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Patterns of Bird Migration Defined by a Weather Radar at Part of the East European Flyway (*Via Pontica*)

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Abstract: The results of the first comprehensive radar survey of the spring and autumn bird migration in Bulgaria in a key area of the migratory flyway *Via Pontica* are presented. The weather radar of Bulgarian Air Traffic Services Authority (BULATSA) located nearby the town of Aksakovo (Varna Region, North-Eastern Bulgaria) was used. The survey covered 1101 days and nights of four years (2014–2017). It was found that during the autumn migration the average Migration Traffic Rate (MTR) was 2.5 times higher than during the spring migration, and the intensity of nocturnal migration was on average 14 times higher than the diurnal one. The autumn nocturnal migration was the most intense, with an average of 17 times more birds than those during the day time in the same period. By contrast, in spring the nocturnal migration was only 11 times higher than the diurnal migration. Seventy four percent of birds were found in the height range of up to 900 m a.g.l. The evaluation of the quantitative characteristics of bird migration in North-Eastern Bulgaria presented in this study could serve as the basis for future monitoring of the important bird migration characteristics in a long-term period when the data of weather radar network will be available for larger territories in Europe.

Key words: diurnal bird migration, nocturnal bird migration, radar research, North-Eastern Bulgaria.

Introduction

Seasonal migration of birds is a well-known adaptive strategy, which allows an individual to gain the benefits of maintaining a breeding territory while avoiding the fitness or survival cost of the seasonal unfavourable conditions in that location (Winger et al. 2019). Bird migration has many possible explanations, ranging from predation pressure (Alerstam 1990, McKinnon et al. 2010, Newton 2010) to optimization of the balance between energy intake and expenditure (Somveille et al. 2018). The birds have developed specific morphological features (Phillips et al. 2018), which allow them to carry out regular seasonal crossings between breeding areas and winter grounds. Doubtless, this adaptation has helped migratory birds surviving global climate changes over a long period of time. Therefore, research on the avian migration is among the hot topics of recent biology.

It is strongly believed that in these studies nothing provides more comprehensive coverage of the land surface than radars (Gauthreaux & Belser 2003), despite their limits related to ability to identify species of birds (Horton et al. 2018).

Radar bird surveys began after World War II with the discovery of unidentified echoes in radar (Lack & Varley 1945). After 1960s, the use of radars for surveys of the direction, speed, height and

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density of fly-over birds started by the work of Eastwood (1967) and was further developed by Harper (1957), Richardson et al. (1957), Gauthreaux (1970, 1971), Alerstam & Bauer (1973), Pennycuick & Alerstam (1979), Alerstam (1990), Buurma (1995), Bruderer et al. (1995), Bruderer & Liechti (1995), Bruderer (1997a, b) and Gauthreaux & Belser (1998, 2003). Additional radar investigations were carried by Schmaljohann et al. (2008), van Gasteren et al. (2008), Dokter et al. (2010) and Nilsson et al. (2018). In Bulgaria, the first radar surveys were conducted through the radars at the airports of Varna and Burgas (Michev et al. 1987, Simeonov et al. 1990). They were combined with visual observations of the autumn migration of the soaring birds at Burgas and partly at the Cape Emine. These surveys were carried out on diurnal migration and covered the airspace of the Bulgarian Black Sea coast from the Frangensko Plateau (north of Varna) down to the Bulgarian-Turkish border, thus covering a part of the important East European bird migratory route *Via Pontica*.

Since the present study is focused on a part of the same significant migratory flyway situated in the region of Varna (North-Eastern Bulgaria), we have to note that data on the bird migration in this area were published in the 20th century by Peshev (1967, 1971), Laine (1978), Königstedt & Robel (1982), and more recently by Zehtindjiev & Whitfield (2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017), Gerdzhikov et al. (2014), etc. However, yet little is known about the nocturnal migration (routes, direction, height, number of migrants, etc.) in the region (Zehtindzhiev & Liechti 2003) and a little bit more is known about the diurnal migration of some soaring birds at medium and small heights in this area (Michev et al. 2012, Gerdzhikov et al. 2014). From the total of 420 species of birds recorded in Bulgaria, most belong to the order Passeriformes (Ivanov et al. 2014), which are the most numerous migrants in the surveyed region. They fly on a wide front with an active (flapping) flight about 500 m above the sea and mostly at night (e.g. Alleon & Vian 1869, Reiser 1894, Varbanov 1912, Patev 1930. 1950, Kumerloeve 1957, Balat 1962, Donchev 1974, Georgiev 1976, Donchev 1980, 1984, Nankinov 1980, 1996, Königstedt & Robel 1982, Bolshakov et al. 1998, Zehtindjiev 2001 a, b, Zehtindjiev & Liechti 2003). The highest concentrations of soaring birds in the autumn were found in the regions of Balchik and Albena in the northern part of the Bulgarian Black Sea coast, and especially in the Burgas Bay area in the southern coastal part, which is also the westernmost point of the Black Sea (e.g. Kumerloeve 1957, Patev 1930, 1950, Roberts 1979, Laine 1978, Königstedt & Robel 1982, Nankinov et al. 2001, Michev et al. 2011, 2012, 2018).

The strong development of wind energy production in 2000–2010 led to the intensification of the bird migration studies in North-Eastern Bulgaria, where the largest country wind farms were constructed. Zehtindjiev & Whitfiled (2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017) demonstrated that the migration pattern could be strongly impacted by the wind situation. This implies that migration should be forecastable and that directed conservation efforts over relatively few days could have good results. Such directed efforts could involve shutting down of the wind turbines in certain areas (https://kaliakrabirdmonitoring.eu/). Considering the presence of the wind farms, the aim of this work is to study the main parameters of diurnal and nocturnal spring and autumn bird migration over a key part of the territory of NE Bulgaria in short- and long-term aspects by an objective method. It has been based on the use of weather radar at Aksakovo (Varna Region, North-Eastern Bulgaria) owned by the Bulgarian Air Traffic Services Authority (BULATSA). The information gathered for first time by such approach will help to build a system for monitoring and management of the risk for birds, and to better understand the adaptive potential of migrating birds to changing environment. It will serve also for increasing the quality of environmental impact assessments of planned in the future wind farms and of the aircraft security in North- Eastern Bulgaria.

Materials and Methods

Study Area

The study area and its adjacent airspace are located in the territory of the Frangensko Plateau (338 m a.s.l.). Its extends 20 km in north-south direction and 22 km in west-east direction. The maximum height is 356.2 m a.s.l. reached at the peak Komanlika, which rises in its westernmost part, 1.6 km west of the village of Vuglen. The entire territory of the Frangensko Plateau falls within the so called *Via Pontica* migratory flyway characterized by a high concentration of migrants (Michev et al. 2012). The weather radar used by us for the study of the bird migration is situated in the southern part of the area (43° 16’ 37” N, 27° 47’ 48” E).

Observation periods

The radar studies of the migrants’ movements were carried out continuously twenty-four hours within the whole spring (1st March – 31st May) and autumn (1st

Table 1. Days and nights with data during spring and autumn migration, 2014–2017.

Year	Spring Migration			Autumn Migration			Grand Total
	Days with data	Nights with data	Total	Days with data	Nights with data	Total	
2014	15	22	37	66	70	136	173
2015	60	61	121	72	75	147	268
2016	63	75	138	78	83	161	299
2017	90	92	182	87	92	179	361
SUM	228	250	478	303	320	623	1101

August – 31st October) migration during four consecutive years (2014–2017). In this way, totally 1101 days and nights were studied (478 in the spring and 623 in the autumn). We have the least data for the spring migration period of 2014 – from 11th April to 9th May (Table 1). When analysing the weather, we used archival data from www.wunderground.com. All radar data were manually scanned for residual rain contamination, and data from periods where rain contamination was detected were excluded from the analysis (Dokter et al. 2011, Rivera 2016, Nilsson et al. 2018). Thus, for the purposes of the analyses, we used 623 days and nights (or 84.5% of 736 days and nights) for the autumn period and 478 days and nights (or 64.9% of 736 days and nights) for the spring period, or a total of 1101 days.

Radar Methods

The radar used was C-band (5.35 cm wavelength) Doppler Meteor 250 Radar with carrier frequency around 5.5 GHz. The data are in the format Rainbow 5 SELEX-SI (former Gematronik). The beam width is 1°; the data are downloaded in sequential radial "beams", which are in one-degree azimuth. Doppler radars also measure radial velocity of objects, thus allowing to determine the speed and direction of moving targets such as birds. This signal, or reflectivity, measured in units of Z within a logarithmic scale in decibel (DBZ), is used as an indicator of bird intensity.

We examined volume scans (in a range of 5 to 25 km from the radar position) and radial velocity data from radar data through application of a single-polarization bird quantification algorithm developed and tested in number of previous studies across Europe (Dokter et al. 2011). To determine the presence or absence of birds, we used a minimum standard deviation of radial velocity of 2 m s^{-1} (Holleman et al. 2008) and maximum reflectivity threshold of 5 dBZ. Reflectivity factor (DBZ) was converted in bird density (in birds per km^{-3}) after Doviak & Zrnicґ (1993), Black & Donaldson (1999), Gauthreaux & Belser (1998) and Dokter et al. (2011). Weather radar reflectivity was converted to approximate bird density (BD) by dividing η in equation by an average bird cross section σbird, which in our study was determined as 11 cm^2 from nocturnal migration after Dokter et al. (2011) because being dominated by small passerines and waders. However, it was 50 cm^2 from diurnal migration based on species composition of migrants described for the same region in long-term monitoring studies (Michev et al. 2011, 2012, 2018, Gerdzhikov et al. 2014; see also the bird target validation paragraph below). Finally, the BD was converted to Migrating Traffic Rate (MTR) multiplying (individuals/km^3), flight speed (km/h) and the height of the bin (0.2 km) (Nilsson et al. 2018). For this purpose, we used data collected in four consecutive years (2014-2017).

The MTR is a standard unit to quantify migration rate in absolute terms (Lowery 1951, Liechti et al. 1995). MTR provides information on the average number of birds crossing an imaginary vertical line of 1 km width during an hour. MTR is thus a normalised unit and can be used to compare results from different radar systems and observation points at migration routes. It can be divided into several altitude ranges. Measurements have been conducted at the restricted heights between 300 to 1,500 m a.g.l. because after the 1,500 m height the data obtained are with large errors and therefore have been excluded from the analysis. The lowest height layer (0–300 m) has been removed from our dataset because birds migrating at low altitudes follow preferable habitats (Buurma et al. 1986, LWVT/SOVON 2002) causing spatially heterogeneous flight paths and potential ground clutter contaminations.

For diurnal migration, we have determined the time between 8.00 h and 18.00 h, while for the nocturnal migration the time chosen was between 19.00 h and 6.00 h.

Bird target validation

For the validation of diurnal bird migration, the Doppler radar data were analysed in respect to bird densities in the air volume simultaneously with visual observations of birds passing through the same territory (Michev et al. 2011, 2012, 2018, Gerdzhikov et al. 2014). The reflectivity used for bird density quantification was compared with the visually identified flying birds. Two well recognisable groups of birds were used in our study for validation of radar data: white storks (*Ciconia ciconia*) at autumn migration and gulls (*Larus* spp.) feeding at the dunk-hill in the winter season. The white storks have relatively constant phenology in autumn, with clear peaks of migration when the species is present in big flocks of thousand individuals at the range of radar. The same dynamics of white storks was confirmed in number of previous publications based on visual observations in the same region and in close vicinity of the current radar study (Michev et al. 2011, 2012, 2018, Gerdzhikov et al. 2014).

Statistical analyses

Ordinary Least Squares (OLS) regression analyses were used to explain the variation in flight height (km a.g.l.) depending on temperature (°C) during autumn nocturnal migration (ANM) and autumn diurnal migration (ADM) in 2014–2017. Dynamics and composition of migrating birds during autumn migration in this area were studied by Michev et al. (2011, 2012, 2018) and Gerdzhikov et al. (2014). The goodness of fit of the regression models was assessed through the coefficients of determination (R^2) and F-test for significance of the regression. The variation of the average bird density between the observation periods was investigated by robust one-way (single factor) analyses of variance (Wilcox 2013).

For calculation of mean direction of the migrating birds and the length of the mean vector, we used ORIANA 3.0 software (Kovach Computing Services 2009) to analyse the data according to conventional methods applied in circular statistics.

Results

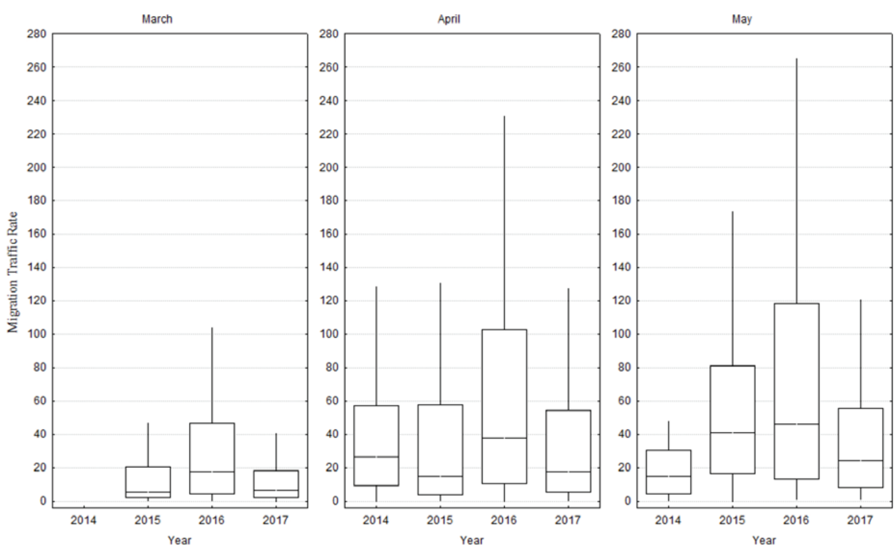
Spring migration

Spring diurnal migration (SDM)

In different years of the study, the average MTR of migrants during SDM was 40 birds km^{-1} h^{-1}, varying between 30 and 57 birds km^{-1} h^{-1}, with the highest number of flied-over birds in 2016 (Table 2). In terms of months, diurnal migration was the most intense in April and May but there was no statistically significant difference between the diurnal migration intensity in any of the spring months (Fig. 1). Connsidered day-by-day (Fig. 2), values between 2.70 and 150.45 birds km^{-1} h^{-1} in SDM were ascertained. The most intense bird migration occurred

Table 2. Migration Traffic Rate (MTR) mean, standard deviation (SD) and number of records (N) for spring diurnal migration (SDM) and spring nocturnal migration (SNM) during four consecutive years (2014-2017).

Year	SDM			SNM		
	Mean	SD	N	Mean	SD	N
2014	30.249	38.322	178	431.219	473.795	217
2015	41.210	69.857	830	472.282	506.041	635
2016	57.673	82.698	820	503.369	563.479	791
2017	31.897	47.733	1118	380.674	441.124	921



KW-H (2; 582) = 27.66; p < 0.001 KW-H (3; 842) = 24.9665; p < 0.001 KW-H (3; 803) = 48.8715; p < 0.001

Fig. 1. Box Plot of Migration Traffic Rate (MTR) of March, April and May spring diurnal migration grouped by year (2014–2017). The box includes the values between the lower (Q1) and the upper (Q3) quartiles, the horizontal line

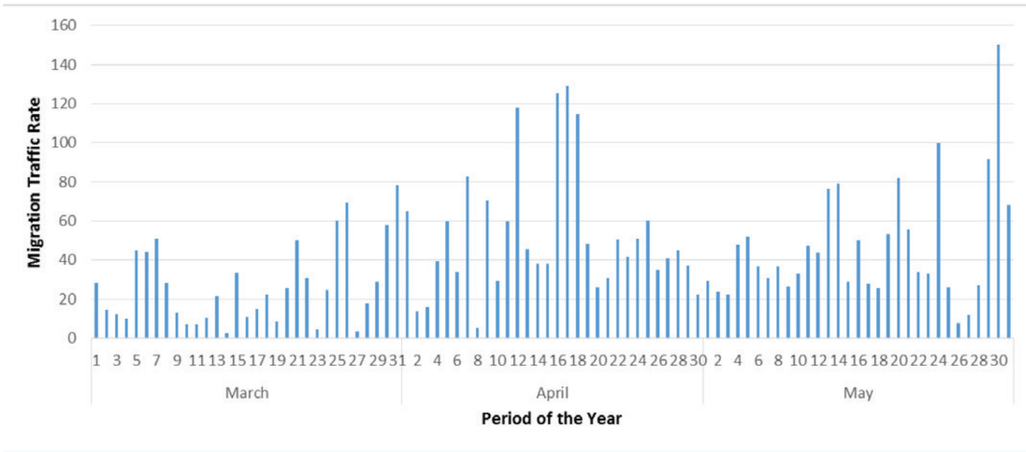


Fig. 2. Average Migration Traffic Rate (MTR) per day of the different months during the spring diurnal migration (SDM) in 2014–2017.

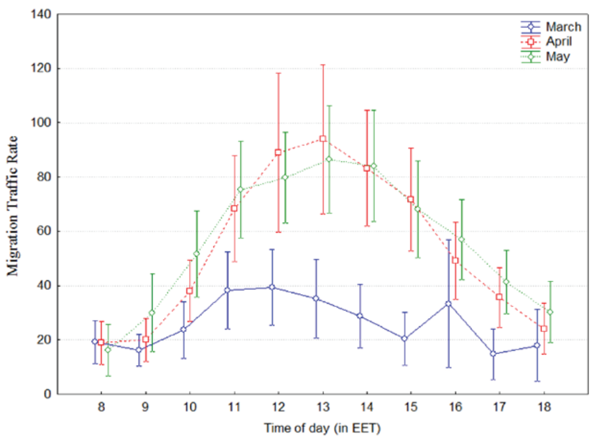


Fig. 3. Average monthly Migration Traffic Rate (MTR) per diurnal hours of the different months during the spring diurnal migration (SDM) in 2014–2017.

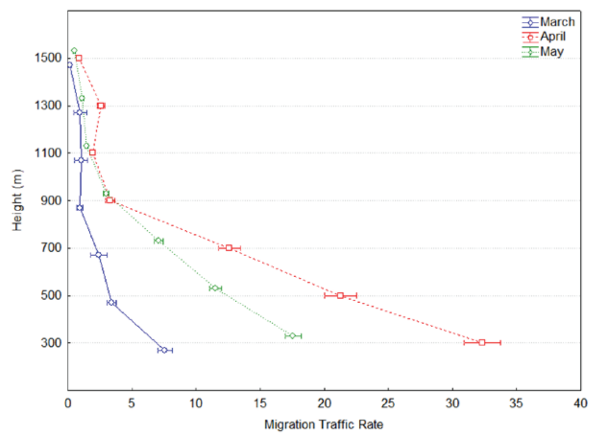


Fig. 4. Average monthly Migration Traffic Rate (MTR) in different flight height layers (a.g.l.) during the spring months of the spring diurnal migration (SDM) in 2014–2017.

during the second and third ten days of April and May. The peak days were around April 16th – 18th, as were also some days at the end of May. The study of SDM at different hours of the day during the different months showed that the most intense migration in all three months was between 11.00 h and 14.00 h (Fig. 3). During the spring diurnal migration, most birds migrated at a height of between 300 and 700 m a.g.l. (Fig. 4).

An important element of the migration parameters is the direction of the migration flow. We estimated direction of the birds detected by the radar in the surveyed territory during SDM on the basis of 89,174 radar observations, where the Mean Vector (μ) was 39.739°, Circular Standard Deviation was 114.029°, Length of Mean Vector (r) was 0.138, and Rao's Spacing Test (p) was < 0.01 (Fig. 5). This distribution exhibited also variation across the three studied spring months (Fig. 6).

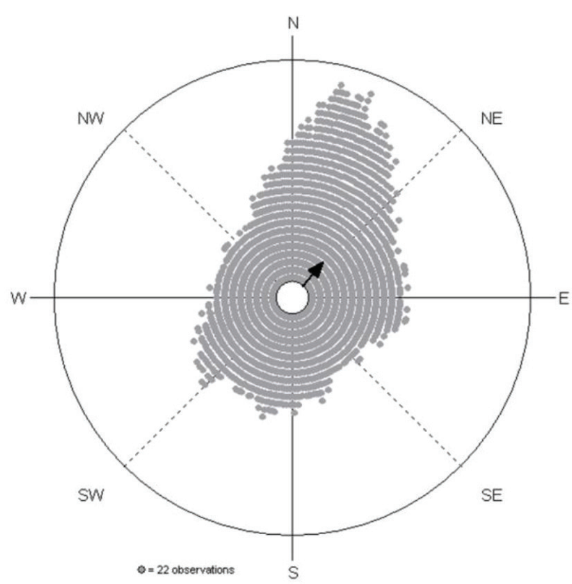


Fig. 5. Circular distribution of flight directions for diurnal spring migration (2014–2017).

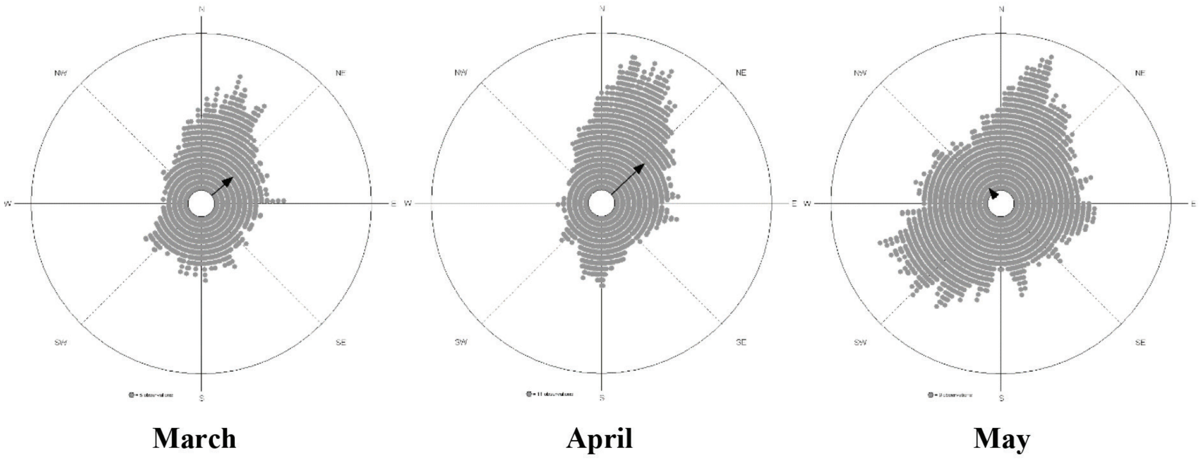


Fig. 6. Circular distribution per month of flight directions for diurnal spring migration (2014–2017).

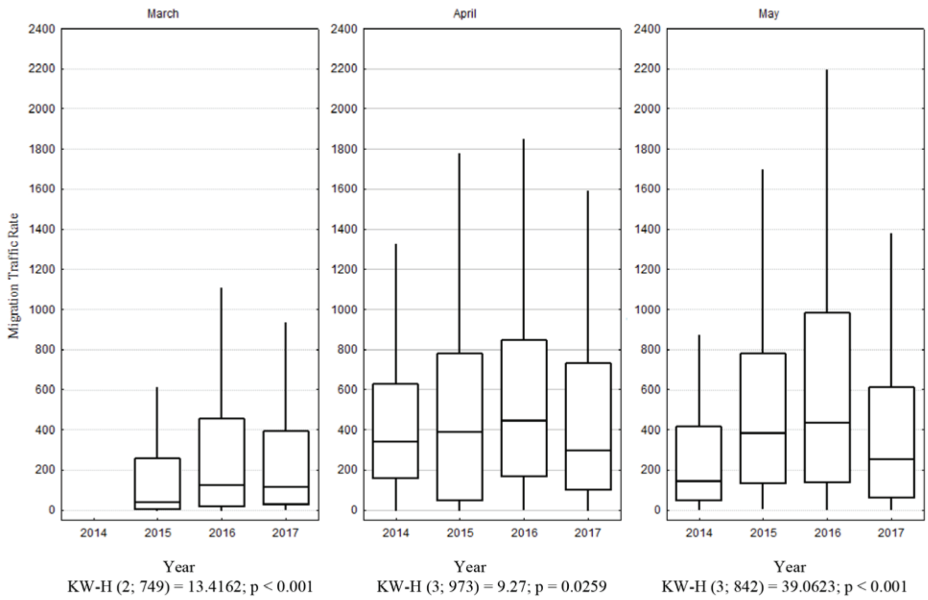


Fig. 7. Box Plot of Migration Traffic Rate (MTR) of March, April and May spring diurnal migration grouped by year (2014–2017). The box includes the values between the lower (Q1) and the upper (Q3) quartiles, the horizontal line represents the median and the vertical line – the non-outlier range. KW-H – Kruskal-Wallis H statistics.

Spring nocturnal migration (SNM)

In different years of survey, the average MTR was 446 birds km^{-1} h^{-1} varying between 380 and 503 birds km^{-1} h^{-1}, with the highest numbers in 2016 (Table 2). The most intense SNM was in April and May (Fig. 7). The most intense SNM occurred in mid-March (21st March) and the last days of March and mid- and late April; in May, there were three peaks of the intense migration (Fig. 8): early May (4th – 7th May), mid-May (11th – 12th May) and end of May (20th – 21st May). The hourly dynamics of nocturnal migration in the spring showed that the most intense migration was around 21.00–22.00 h in April and May, and around 23.00 h in March (Fig. 9). During spring nocturnal migration, most birds migrated at a height of between 300 and 900 m a.g.l. (Fig. 10). The primary migration direction in the surveyed territory during SNM was estimated on the basis of 134,698 radar observations, where the Mean Vector (μ) was 24.412°, Circular Standard Deviation was 90.053°, Length of Mean Vector (r) was 0.291, Rao's Spacing Test (p) was < 0.01 (Fig. 11). The main flight directions were rather uniform across the studied months (Fig. 12).

Autumn Migration

Autumn diurnal migration (ADM)

The average MTR of the Autumn Diurnal Migration (ADM) found in our study was 70 birds km^{-1} h^{-1}, with the measured values varying across the season

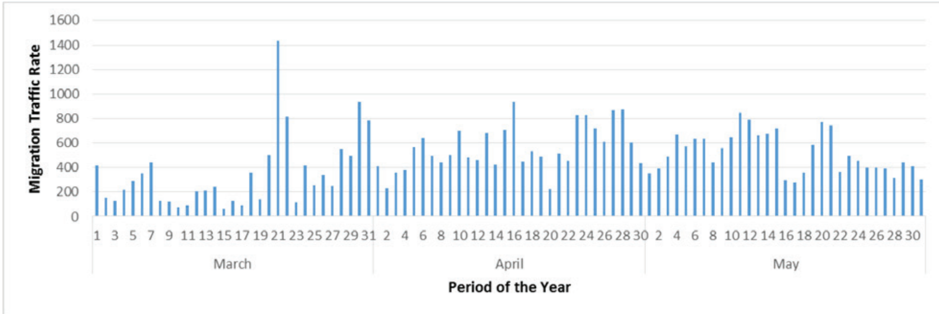


Fig. 8. Average Migration Traffic Rate (MTR) per night of the different months during the spring nocturnal migration (SNM) in 2014–2017.

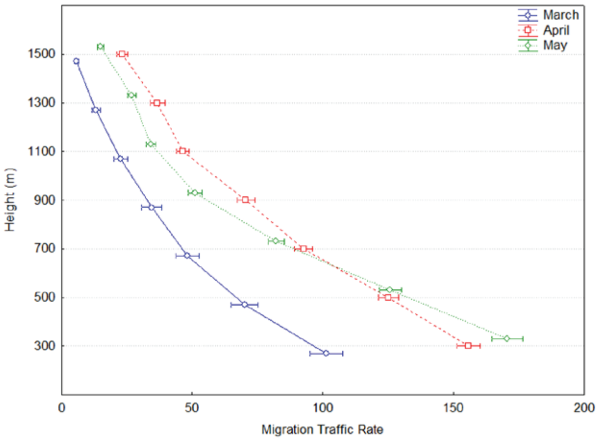


Fig. 9. Average Migration Traffic Rate (MTR) during spring nocturnal migration (SNM) per hours during 2014–2017.

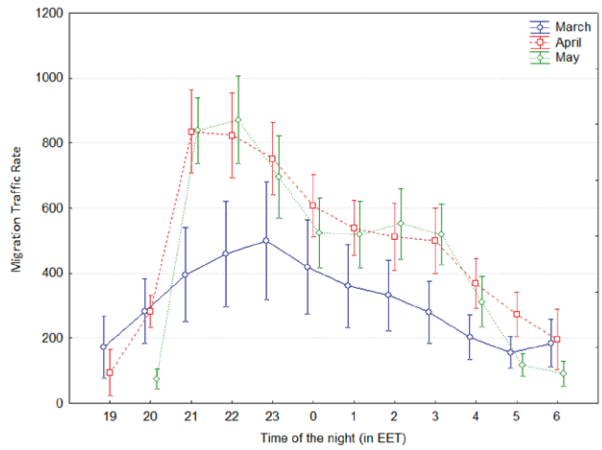


Fig. 11. Circular distribution of flight directions for nocturnal spring migration, 2014–2017.

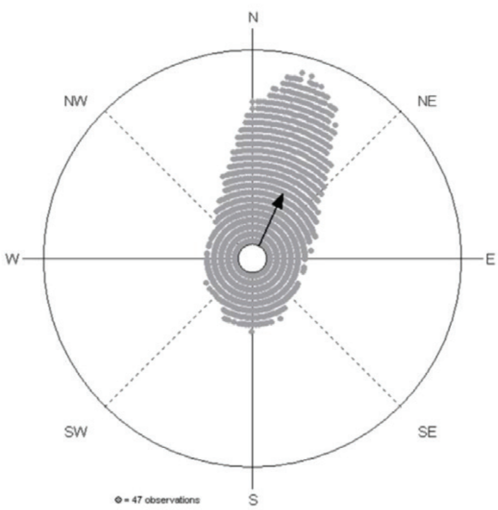


Fig. 10. Average monthly Migration Traffic Rate (MTR) in different flight height layers (a.g.l.) during the spring nocturnal migration (SNM) in 2014–2017.

between 59 and 89 birds km^{-1} h^{-1} (Table 3). According to our study, there was no significant difference in the average bird density (birds km^{-3}) between ADM in different years, except September 2016 and 2017 (Fig. 13). The most intense ADM occurred at the end of August, with some high values recorded in the middle of September in two consecutive years (Fig. 14). The dynamics of ADM show that the highest MTR was in the range between 10.00 h and 14.00 h (Fig. 15). According to the height distribution of flying-over birds during the ADM, most migrants flew between 300 and 900 m above the ground (Fig. 16).

The main ADM direction in the study area was estimated on the basis of totally 183,280 radar observations with a Mean Vector (μ) of 225.109° at Circular Standard Deviation 87.984°, Length of Mean Vector (r) 0.308 and Rao's Spacing Test (p) < 0.01 (Fig. 17). It was characterised by substantial variation across the autumn months (Fig. 18).

Autumn nocturnal migration (ANM)

Our study found average MTR of migrating birds during the autumn season as being 1,140 birds km^{-1} h^{-1}. In different years of the survey, the average for the respective autumn density of migrants varied between 1,047 and 1,234 birds km^{-1} h^{-1}, with the highest numbers registered in 2014 (Table 3). The comparison of the intensity of the migration by months showed that the most intense autumn nocturnal migration (ANM) was in August and in the beginning

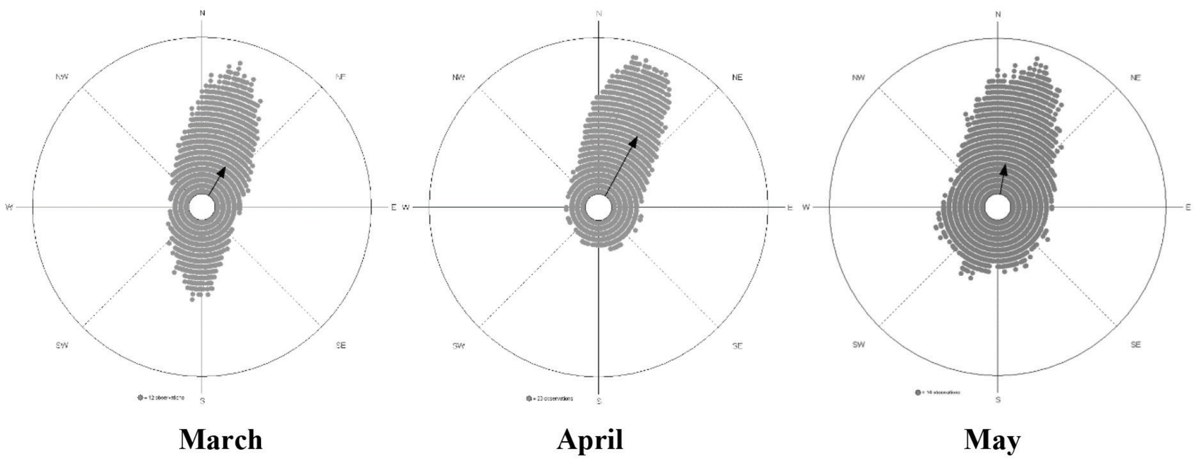


Fig. 12. Circular distribution per month of flight directions for nocturnal spring migration, 2014–2017.

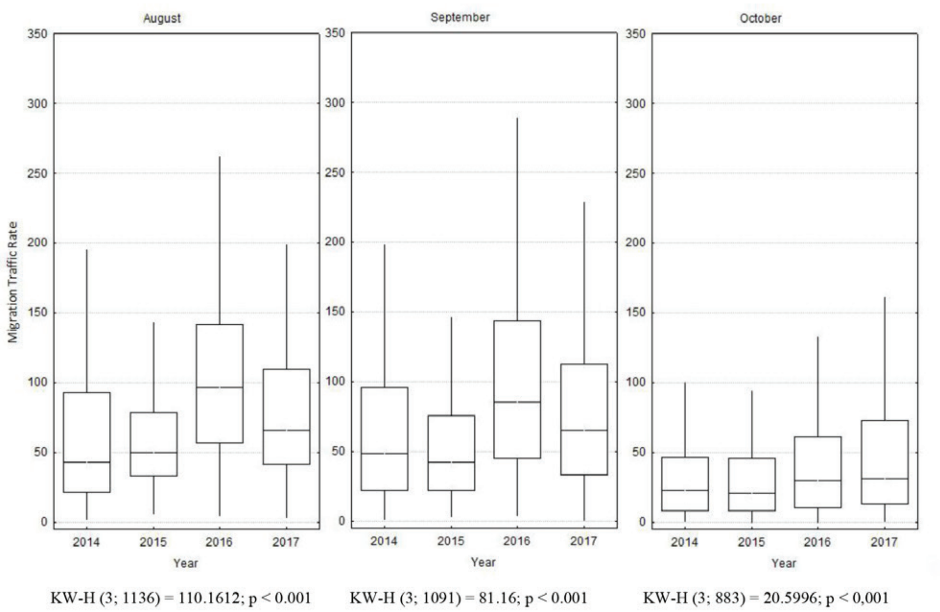


Fig. 13. Box Plot of Migration Traffic Rate (MTR) of August, September and October spring diurnal migration grouped by year (2014–2017). The box includes the values between the lower (Q1) and the upper (Q3) quartiles, the horizontal line represents the median and the vertical line – the non-outlier range. KW-H – Kruskal-Wallis H statistics.

Table 3. Migration Traffic Rate (MTR) mean, standard deviation (SD) and number of records (N) for autumn diurnal migration (ADM) and autumn nocturnal migration (ANM) during four consecutive years (2014-2017).

Year	ADM			ANM		
	Mean	**SD**	**N**	**Mean**	**SD**	**N**
2014	59.509	63.518	833	1234.788	1173.822	774
2015	58.648	64.510	993	1047.296	937.3697	866
2016	89.878	91.052	1035	1117.847	1020.170	975
2017	73.359	66.305	1105	1163.189	1042.302	1025

of September (Figs. 19 and 20). Viewed by hours, there was a sharp increase in night-time migrants in the first hours of the night, with a gradual decrease in the intensity of migration to sunrise typical of August and September and more even distribution of the number of birds throughout the night in October (Fig. 21). During ANM, the highest numbers of migrating birds at night were recorded at heights to about 900 meters above the ground (Fig. 22).

The main direction during the ANM in the study area was estimated on the basis of 252 931 radar observations, where Mean Vector (μ) was 203.128°, Circular Standard Deviation was 72.484° and Length of Mean Vector (r) was 0.449 (Figs. 23, 24).

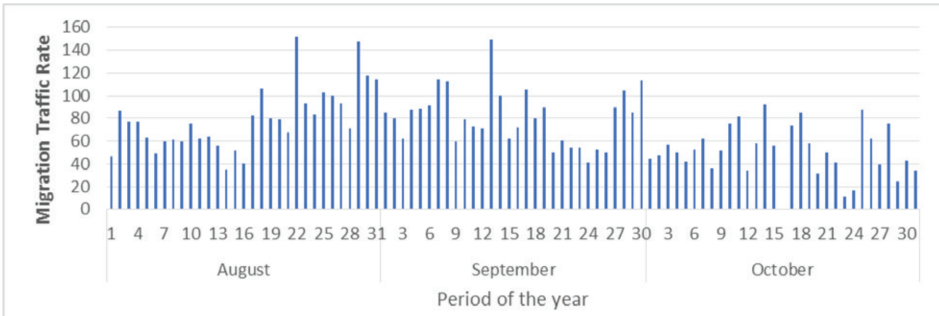


Fig. 14. Average Migration Traffic Rate (MTR) per days of the different months during the autumn diurnal migration (ADM) in 2014–2017.

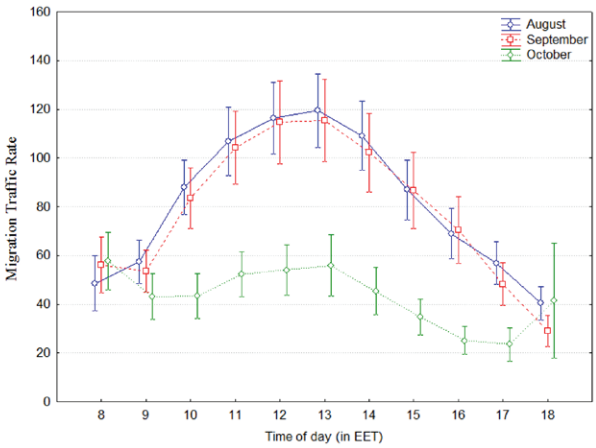


Fig. 15. Average Migration Traffic Rate (MTR) per diurnal hours of the different months during the autumn diurnal migration (ADM) in 2014–2017.

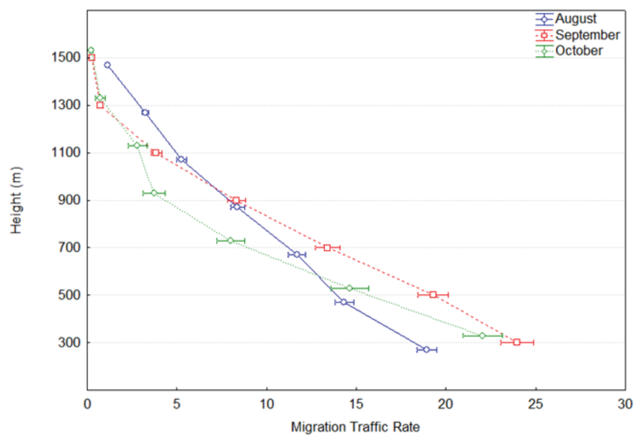


Fig. 16. Average Migration Traffic Rate (MTR) during diurnal autumn migration (ADM) arranged by a flight height (in m a.g.l.) in different months of 2014–2017.

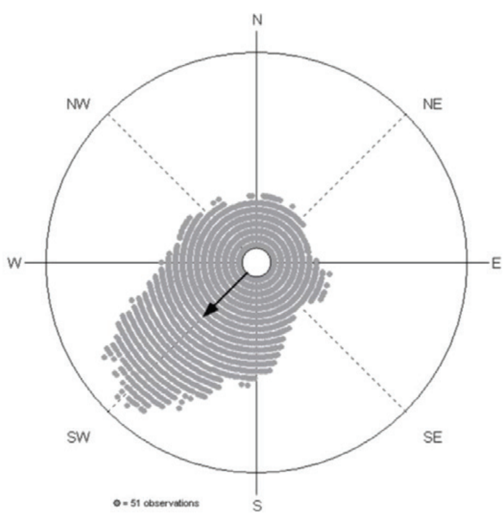


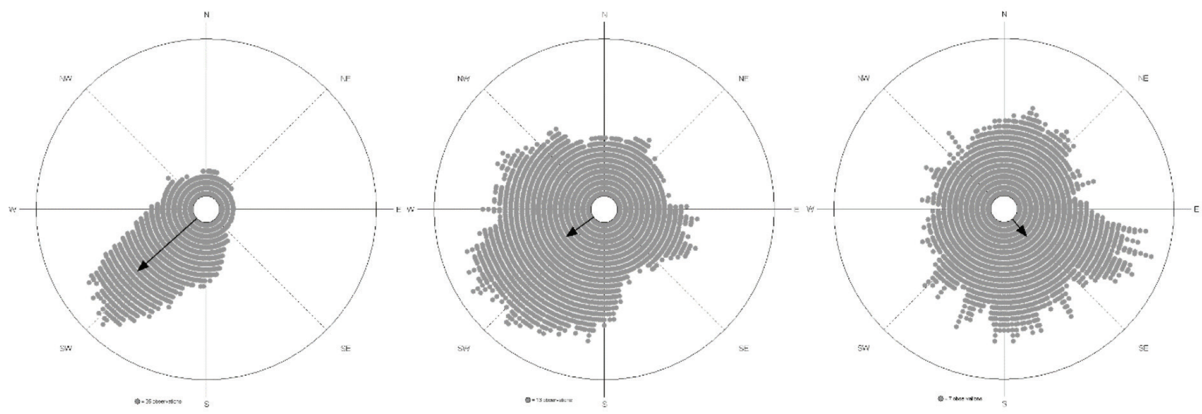
Fig. 17. Circular distribution of flight directions for diurnal autumn migration, 2014–2017.

Correlation of bird migration and temperature

The analysis of the relationship between the flight height (km a.g.l.) and the air temperature (°C) in autumn migration (Fig. 25) revealed that the increase of temperature resulted into the significant increase of flight height in both autumn nocturnal migration (ANM, $R2=0.09$, $F=32.29$, $p<0.001$, $DF=318$) and autumn diurnal migration (ADM, $R2=0.28$, $F=117$, $p<0.001$, $DF=301$).

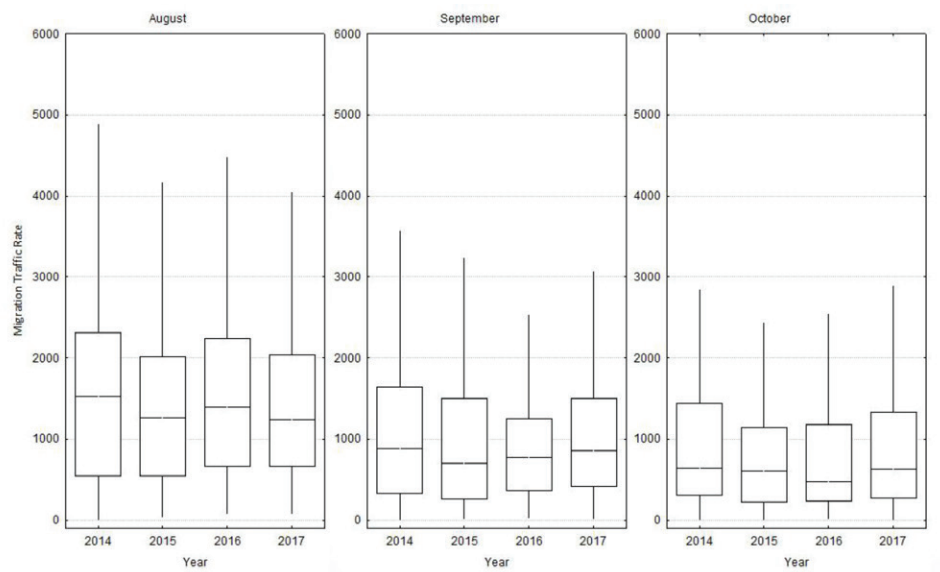
Discussion

In the recently published large-scale survey of bird migration over a part of Europe, scarce data only have been presented for nocturnal bird migration in the region of SE Europe (Nilson et al. 2018). For the first time, we show and quantify by means of a weather radar the bird migration passing through a part of Eastern Europe during 1,101 days and nights of the autumn and the spring seasons of four consecutive years (2014–2017). Our study is the first attempt to investigate bird migration in a long-term period by an objective method in Bulgaria, including diurnal migration. The bird density established as function from the reflectivity in the radar data reflects the dynamics of birds observed visually (Michev et al. 2011, 2012, 2018, Gerdzhikov et al. 2014). According to our results, the migration varies remarkably in numbers, altitudes and directions, with the highest number of birds passing through



August **September** **October**

Fig. 18. Circular distribution per month of flight directions for diurnal autumn migration, 2014–2017.



KW-H (3; 1167) = 3.1388; p = 0.3707 KW-H (3; 1245) = 6.4176; p = 0.0930 KW-H (3; 1126) = 6.8953; p = 0.0753

Fig. 19. Box Plot of Migration Traffic Rate (MTR) of August, September and October spring diurnal migration grouped by year (2014–2017). The box includes the values between the lower (Q1) and the upper (Q3) quartiles, the horizontal line represents the median and the vertical line – the non-outlier range. KW-H – Kruskal-Wallis H statistics.

NE Bulgaria in 115 nights of September and 108 days in August. This period of the highest migration is in full accordance with all collected visual long-term data on bird migration over eastern Bulgaria (Michev et al. 2011). There is no significant difference in the direction of the daily and nocturnal migration in both spring and autumn.

The direction of the bird flights in the autumn period is in accordance with the flight direction in North-Eastern Bulgaria reported earlier by Zehtindjiev & Liechti (2003) and with the direction of the Western European Migration Flyway (van Gasteren et al. 2008, Dokter et al. 2010, Nilsson et al. 2018). The recorded direction of the spring migration, as expected, is North-Northeastern (Zehtindjiev & Liechti 2003, Dokter et al. 2011, Weisshaupt 2018) and can be explained with a high probability with the effect of the guiding line of Black See coast. The consistency in mean directions of the migrating birds observed in our study shows the nature of bird migration over South-Eastern Europe. The results obtained suggest also that the origin of the birds crossing the study region is mainly in locations situated North-East from Bulgaria.

Our results on the correlation between temperature and flight heights in autumn prove the broadly accepted opinion that temperature is by far the climatic variable most frequently related to avian phenology and migration patterns (e.g. Gordo 2007).

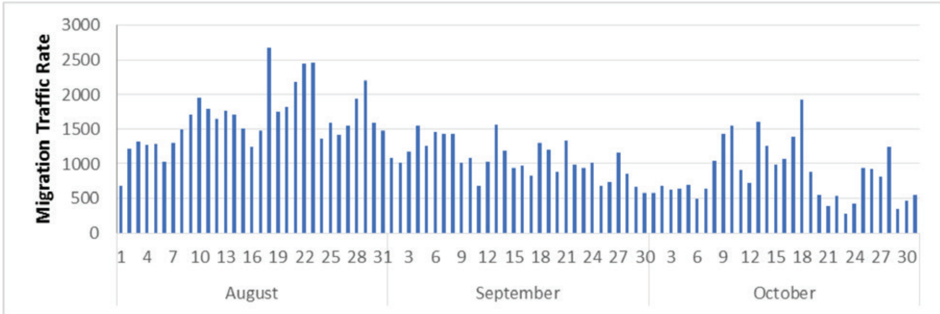


Fig. 20. Average Migration Traffic Rate (MTR) per nights of the different months during autumn nocturnal migration (ANM) in 2014–2017.

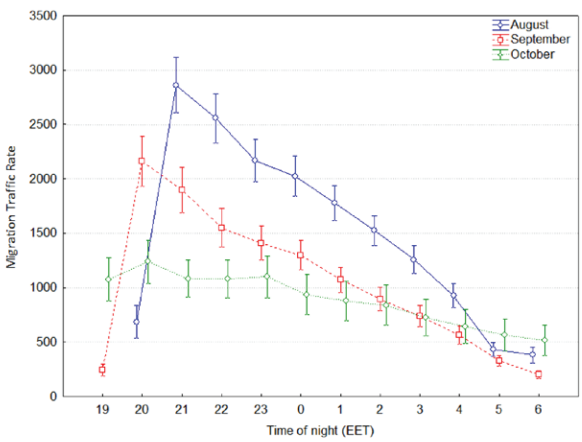


Fig. 21. Average monthly Migration Traffic Rate (MTR) per diurnal hours of the different months during autumn nocturnal migration (ANM), 2014–2017.

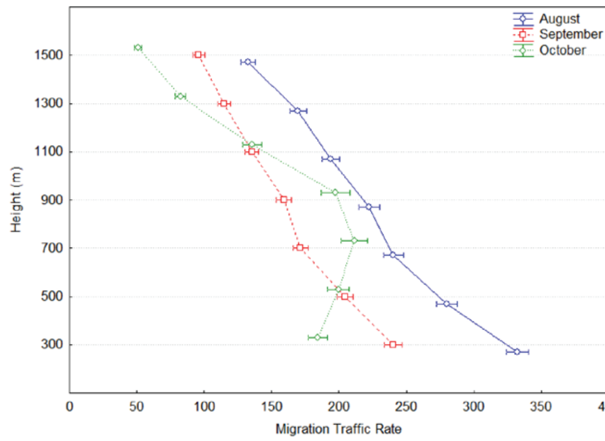


Fig. 22. Average monthly Migration Traffic Rate (MTR) in different flight height layers (m a.g.l.) during the autumn months of ANM, 2014–2017.

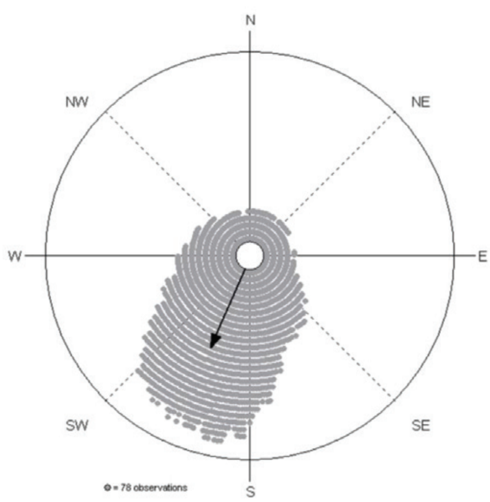
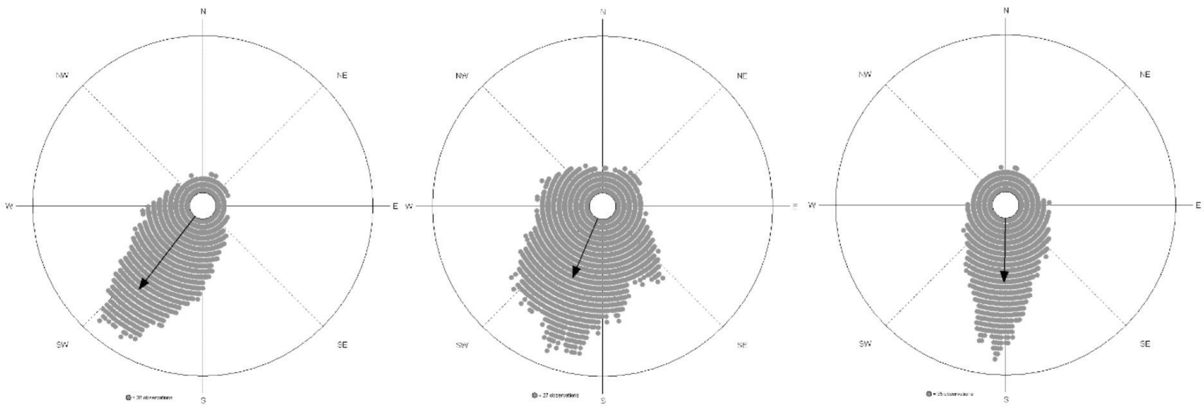


Fig. 23. Circular distribution of flight directions for nocturnal autumn migration, 2014-2017.

Although it is clear that temperature is strongly related to seasonal effects, there are data showing the importance of wind for the height distribution of birds (Schmaljohann et al. 2008, 2009). Previous results of Zehtindjiev & Whitfield (2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017) in the area of the present study also demonstrated that the migration pattern can be strongly impacted by the wind situation.

Doubtless, the temporal and spatial variations of meteorological conditions influence strongly the energy and water budget of birds and, therefore, have strong impact on the flight height (Schmaljohann et al. 2009). According to the same authors, migrating birds can select higher flight altitudes in order to minimise energy costs or water loss, or (if possible) both. Our study showed that nocturnal flight distributions are slightly higher in comparison with diurnal ones but such analysis needs further support with statistical processing. However, we have to emphasise that, in our opinion, excluding the heights below 300 m (which was grounded by literature data in the Materials and Methods) can not distort the results because all our previous visual observations in the same area have demonstrated that the main migrating paths are over 300 m (Michev & Michev, unpublished). Therefore, at present, we state that the chosen height range between 300 and 1,500 m is sufficient for tracking the 24-hours bird dynamics. This height is especially suitable when



August **September** **October**

Fig. 24. Circular distribution per month of flight directions for nocturnal autumn migration, 2014–2017.

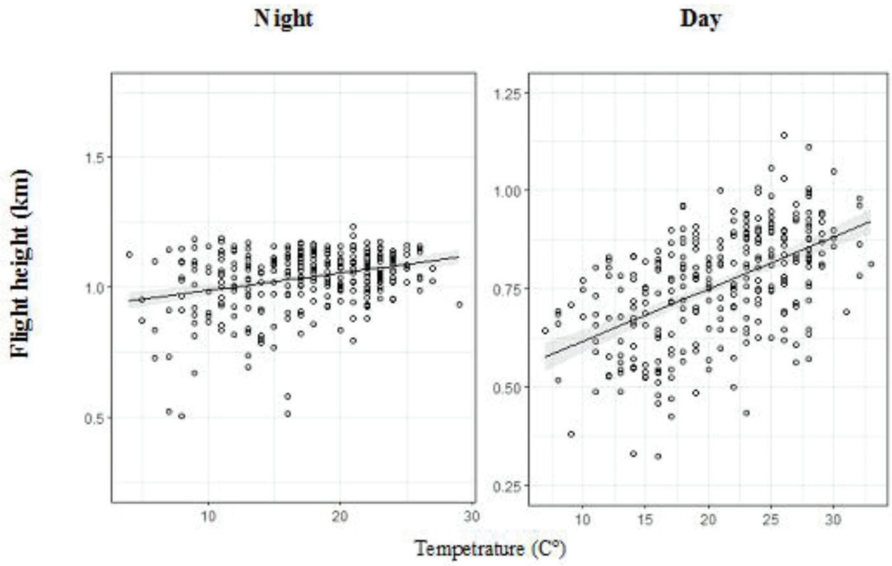


Fig. 25. Average flight height (km a.g.l.) depending on the temperature (C°) during autumn nocturnal migration (ANM) and autumn diurnal migration (ADM) in 2014–2017. Dots represent the nights/days, in which migration was observed.

the nearby location of wind farms and Varna Airport with the numerous landing airplanes are considered.

The comparative analysis of the autumn bird density detected by radars through Europe and Israel allowed us to evaluate the significance of the study region in respect to bird migration. The highest MTR was observed in Israel with an average per night between 4,000 and 6,000 birds in autumn, while in Europe, the MTR previously detected by radars was 1,700 for Germany and 3,400 for the area of Alps in Switzerland (Bruderer 2001) and the mean seasonal MTR was 1,319 in Falsterbo, Sweden (Zehnder et al. 2001). However, the average MTR during 320 nights in our results was 1,140 birds km^{-1} h^{-1}. The average diurnal MTR during 303 days was 70 birds km^{-1} h^{-1}. The higher number of birds observed during the nocturnal autumn migration suggests that the study region is an important area for nocturnal migration in Europe and definitely needs primary attention for future research and conservation.

According to the available literature, up to now, the MTR data reported for the spring migration are as follows: 618 for SNM per night and 154 for SDM per day in March and April 2008 in Trappes, France (Dokter et al. 2010), 1 458 for ten nights of 2014 in Punta Galea and 2,456 for ten nights of 2015 at Cape Higuer (Weisshaupt et al. 2016), and the average MTR for three consecutive years (2007–2009) at Texas coast was 634 (Walsh et al. 2017). According to our date, the average diurnal MTR during 228 days was 40 birds km^{-1} h^{-1}. The average MTR during 250 nights was 446 birds km^{-1} h^{-1}.

In conclusion, it is noteworthy to mention that this first case study is a basis for further development of radar methods and data exchange network. Expanding these data with the inclusion of all of

Europe should be a top priority, as it represents an accessible wealth of new information on bird migration from an already existing network (http://www.enram.eu/). The including of data from countries such as Romania, Greece and Turkey as well as Western Balkans, is of special future importance for mapping the southern part of the flyway and the important passage over the Mediterranean. Therefore, we believe that the evaluation of the quantitative characteristics of bird migration in North-Eastern Bulgaria presented in this study could serve as a significant basis for future monitoring of the important bird migration characteristics in a long-term period when the data of weather radar network will be available for larger territories in Europe.

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