × Age			
Ad. ♂	21	30	0.9629
Ad. ♀	17	8	0.8228
Juv. ♂	23	9	0.9772
	19	43	
Juv. ♀	23	49	0.9177
	23	10	

Independent variable: T: number of sampling days in the study; **dependent variable:** N: sample number (specimen). Period (1 March–10 April).

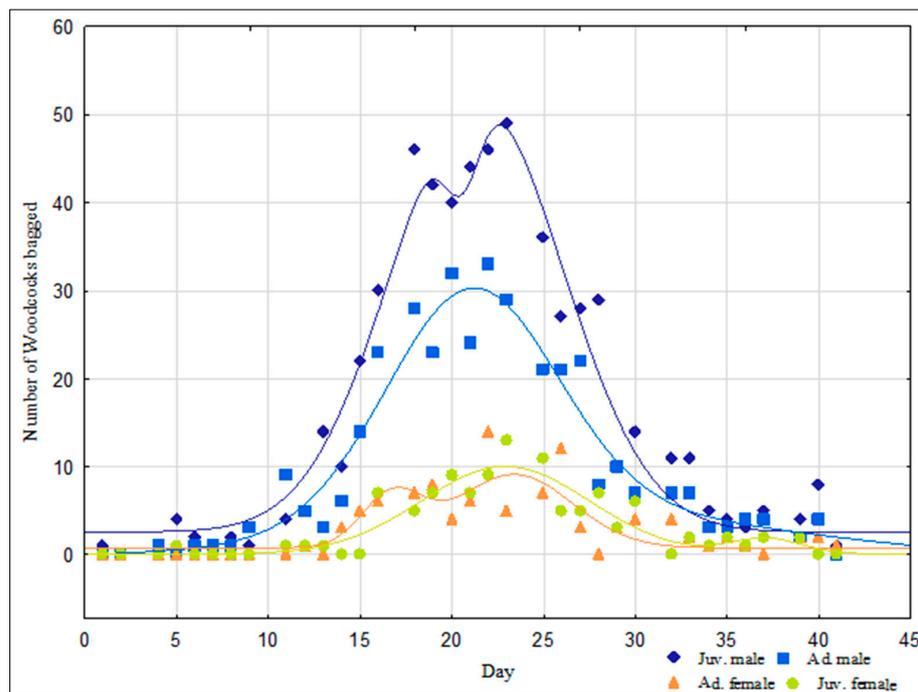


Figure 4. Spring migration dynamics models of the Eurasian Woodcock by sex and age in 2012. Days were counted from the first day of the sampling period (1 March).

To test the first hypothesis, where we investigated whether the process of migration is influenced by the age and sex of the birds, we performed ARIMA time-series analysis on the log-transformed dependent variable. The results of the corresponding ADF test were as follows: ADF statistic: $-6.51, p < 0.001$. The ADF statistic (-6.51) is lower (more negative) than all the critical values at the level of 1%, indicating that the model’s assumptions about stationarity are satisfied. This indicates that the log-transformed series is stationary, making it suitable for time-series modelling without the need for additional differencing.

The analysis revealed that the variables proportion of female and male and proportion of adult and juvenile do not have statistically significant effects on the log of count of individuals, nor does the interaction term. MAE yielded a value of 1.05, with the RMSE being 1.17. The small difference between MAE and RMSE values indicates that the model does not contain large outliers or extremely high errors.

We now report on the results of the ARIMA model (see Table 3).

Table 3. Results of the ARIMA model.

Predictor	Estimate	95% CI (Estimates)	Z-Value	p-Value
Constant	0.8829	[0.6974, 1.068]	9.91	$p < 0.001$
Proportion ♀, ♂	0.0154	[−0.3716, 0.4024]	0.12	$p = 0.9045$
Proportion ad., juv.	0.1007	[−0.0215, 0.223]	1.63	$p = 0.1033$
Proportion ♀, ♂ × ♀ Proportion ad., juv.	0.0041	[−0.0912, 0.0994]	0.08	$p = 0.9332$
AR(1) (ar.L1)	0.8854	[0.8231, 0.9477]	23.6	$p < 0.001$
MA(1) (ma.L1)	−0.4031	[−0.5240, −0.2823]	−6.44	$p < 0.001$

The variables “Proportion of sex” and “Proportion of age” and their interaction do not significantly affect the dependent variable. With a Z-value of 9.91 ($p < 0.001$) for the constant, this coefficient is statistically significant, indicating that the constant is significantly different from zero. The coefficient belonging to the variable “Proportion_hen_cock” (0.0229) indicates that for each one-unit increase in the Proportion_hen_cock, the log-transformed dependent variable is expected to increase by 0.0229 units, holding all other variables con-

stant. The Z-value (0.11) and p -value (0.9119) show that proportion of sex is not statistically significant, indicating no impact on the dependent variable. Proportion_adult and juvenile yielded a value of 0.1087, showing that for each one-unit increase in proportion of age, the log-transformed dependent variable is expected to increase by 0.1087 units, holding all else constant. The Z-value (1.68) and p -value (0.0925) suggest that adult and juvenile proportion is not significant.

Importantly, an AR(1) coefficient of 0.8849 indicates a strong positive relationship between the previous values of Log_Count_of_Individuals and the current values. The Z-value (23.52) and p -value ($p < 0.001$) indicate that this term is significant, suggesting that the dependent variable is highly influenced by its own past values. Also, crucially, the Ma.L1 term is -0.4025 , indicating that the moving average term reflects the impact of the lagged forecast errors on the current values.

A negative coefficient suggests that past forecast errors negatively influence the current period. With a Z-value of -6.43 (MA1) and a p -value less than 0.001, this term is also highly significant, demonstrating that the forecast errors are an important part of explaining the fluctuations in the dependent variable. Not surprisingly, the σ^2 yielded a value of 0.8846, as the dependent variable fluctuates significantly in magnitude and the independent variables are not significant. Hence, a residual variance of 0.8846 might be reasonable. Consistent with this result, the Z-value (10.57) and p -value ($p < 0.001$) suggest that the residual variance is significantly different from zero.

The autoregressive term (Ar.L1) is the strongest predictor, indicating that past values of the dependent variable are highly influential. Both the moving average term (Ma.L1) and the constant are significant, showing that past forecast errors and the baseline values are important in predicting the dependent variable. In sum, the time-series components (i.e., past values and forecast errors) play a major role in explaining variations in the count of individuals, while the proportion variables do not have one.

The Ljung–Box Test assessed autocorrelation in the residuals and indicated no significant autocorrelation in residuals ($p > 0.05$). A Q-Q plot was generated to visually assess the normality of the residuals. Additionally, the Jarque–Bera Test confirmed that the residuals follow a normal distribution ($p > 0.05$). Plots of residuals vs. fitted values show no clear pattern, indicating homoscedasticity (constant variance). The Breusch–Pagan Test confirmed no significant heteroscedasticity in the residuals ($p > 0.05$). The AIC was 1051.87, while the BIC yielded a value of 1063.01, supporting the adequacy of the model specification.

MAE was 1.07, while RMSE yielded a value of 1.19. MAPE yielded 6.89%. These values indicate that the model's errors are small, reflecting a good model fit. A holdout sample was used to validate the model's forecasting ability. The RMSE for out-of-sample data was 1.23, which is only slightly higher than the in-sample RMSE, indicating good forecasting performance.

The CUSUM and CUSUM of Squares tests were applied to check for structural stability of the model coefficients over time ($p > 0.05$). Both tests showed that the model parameters remained stable throughout the analysis period ($p > 0.05$), indicating no significant structural breaks. The VIF values for proportion of female and male (1.03), "Proportion_adult and juvenile" (1.06), and their interaction (1.02) indicated no multicollinearity (Table 3).

The strongest predictor of the dependent variable is its own past value (AR(1)), and the forecast errors (MA(1)) play a significant role in explaining the fluctuations. The AR(1) and MA(1) terms remain the most influential predictors, while the variables "Proportion_hen_cock" and proportion of adult and juvenile, both individually and in interaction, have no effects on the log-transformed count of individuals.

The assumptions of the model have been tested for residual autocorrelation, normality, and stability. The model's in-sample and out-of-sample performance is strong, with low

forecast error values. The model diagnostics confirm that all assumptions of the ARIMA model are met, and the forecasting accuracy remains consistent. Therefore, the interaction term does not offer any added value in this specific time-series model, i.e., hypothesis (I.), that neither sex nor age affect the temporal variation in the number of migrating birds, is confirmed.

Our second hypothesis, that spring hunting is selective intensively for the male, has already been shown clearly in the Gaussian models. The results from the binomial tests with the Benjamini–Hochberg corrected p -values are highly significant for each year (both before and after correction), confirming that the proportion of males is significantly higher than the expected 50% across all investigated years. The average proportion of males over the sampling period from 2010 to 2019 was 82.7% (Figure 5).

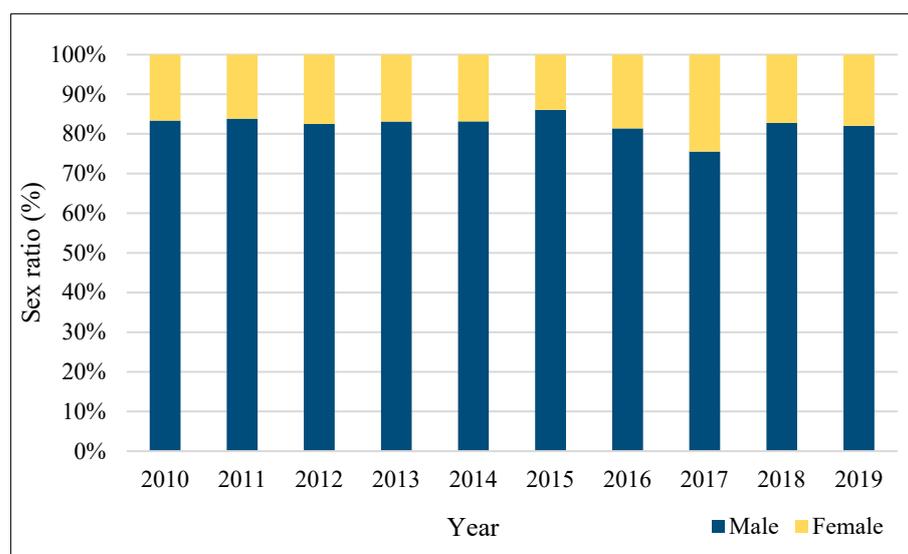


Figure 5. Proportion of males by age during the spring migration in Hungary between 2010 and 2019.

4. Discussion

Our study confirms the hypothesis that there are no statistically verifiable differences in the spring migration of Eurasian Woodcock between females and males, or between age groups of females and males.

Protandrous spring migration is typical of many bird species, including several shorebirds [72,73]. However, some species do not exhibit differential migration, as reflected not only in the timing of migration but also in the different migration distances of males and females, and some species may exhibit spring protandry or even protogynia [74–77]. Among the close relatives of the Eurasian Woodcock, research has also confirmed the presence of spring protandry in the common snipe (*Gallinago gallinago*) [78] and Wilson’s snipe (*G. delicata*) [79].

According to [80], the first-year Eurasian Woodcocks have a close one-to-one breeding ratio, and significant sex ratio deviations from this value are rare in natural conditions. The significant shift in breeding in favour of males in Hungarian spring bags can be explained by the selectivity of hunting during roding [9,50,53–58,81–93], but so far, we have no data on whether there is a statistically verifiable difference in the migration patterns of females and males during spring migration. Studies in Spain revealed that the effect of hunting was the main reason for winter death, and it affected the first-year birds more than adults [31]. Our results indicate that there is no statistically verifiable difference in the timing of spring migration of each sex. Based on the above, the time and method of hunting result in a

significant shift in ratio regarding the different moving patterns between the sexes, which means the short 20–30 min interval of the dawn and dusk movements during hunting. [94].

The temporal development of the age and sex characterising the spring migration of the Eurasian Woodcock is also a poorly researched topic, and only a few studies discuss the characteristics of the autumn migration. In Denmark, there is a confirmed temporal difference in the autumn migration of Eurasian Woodcock by sex and age, with young females starting the migration in October–November, followed by young males and finally old birds [4]. This result also confirms the results of Danish [27] and French studies [95,96] carried out between 1969 and 1971, which showed that females arrive earlier at their wintering grounds. It is assumed that males try to stay as close as possible to breeding territories in autumn and winter, so that their early arrival and territory occupation helps their reproductive success [4,27,28]. This latter pattern of behaviour was demonstrated in the American Eurasian Woodcock (*Scolopax minor*) [25]. According to [97,98], males typically only engage in reproduction from the second year of life. In this case, it would be logical for adult males to leave for their breeding grounds earlier in the spring, so that they would predominate in the breeding territories at the start of migration. However, our results do not support an earlier start of the spring migration of adult males, as in this case there would be a time-series verifiable phase lag between the migration patterns of different age classes of males. According to [99], however, males are already involved in reproduction in their first year. This assumption is supported by our results. Although several authors [14,100,101] report aggressive reactions to vocalisations observed during roding, territorial behaviour has not been confirmed in case of the Eurasian Woodcock [99,102,103]. Otherwise, there would be an advantage for adult males to reach the nesting area earlier, but the timing of the two sexes and the spring migration of the males' ages did not differ.

When evaluating migration, it is also important to consider the fact that hunting and sample collecting can also cause age and sex differences. Ref. [104] also drew attention to the fact that in Denmark there is a difference of about 10% in the share of young birds in favour of hunting with dogs (61%) compared to other hunting methods (52%). Hunting during spring roding is known to be sex-selective [9,59,81–84]. However, in addition to the shift in proportions caused by sampling, the models describing sampling dynamics should also indicate a temporal shift if migration was different between sexes and ages. Examining the sex distribution of Eurasian Woodcocks from France [105–119] bagged between 2001 and 2015, the average ratio of males to females was found to be 1:1.56. In the most closely related species, the American Woodcock (*Scolopax minor*), females also predominate in the bags (58.8–53.8%) [26,120–122]. According to the hypothesis of [95], the hunting mortality of females is higher in autumn because they arrive earlier from the breeding grounds and thus are under greater hunting pressure in the wintering grounds, but the significant increase in the number of females between seasons is due to the different selectivity of the hunting methods. The selectivity of drive and dog-hunting for females is a known fact, as is the marked shift in spring bags towards males [9,60]. In addition to climatic extremes, hunting utilisation has a significant impact on the species' populations. In two hunting areas in Spain, where the number of days of hunting per week was 50% longer, the chances of bird survival decreased by 10% [123]. Autumn–winter hunting, with its higher female numbers, remains popular among European hunters [2,3]; it is not unimportant to integrate the impact of hunting on population sizes into national species management plans by taking into account the size of the hunting bags [124], in order to better meet the standards defined by the African-Eurasian Waterbird Agreement (AEWA) and the European Union Birds Directive, and the sustainability criteria for hunting utilisation.

In relation to the limits of our research, it is important to note that we were only able to research a narrow period (1 March–10 April) each year, in order to comply with the

EU Convention on the Conservation of Birds [59]. Accordingly, it was not possible to collect samples directly from the beginning to the end of migration. However, the findings from this data provide a valuable contribution to a better understanding of the spring migration, which can be used as a basis for species management plans in connection with hunting opportunities for this species in Europe. A more detailed (direct) method than our bagging analyses, i.e., the examination of birds fitted with transmitters, could provide further opportunities.

Author Contributions: Conceptualization, A.B., I.F., L.B. and R.L.; methodology, I.F. and V.C.; software and validation, A.B., I.F. and L.B.; formal analysis I.F. and V.C.; investigation, funding, and data curation, A.B., R.L. and T.P.; writing—original draft preparation, A.B., L.B., I.F., R.L. and T.P.; writing—review and editing, A.B., L.B., I.F., R.L. and T.P.; visualisation, I.F. and A.B.; supervision S.F.; project administration A.B.; funding acquisition, A.B. and S.F. All authors have read and agreed to the published version of the manuscript.

Funding: Project no. RH-75-1-39/2024 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the EKÖP-24-4-II-SOE-25 funding scheme.

Institutional Review Board Statement: Ethical review and approval were waived for this study, because the monitoring permit was not issued to the research centre (Institute of Wildlife Biology and Management), but to the hunting permit holders who voluntarily agreed to participate in the national monitoring programme and to provide the data required by the monitoring contracts. Each data provider was contracted separately by the Hungarian Hunters' National Association. Our institute was responsible for the formulation of the data collection methodology, data processing, age estimation, and publication of the results. The monitoring programme was coordinated by the Ministry of Agriculture and the Hungarian Hunters' National Association. During the period between 2010 and 2019, the hunting of woodcock was only allowed for participants who fulfilled the obligation to sample each bird according to strict regulations (fixed sampling location and adherence to the quota system). The primary objective of the sampling was to assess the sex and age structure of the population, evaluate trends, describe migration characteristics, and evaluate biometric features. The status of the woodcock in Hungary did not change in 2009 and after the enforcement of 79/409/EEC also has not changed, and the species has been and still is considered as a game bird.

Data Availability Statement: All data are available directly by request from the corresponding author.

Acknowledgments: The evaluation of the migration dynamics of the Eurasian Woodcock was made possible by a monitoring programme coordinated by the Hungarian Hunters' National Association. Special thanks are due to the hunters who, in addition to collecting the shooting data, also helped the Hungarian Woodcock Bag Monitoring by sending in the wing samples necessary for age determination.

Conflicts of Interest: The authors declare no conflicts of interest.

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