

Autumn passage of soaring birds over Dobrogea (Romania): a migration corridor in Southeast Europe

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The Dobrogea region in southeastern Romania, which is part of the Eurasian-East African Flyway, is listed as one of the important migration corridors for soaring birds on the western coast of the Black Sea. However, our knowledge regarding migration intensity, phenology and geographical patterns of soaring birds over the area is poor. To determine the migration intensity and phenology of soaring birds, we recorded the autumn migration in the Măcin Mountains (northern Dobrogea) from mid-August to the end of October between 2002–2007. To describe the geographical patterns of migration at a regional scale, we recorded migration intensity in the second half of September in 2010 and 2011, simultaneously from 15 and 13 counting points, respectively, covering the entire region of Dobrogea. In the Măcin Mountains we recorded a mean number ($\pm$ SD) of $11,297 \pm 2333.5$ ($CV = 20.7\%$) migrating raptors per year, and of $21,367 \pm 10,949.3$ (51.2%) and 455.6 ± 43.6 (9.6%) migrating White Storks *Ciconia ciconia* and Black Storks *Ciconia nigra*, respectively. Migration phenology parameters varied across raptor and non-raptor species. Migration occurred over a broad front, covering all of Dobrogea. However, migration intensity was more pronounced in the western, central and eastern parts of the region, and was less intensive in the northern central areas. Overall, we recorded 30 migrating raptor species and three non-raptor species. The most abundant raptors were Common Buzzard *Buteo buteo*, European Honey Buzzard *Pernis apivorus*, Lesser Spotted Eagle *Clanga pomarina*, Eurasian Sparrowhawk *Accipiter nisus* and Western Marsh Harrier *Circus aeruginosus*. The three non-raptor species were White Stork, Black Stork and Great White Pelican *Pelecanus onocrotalus*. Our study provides the first general overview of the autumn passage of soaring birds over Dobrogea, highlighting the importance of this area as part of a global migration network.

Key words: raptors, storks, pelicans, migration, Măcin Mountains, Dobrogea, Eurasian-East African Flyway

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Figure 1. (A) Schematic overview of the Eurasian-East African Flyway indicating the major migration corridors and bottlenecks, and the location of the Dobrogea region along the western route of the Eurasian-East African Flyway. The dotted line shows the approximate border between the western (W) and eastern (E) routes (following Newton 2008). (B) Detailed overview of the Dobrogea region indicating the exact locations of the count points used to record soaring bird migration between 2002–2007 and 2010–2011. The count point from the Măcin Mountains (Râioasa Peak) is indicated by an oversized symbol.

The Eurasian-East African Flyway is one of the most important global migration corridors for soaring birds (i.e. large raptors, storks and pelicans), linking the breeding grounds from Northeastern Europe and Western Asia with the Southern African wintering areas (Figure 1A; Bildstein 2006, Newton 2008). The Eurasian-East African Flyway has two main known routes, which converge to Africa: the western and the eastern route (Newton 2008). The western route connects the Black Sea region with Africa (both east and west coasts), while the eastern route links the Caspian Sea region with Africa (Newton 2008; Figure 1A).

The autumn migration of soaring birds has been thoroughly studied in most parts of the Eurasian-East African Flyway, especially at geographical bottlenecks (Figure 1A), where large concentrations of soaring birds are recorded (reviewed by Newton 2008; Michev *et al.* 2011, Verhelst *et al.* 2011, Fülöp *et al.* 2014). Yet, in the northern parts of the western route of the Eurasian-East African Flyway (i.e. the Black Sea region), most efforts of systematically monitoring soaring bird migration have not been so comprehensive. On the

eastern coast of the Black Sea, systematic migration counts commenced in the 1960s (Verhelst *et al.* 2011). On the western coast, in the southern Balkan region (Bulgaria), both sporadic and systematic counts have also been made since about this time (Kumerloev 1957, Roberts 1979, Michev & Simeonov 1981, Michev *et al.* 2011, 2012). However, few systematic counts have been made north of Bulgaria to study the autumn migration of soaring birds (but see Domahidi *et al.* 2004, Fülöp *et al.* 2012).

Dobrogea is a region situated in Southeast Romania, bordered by the Danube river in the north and west, by the Black Sea in the east and by Bulgaria in the south (Figure 1B). Dobrogea is recognized as an important section of the Eurasian-East African Flyway due to its geographic position, making it an important transit area for soaring migrants (Zalles & Bildstein 2000, Bildstein 2006). Both for birds arriving from eastern Romania, Moldova, Ukraine in the north and northwest, migrating along the ridges of the Carpathian Mountains, and for birds arriving from Ukraine in the northeast, migrating along a broad corridor stretching

along the Black Sea coastline, Dobrogea is an area which migrants need to pass through while proceeding to the Bosphorus. Nonetheless, data on the intensity, phenology of migration and migration routes over the region are scarce.

We present the results of two systematic surveys where we describe (1) the intensity- and phenology of the autumn migration of soaring birds in northern Dobrogea, recorded over a six-year period, and (2) the intensity of soaring bird migration over the whole region of Dobrogea, indicating the main migration routes at a regional scale for species migrating on mass. We aim to provide a general overview of the autumn migration of soaring birds over Dobrogea to be used as a baseline for future studies, but also for use in nature conservation, e.g. in relation to wind farm development. At the same time we generate a comparative overview of migration over the entire Balkan region to evaluate migration in Dobrogea from a flyway perspective.

METHODS

Intensity and phenology of migration in the Măcin Mountains

To determine the intensity and phenology of soaring bird migration, we carried out observations from the Râioasa Peak in the Măcin Mountains (Figure 1B; coordinates in Table S1).

The Măcin Mountains are a natural mountain range located in the northern part of Dobrogea and represent the highest elevation in the region. This mountain range is comprised of two major parts: the northern part, Culmea Pricopanului, characterized by bare slopes and shrubby areas, and the southern part, Culmea Măcinului, covered mostly by mature deciduous forests. The Râioasa Peak (346 m a.s.l.) is the second highest point of the northern part and offers the best view over the surrounding hills and plateaus, making it the best observation point for migration surveys.

We recorded the migration of soaring birds over a six-year period, between 2002–2007. We consider 2002 as a pilot study year, because we started our observations later in the season (1 September), missing the passage of some early migrating species (e.g. European Honey Buzzard *Pernis apivorus*, Western Marsh Harrier *Circus aeruginosus*, Black Kite *Milvus migrans*, White Stork *Ciconia ciconia*). Between 2003–2007, however, we started the observations in mid-August and continued until the second half of October, covering the full autumn migration period of soaring birds (see Table S2 for details).

Intensity of migration over Dobrogea

To identify the geographic distribution of the main migration routes of soaring birds over Dobrogea, we recorded the intensity of migration over the entire

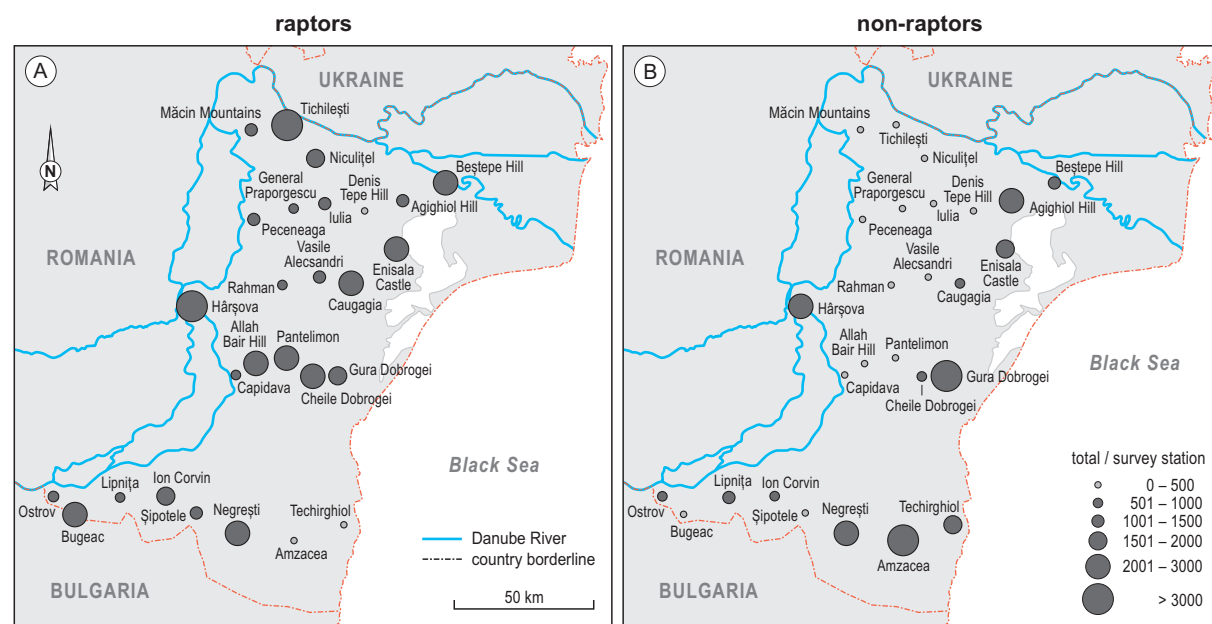


Figure 2. Migration intensity of (A) raptors and (B) non-raptors over Dobrogea, recorded in 2010 and 2011, indicating the geographical pattern of migration over the area.

region from multiple count points. To accomplish this, we divided Dobrogea into a northern and southern area. We recorded the intensity of migration in the northern area simultaneously from 15 survey stations in 2010, and in the southern area from 13 stations in 2011 (Figure 2A, B, Tables S1, S3 and S4). One count point (i.e. Allah Bair Hill) was used as a control and was surveyed in both years. In both years, the exact locations of the count points were selected based on the following criteria: (1) we attempted to maintain comparable distances between count points to create a relatively uniform coverage of the whole survey area, (2) we took into account the topography of the ground surface and the main altitude above sea level, and (3) we accounted for logistic aspects, such as accessibility and access permission. Using these criteria, the mean distance between the neighbouring count points was 16.7 ± 6.5 km ($\pm$ SD) in 2010 and 13.5 ± 4.1 km in 2011, and count points were positioned on elevated points (e.g. hill tops, if present) with good views, to maximize the opportunity of observing migrating birds over large distances. From our previous experience of observations of soaring bird migration (Fülöp *et al.* 2012, 2014), we knew that during average local weather conditions, large-sized soaring migrants (e.g. Common Buzzard *Buteo buteo*, Lesser Spotted Eagle *Clanga pomarina*, White Stork, Black Stork *Ciconia nigra* and Great White Pelican *Pelecanus onocrotalus*) can be observed and identified accurately from a maximum distance of c. 3–5 km.

We recorded the migration of soaring birds on 11 days between 20 and 30 September in 2010, and on 13 days between 19 September and 1 October in 2011. We made our observations in the second half of September, since our results from the Măcin Mountains indicated that the majority of the most abundant species pass through Dobrogea in this period during their autumn migration. Exceptions are the European Honey Buzzard, Western Marsh Harrier and the White Stork (see Table 1 and Figure 3). Hence, our focal species were the Lesser Spotted Eagle, Common Buzzard, Eurasian Sparrowhawk *Accipiter nisus*, Black Stork and the Great White Pelican.

Count method

We used the count method as described by Fülöp *et al.* (2012, 2014; see also Bird & Bildstein 2007). Observations were made daily between 7:00 and 20:00 (in 2002), between 8:00 and 19:00 (between 2003–2007), and 9:00 and 18:00 (in 2010 and 2011). During these hours, 2–4 trained observers were present at each count point, actively searching for migrating birds.

Observers were equipped with binoculars (magnification 10–12 $\times$) and spotting scopes (magnification 20–60 $\times$). Observations were made continuously and were suspended only in case of unfavourable weather conditions (e.g. fog, heavy rain or thunderstorm), when visibility decreased significantly. We recorded all the observed migrating individuals on standard forms. Wandering individuals were also noted, e.g. birds coming from the south. When possible, we identified the migrating birds to species level, and otherwise birds were classified to genus level or marked as unknown. We counted all migrants individually. However, when migration intensity increased and counting individuals became impossible, birds were counted in increments of ten. Because in 2010 and 2011 we counted from multiple count points simultaneously, some overlap in the number of migrants might exist between the neighbouring count points. Nonetheless, we are confident that this does not affect our results, since our aim was not to compare numbers at separate locations with each other, but to identify at a local scale those areas where mass migration occurs.

Statistical analyses

Statistical analyses were performed in the statistical environment R (v. 3.2.4; R Core Team 2016). To characterize the intensity of migration in the Măcin Mountains, we first calculated the total number of observed individual raptor and non-raptor migrants recorded on the survey point for each year separately (i.e. overall abundance), the mean number of migrants recorded per year, the standard deviation (SD) and the coefficient of variation (CV, %). We then calculated the same parameters for each species separately. To describe the migration phenology in the Măcin Mountains, we calculated the following migration phenology characteristics for each species separately: median migration date, dates of first 5% and first 95% of passage, and duration of central 90% of passage (see Verhelts *et al.* 2011). To avoid any biases in our results, in the calculation of migration intensity (except the overall abundance of migrants) and phenology characteristics we excluded data from 2002 (the pilot study year), and only included those species with a minimum yearly average of ten observed individuals. To characterize the intensity of migration over Dobrogea, we calculated the total number of individual migrants observed each year as recorded on the different count points, and the mean, SD and CV of the total number of migrants in the whole region, separately for each year. Since significant overlap in the number of migrants recorded on the different count points may have

occurred, we did not compare abundances between count points to avoid statistical biases. Due to similar concerns, the total abundance of migrants recorded over Dobrogea in 2010 cannot be compared with those recorded in 2011. However, since Allah Bair Hill count point was surveyed in both study years, we compared the total abundance of soaring birds, and of raptors and

non-raptors separately, for Allah Bair between 2010 and 2011, using Wilcoxon Rank-sum Test as implemented in the R package ‘exactRankTests’ (Hothorn & Hornik 2015). A significance level of $P < 0.05$ is used throughout. Means are shown with SD and coefficient of variation (CV).

Table 1. Migration intensity and phenology of raptors and non-raptors as recorded in the Măcin Mountains in the autumns of 2003–2007. The table indicates the mean number of migrants recorded per species per year, standard deviation (SD), coefficient of variation (CV, %), date of first 5%, average median date, date of first 95% and duration of central 90% of passage (days). Migration phenology parameters are reported only for species with >10 observed individuals per year on average.

Species	Mean	SD	CV (%)	Date of first 5%	Median date	Date of first 95%	Length of central 90% (days)
Raptors							
European Honey Buzzard <i>Pernis apivorus</i>	2004.0	760.2	37.9	18/08	04/09	25/09	38
Griffon Vulture <i>Gyps fulvus</i>	0.2	0.5	-	-	-	-	-
Egyptian Vulture <i>Neophron percnopterus</i>	0.2	0.5	-	-	-	-	-
Common Buzzard <i>Buteo buteo</i>	6254.4	2207.6	35.3	18/09	04/10	18/10	30
Long-legged Buzzard <i>Buteo rufinus</i>	24.2	17.6	72.6	18/08	01/10	17/10	60
Rough-legged Buzzard <i>Buteo lagopus</i>	5.2	7.0	-	-	-	-	-
Golden Eagle <i>Aquila chrysaetos</i>	1.2	1.3	-	-	-	-	-
Eastern Imperial Eagle <i>Aquila heliaca</i>	3.6	2.6	-	-	-	-	-
Steppe Eagle <i>Aquila nipalensis</i>	1.0	1.2	-	-	-	-	-
Booted Eagle <i>Aquila pennata</i>	52.8	14.2	26.9	20/08	14/09	25/09	36
Greater Spotted Eagle <i>Clanga clanga</i>	4.2	2.5	-	-	-	-	-
Lesser Spotted Eagle <i>Clanga pomarina</i>	1354.8	738.4	54.5	02/09	20/09	02/10	30
Western Marsh Harrier <i>Circus aeruginosus</i>	471.2	169.8	36.0	20/08	08/09	30/09	41
Hen Harrier <i>Circus cyaneus</i>	37.4	20.4	54.5	03/10	12/10	20/10	17
Montagu's Harrier <i>Circus pygargus</i>	139.4	80.4	57.7	17/08	30/08	19/09	33
Pallid Harrier <i>Circus macrourus</i>	22.6	3.0	13.1	17/08	18/09	08/10	52
Black Kite <i>Milvus migrans</i>	36.0	7.3	20.2	17/08	04/09	29/09	43
Northern Goshawk <i>Accipiter gentilis</i>	12.8	7.8	60.6	10/09	06/10	18/10	38
Eurasian Sparrowhawk <i>Accipiter nisus</i>	531.6	101.2	19.0	12/09	01/10	18/10	36
Levant Sparrowhawk <i>Accipiter brevipes</i>	32.2	26.6	82.5	17/08	30/08	24/09	38
Short-toed Eagle <i>Circus gallicus</i>	76.4	14.1	18.5	28/08	21/09	07/10	40
White-tailed Eagle <i>Haliaeetus albicilla</i>	9.8	3.8	-	-	-	-	-
Peregrine Falcon <i>Falco peregrinus</i>	8.6	6.1	-	-	-	-	-
Saker Falcon <i>Falco cherrug</i>	2.6	2.5	-	-	-	-	-
Common Kestrel <i>Falco tinnunculus</i>	31.0	3.2	10.5	07/09	29/09	16/10	39
Red-footed Falcon <i>Falco vespertinus</i>	51.4	71.9	139.8	23/08	20/09	30/09	38
Eurasian Hobby <i>Falco subbuteo</i>	55.4	46.1	83.1	27/08	21/09	05/10	39
Merlin <i>Falco columbarius</i>	3.6	2.6	-	-	-	-	-
Osprey <i>Pandion haliaetus</i>	10.8	5.5	51.3	25/08	13/09	06/10	42
Unidentified raptor	58.4	37.1	-	-	-	-	-
Total	11297.0	2333.5	20.7				
Non-raptors							
White Stork <i>Ciconia ciconia</i>	21367.0	10949.3	51.2	20/08	28/08	18/09	29
Black Stork <i>Ciconia nigra</i>	455.6	43.6	9.6	20/08	16/09	08/10	49
Total	21822.6	10972.2	50.3				

RESULTS

Intensity and phenology of migration in the Măcin Mountains

In the Măcin Mountains, in the period 2003–2007, we observed $11,297 \pm 2333.5$ (SD; CV: 20.7%) migrating raptors per year, and $21,367 \pm 10,949.3$ (51.2%) and 455.6 ± 43.6 (9.6%) migrating White Storks and Black Storks, respectively (Table 1).

During the six years of observations we observed a total of 29 migrating raptor species and two migrating non-raptor species (Table 1 and see Table S2 for details). The five most abundant raptor species were the Common Buzzard (55.6% from the total number of individuals observed), European Honey Buzzard (17.2%), Lesser Spotted Eagle (12.0%), Eurasian Sparrowhawk (4.8%) and Western Marsh Harrier (4.5%). The rest of the species (c. 6.0%; $n = 24$) occurred in lower numbers (Table 1 and Table S2). The phenology of migration of the most abundant raptor species and of White- and Black Storks are shown in Table 1 and Figure 3.

Intensity of migration over Dobrogea

In 2010 and 2011, migrants (28 raptors species, 3 non-raptor species and the non-migratory Dalmatian Pelican *Pelecanus crispus*) were recorded at all count points in Dobrogea, however, numbers varied between both years (Figures 2 and 4, Tables S3 and S4 for details). In 2010, in northern Dobrogea, the number of migrating raptors at the different count points was 1802.7 ± 1092.5 (CV: 60.6%), while the number of migrating non-raptors was 710.3 ± 934.3 (131.5%; Table S3). In 2011, in southern Dobrogea, the number of migrating raptors at the different count points was 1493.2 ± 827.2 (55.4%), the number of migrating non-raptors was 1709.6 ± 2432.9 (142.3%; Table S4). There was no significant difference between years in the total number of soaring migrants ($W = 331.5$, $P = 0.91$), and in the number migrating raptors and non-raptors recorded on the count point at Allah Bair Hill (raptors: $W = 217.5$, $P = 0.57$; non-raptors: $W = 11.0$, $P = 0.43$).

DISCUSSION

Intensity and phenology of migration in the Măcin Mountains

We recorded a total of 29 raptor species, of which the five most abundant species were Common Buzzard, European Honey Buzzard, Lesser Spotted Eagle,

Eurasian Sparrowhawk and Western Marsh Harrier. Common Buzzards made up more than half of all migrants recorded. The Common Buzzard is one of the most widespread and common Western Palearctic raptor species (Ferguson-Lees *et al.* 2001). Over its European breeding range, two subspecies, *B. b. buteo* and *B. b. vulpinus* (Steppe Buzzard), can be distinguished. During migration in the Black Sea region, *vulpinus*, a long distance migrant wintering in Africa, is the most abundant subspecies (pers. obs.; Michev *et al.* 2011, Verhelst *et al.* 2011). In contrast, *B. b. buteo* is characterized by sedentary or partially migratory populations (Forsman 1999, Ferguson-Lees *et al.* 2001). In our study, Common Buzzards were migrating during the whole migration period. However, the highest numbers were recorded in late September and early October (median: 4 October).

The European Honey Buzzard was the second most abundant raptor species recorded in the Măcin Mountains. Honey Buzzards migrate in large numbers on both sides of the Black Sea (Michev *et al.* 2011, Verhelst *et al.* 2011). Birds originating from Central-Eastern Europe most probably use the west coast of the Black Sea, whereas birds from European Russia migrate on the east coast (Verhelst *et al.* 2011). European Honey Buzzards were migrating mostly in late August and early September (median: 4 September).

The third most numerous migrating raptor species recorded was the Lesser Spotted Eagle. Since the global population of the species is concentrated in Central and Eastern Europe (Ferguson-Lees *et al.* 2001), its main migration route stretches in part over the west coast of the Black Sea, explaining the high numbers encountered in our study (see also Domahidi *et al.* 2004, Michev *et al.* 2011, Fülöp *et al.* 2012). In addition, the species was also recorded in high numbers at the Bosphorus (Fülöp *et al.* 2014), but only in small numbers at Batumi, at the eastern Black Sea migration route (Verhelst *et al.* 2011). Lesser Spotted Eagles migrated mostly in the second half of September until the start of October, with a peak between 10 and 30 September (median: 20 September).

The Eurasian Sparrowhawk was the fourth most numerous observed raptor species. Depending on the population, Eurasian Sparrowhawks show various migratory strategies, some being sedentary, others partially or fully migratory (Ferguson-Lees *et al.* 2001). Since the local populations are likely resident, birds recorded migrating originated most probably from northern populations. Sparrowhawks migrated mostly in the second half of the autumn migration period (median: 1 October).

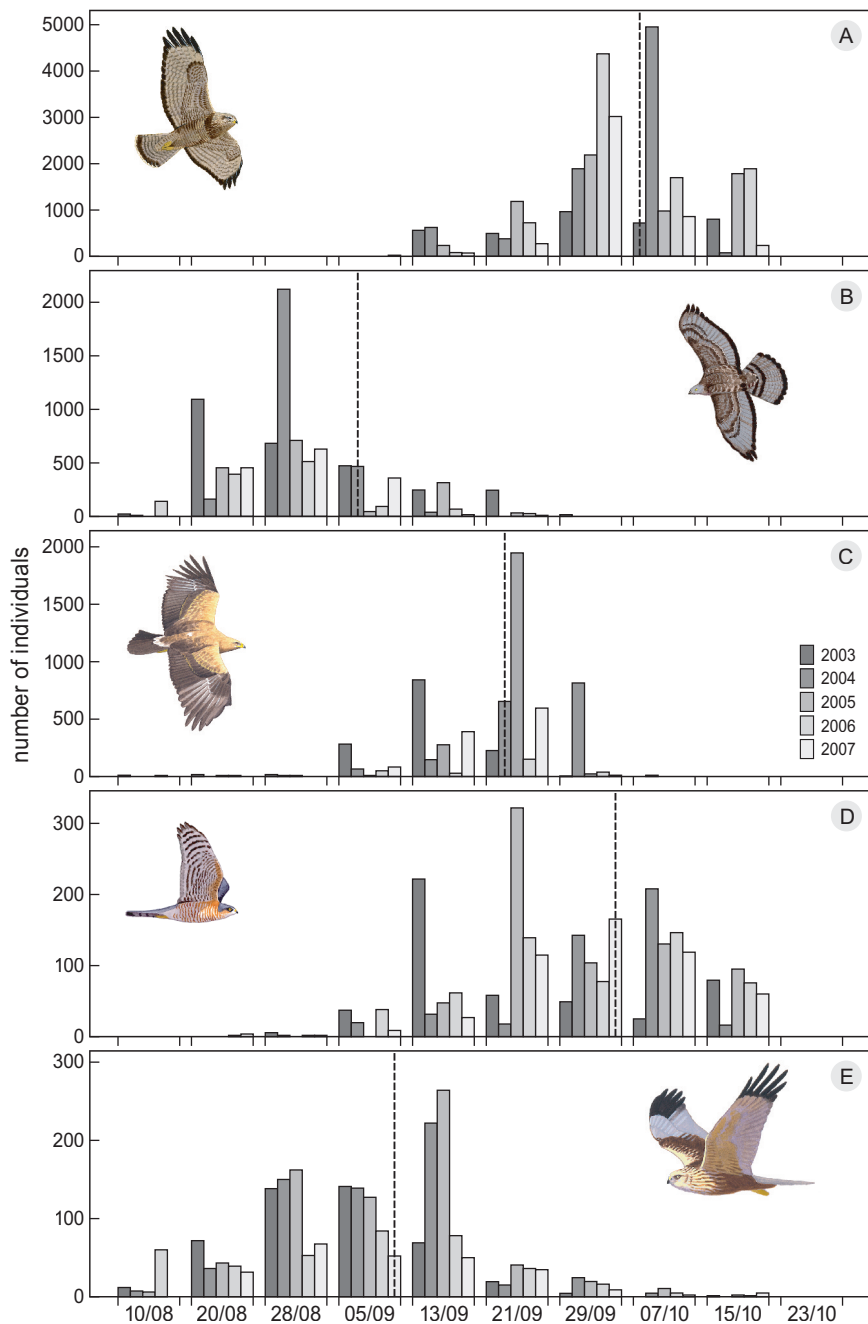


Figure 3. Migration phenology of the five most abundant raptor species recorded in the Măcin Mountains. (A) Common Buzzard *Buteo buteo*, (B) European Honey Buzzard *Pernis apivorus*, (C) Lesser Spotted Eagle *Clanga pomarina*, (D) Eurasian Sparrowhawk *Accipiter nisus* and (E) Western Marsh Harrier *Circus aeruginosus*. Bars indicate the total number of observed individuals per year between 2003–2007 during eight-day periods. Dotted lines indicate the median migration dates.

With similar numbers to the Eurasian Sparrowhawk, the Western Marsh Harrier was the fifth most abundant raptor species recorded. Harriers migrate mostly using active flight, and therefore occur in a broad front (Spaar 1997). Nevertheless, Marsh Harriers passed in

fairly constant numbers at our study site. Marsh Harriers passed through mostly in the first half of the autumn migration period (median: 8 September).

The remaining 24 raptor species recorded during the six years of study in the Măcin Mountains occurred

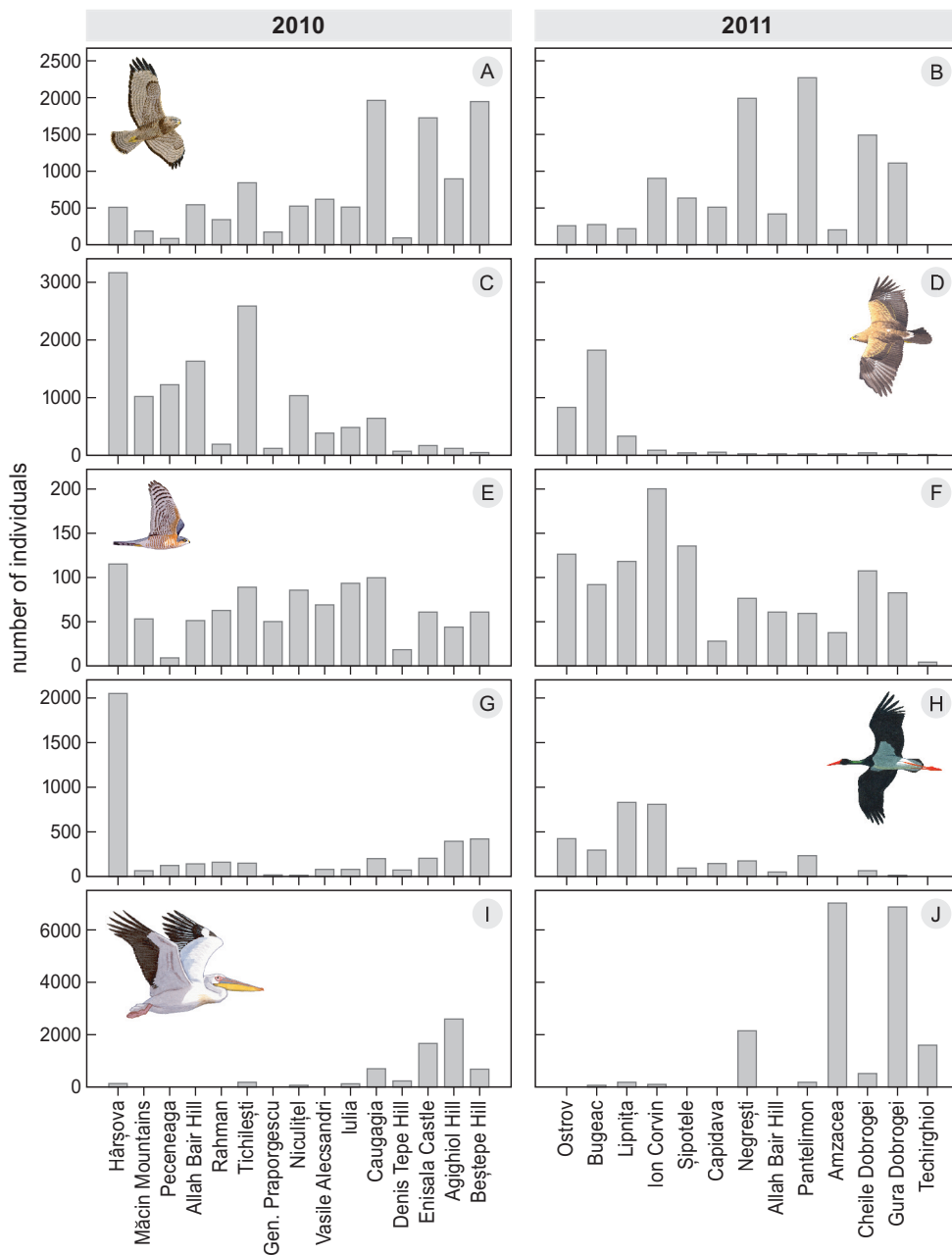


Figure 4. Migration intensity of the five most abundant soaring bird species, recorded in 2010 and 2011 in Dobrogea, indicating the geographical pattern of migration (i.e. concentrated vs. broad front) over the area. (A, B) Common Buzzard *Buteo buteo*, (C, D) Lesser Spotted Eagle *Clanga pomarina*, (E, F) Eurasian Sparrowhawk *Accipiter nisus*, (G, H) Black Stork *Ciconia nigra* and (I, J) Great White Pelican *Pelecanus onocrotalus*. Bars indicate the total number of observed individuals on the different count points, which are ordered along a west-east longitudinal gradient.

in low numbers or only a few individuals. Some of these species (e.g. *Circus* spp., *Falco* spp.) probably migrate in broad fronts, typically using flapping flight more frequently, instead of thermal soaring (Spaar 1997). Hence, their migration is not restricted to

narrow routes and/or geographical bottlenecks (see also Fülöp *et al.* 2014).

The two migratory non-raptor species recorded in the Măcin Mountains were White and Black Stork. White Storks occurred each year in high numbers

(except in 2002), although highly variable between years. The migration phenology of the two stork species is different. While White Storks reached peak migration at the end of August (median: 28 August), Black Storks migrated on average a few weeks later (median: 16 September). This difference between the migration peaks of these species is in agreement with earlier findings (Cramp & Simmons 1977).

Intensity of migration over Dobrogea

Migration occurred over the entire region of Dobrogea, however there were large variations in the abundance of migrants among the count points. Raptors migrated across most parts of Dobrogea, with some exceptions (Figure 2A). Migration tended to be more pronounced in the west (Tichilești, Hârșova, Bugeac count points) and east (Beștepe, Enisala Castle, Caugagia, Gura Dobrogei), and in the central (Allah Bair Hill, Pantelimon, Cheile Dobrogei) and southern central parts (Negrești) of the area. In contrast, migration was generally less intensive in the northern central parts of Dobrogea (Peceneaga, General Praporgescu, Iulia, Denis Tepe Hill, Rahman, Vasile Alecsandri) and was absent in the southeast (Amzacea, Techirghiol). This migration pattern of raptors was mostly determined by the migration patterns of the two most frequently observed species, the Lesser Spotted Eagle and the Common Buzzard. Although there were daily variations in the migration intensity of the species on the different count points, Lesser Spotted Eagles migrated mostly, but not exclusively, in the western parts of Dobrogea, while Common Buzzards arrived from the northeast and followed a southwestern direction (Figure 4).

The migration of non-raptors showed a different pattern compared to raptors (Figure 2B). Non-raptors migrated mostly in the western (Hârșova, Ostrov, Lipnița, Ion Corvin) and eastern parts (Agighiol Hill, Enisala Castle, Gura Dobrogei, Negrești, Amzacea, Techirghiol) of Dobrogea, and occurred only in low numbers in the other parts of the region. As in raptors, this migration pattern was also governed by two species: the Black Stork and the Great White Pelican. Black Storks occurred mostly, but not exclusively, on the western part of the region, while Great White Pelicans migrated in large numbers parallel to the coastline of the Black Sea, and were absent elsewhere (Figure 4).

Overall, migration tended to be more pronounced in some parts of Dobrogea, defining two minor flyways over the region. One of the flyways is situated between the Danube and the line between Tichilești, Allah Bair and Ion Corvin, following a north-south direction in the

western part of Dobrogea (see Figure 2). The other flyway is crossing the area diagonally, from northeast to south and southwest. This flyway follows a parallel line to the Black Sea coastline in its northern section (e.g. Beștepe, Enisala Castle, Gura Dobrogei), but deviating from it slightly at a certain point (i.e. Cheile Dobrogei, Pantelimon), finally heading to a southwestern direction in its southern parts (Negrești, Amzacea). Both flyways are heading to Burgas (Bulgaria), which is the most western point of the Black Sea. Migration tended to be moderate in the northern central areas of Dobrogea (Peceneaga, General Praporgescu, Iulia, Rahman, Vasile Alecsandri).

The general pattern of migration over Dobrogea can have several causes. It is well known that migration characteristics can be influenced by many factors, including species-specific traits (e.g. body size, wing morphology, flight style), weather, geography and topography, or by interactions among these (Panuccio *et al.* 2013a, 2013b, Vansteelant *et al.* 2014, Mellone *et al.* 2015). Wind, especially, can directly shape migration intensity and routes at both local and regional scales (Panuccio *et al.* 2010, Klaassen *et al.* 2011, Panuccio 2011, Limiñana *et al.* 2013, Vidal-Mateo *et al.* 2016). Therefore, our results regarding migration patterns over Dobrogea may vary with changes in external factors. We recorded the migration of soaring birds in two different years to minimize year-effects, and we also found no significant difference between the study years 2010–2011 in the abundance of migrants on our control point. Moreover, migration patterns of the most common species were similar in the different years (see Figure 4). Nevertheless, we stress to be cautious when interpreting our results and emphasize the importance of long-term systematic surveys, covering the full autumn migration period, to account for the temporal and spatial variation in timing, intensity and geographical patterns of migration over Dobrogea. It should be noted that mass-migration of European Honey Buzzards and White Storks was not recorded in 2010–2011, since their migrations occur before our observation period began. These species might use other routes than those indicated by our results, and future studies are needed to elucidate the geographical pattern of their migration over Dobrogea.

Conservation implications

Our results on autumn migration intensity clearly indicate that Dobrogea is an important transit zone for soaring migrants. At the same time, Dobrogea is considered having high potential for wind farming (RWEA

2015). Although wind energy is generally considered 'green', several adverse impacts of wind turbines on flying animals have been described (reviewed by Drewitt & Langston 2006, 2008, Schuster *et al.* 2015, Wang & Wang 2015, O'Shea *et al.* 2016). Among the most important risks are collision, barrier effects and habitat disturbance (Drewitt & Langston 2006). As shown by a large and increasing body of evidence, one of the most affected groups by wind farms are large-sized soaring birds (Garvin *et al.* 2011, Dahl *et al.* 2012, Martínez-Abraín *et al.* 2012), due to multiple causes. During their flight, soaring birds rely on thermal uplifts which usually form in locations where wind turbines are also mounted, e.g. slopes and mountain ridges (Barrios & Rodríguez 2004, Drewitt & Langston 2006, Katzner *et al.* 2012). Besides, they have specific morphological characteristics (e.g. low wing loading, i.e. the ratio of body mass to wing area, high aspect ratio, i.e. the ratio of wing span squared to wing area), imposing limitations to manoeuvrability in flight and, therefore, making them exposed to collision with wind turbines (Barrios & Rodríguez 2004, De Lucas *et al.* 2008). During our observations in Dobrogea we have recorded a high number of raptors and non-raptors which are predominantly using soaring flight during migration. The most numerous soaring raptor species were Common Buzzard, European Honey Buzzard and Lesser Spotted Eagle, while the most abundant soaring non-raptors were White Stork, Black Stork and Great White Pelican. These species, among others, might be highly affected by wind turbines. Also, it should be noted that the largest breeding population (c. 83%) of the Great White Pelican from Europe is located in the Danube Delta (BirdLife International 2016) and migrates over Dobrogea in the autumn.

Migration in Dobrogea: a flyway perspective

From a broader geographical perspective, Dobrogea is the northernmost area of the western route of the Eurasian-East African Flyway, where migrants are starting to concentrate over a relatively narrow geographical corridor in the Balkan region, on the western coast of the Black Sea. Migrants coming from the north first pass over Dobrogea, then fly over Burgas, and finally reach the Bosphorus. Therefore, the species-specific migration intensity and phenology from the Măcin Mountains in Dobrogea is expected to show similar patterns as described from Burgas and the Bosphorus. In addition, migration characteristics such as timing can be similar to those reported from more distant bottleneck sites, but which are located on similar geographical longitudes (e.g. Batumi).

Species composition was very similar in Dobrogea to that recorded at Burgas, and the five most abundant raptor and non-raptor species were mostly the same (Michev *et al.* 2011). The only notable difference for raptors was the presence of Red-footed Falcon *Falco vespertinus* in the top five species recorded at Burgas, while Eurasian Sparrowhawks were more abundant in Dobrogea. Comparing the results from Dobrogea and Burgas with those from Bosphorus, however, is rather difficult, because no full season counts have been made there recently (see a review of studies in Fülöp *et al.* 2014). Nevertheless, considering the migration period of the different species, there is an overall agreement between the results of the various studies from all three areas regarding species composition, both in terms of raptors and non-raptors (van den Bossche & Lens 1994, Arslangündoğdu 2011, Michev *et al.* 2011, Fülöp *et al.* 2014, Panuccio *et al.* 2017). Yet, there are also some notable differences, for instance the relatively low number of European Honey Buzzards and high number of Levant Sparrowhawks *Accipiter brevipes*, recorded at Bosphorus and compared to Dobrogea and Burgas (van den Bossche & Lens 1994, Arslangündoğdu 2011, Michev *et al.* 2011, Fülöp *et al.* 2014, Panuccio *et al.* 2017). These differences, however, can be explained most probably by the timing of the various studies from the Bosphorus or the locations of the observation sites, factors which both can significantly affect the amount of the observed individuals per species (Fülöp *et al.* 2014).

The mean number of migrants recorded per year was lower in Dobrogea than in Burgas. The number of raptors and non-raptors (storks) from the Măcin Mountains equaled c. 30% and 15%, respectively, of the number of raptors and non-raptors counted at Burgas (Michev *et al.* 2011). In addition, numbers of migrating raptors from the Măcin Mountains and Burgas were strongly correlated (Spearman's rank correlation of 33 species: $r = 0.92$, $P < 0.001$). Similar comparisons of means from Dobrogea, Burgas and Bosphorus are difficult to make (see above; Fülöp *et al.* 2014). However, summing all counts made at the Bosphorus in the different periods of the autumn migration season (van den Bossche & Lens 1994, Arslangündoğdu 2011, Michev *et al.* 2011, Fülöp *et al.* 2014, Arslangündoğdu *et al.* 2017, Panuccio *et al.* 2017), we can provisionally estimate that migration intensity over the Bosphorus during the entire autumn season is at least five to ten times higher than that reported from Burgas, and around fifteen to thirty times that from Dobrogea.

Finally, species-specific timing of migration of both raptors and non-raptors from Dobrogea was in line

with the results reported from Burgas (Michev *et al.* 2011) and Bosphorus (van den Bossche & Lens 1994, Arslangündoğdu 2011, Fülöp *et al.* 2014, Arslangündoğdu *et al.* 2017, Panuccio *et al.* 2017), as the different species were migrating in similar autumn periods. Our results on migration timing of the mass-migrating species were also in strong accordance with the mean passage dates of the same species reported from Batumi (Verhelst *et al.* 2011), indicating that the migration timing of soaring birds from different geographical latitudes, but similar longitudes, is strongly correlated.

Migration monitoring has proven to be a useful and cost-effective tool in estimating long-term population trends and/or breeding population sizes in raptors and other soaring birds (Bednarz *et al.* 1990, Agostini *et al.* 2007, Farmer *et al.* 2007, 2010, Martín *et al.* 2016). Our study is meant to serve as a baseline for future migration monitoring at this section of a globally important flyway. Future studies should also focus on the temporal and spatial variations in migration intensity over Dobrogea in order to be able to mitigate conflicts between wind energy exploitation and nature conservation.

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SAMENVATTING

De in het zuidoosten van Roemenië gelegen Dobrogea maakt deel uit van de Oost-Europese en Oost-Afrikaanse trekroute. Het gebied wordt aangemerkt als een van de belangrijke trekcorridors langs de westkust van de Zwarte Zee voor vogels die gebruikmaken van thermiek. Onze kennis over de trekintensiteit, fenologie en geografische patronen van de vogels die over het gebied trekken, is echter slecht. Wij onderzochten in 2002–2007 van half augustus tot eind oktober het in het noorden van de Dobrogea gelegen Măcingebergte de trekintensiteit en fenologie van vogels die tijdens de trek gebruikmaken van thermiek. Om de ruimtelijke trekpatronen over de Dobrogea vast te leggen, werd in 2010–2011 in de tweede helft van september op respectievelijk 15 en 13 telpunten simultaantellingen gehouden. In het Măcingebergte werden in de twee jaren gemiddeld 11.297 ± 2334 (SD; CV = 20,7%) trekkende roofvogels waargenomen, alsmede 21.367 ± 10.949 (51,2%) trekkende Ooievaars *Ciconia ciconia* en $455,6 \pm 43,6$ (9,6%) Zwarte Ooievaars *Ciconia nigra*. De trekfenologie varieerde zowel

tussen de verschillende soorten roofvogels als tussen de twee soorten ooievaars. De trek vond over een breed front over de Dobrogea plaats. De trekintensiteit was echter het groots in de westelijke, centrale en oostelijke delen van het gebied en minder intensief in het noordelijke deel van het centrale gebied. In totaal werden 30 trekkende soorten roofvogels en drie soorten niet-roofvogels boven de Dobrogea geregistreerd. De meest voorkomende roofvogels waren Buizerd *Buteo buteo*, Wespiedief *Pernis apivorus*, Schreeuwarend *Clanga pomarina*, Sperwer *Accipiter n. nisus* en Bruine Kiekendief *Circus a. aeruginosus*. De drie niet-roofvogelsoorten betroffen Ooievaar, Zwarte Ooievaar en Roze Pelikaan *Pelecanus onocrotalus*. Ons onderzoek (het eerst gebiedsdekkende onderzoek naar het verloop van de najaarstrek over het gebied van vogels die gebruikmaken van thermiek) benadrukt het belang van de Dobrogea als onderdeel van een wereldwijd vogeltreknetwerk.

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SUPPLEMENTARY MATERIAL

Table S1. GPS coordinates of the count points used for migration counts between 2002–2007 and 2010–2011 in Dobrogea.

Nr.	Survey station name	Year	Location coordinates	
			Longitude (degrees)	Latitude (degrees)
1	Măcin Mountains (Râioasa Peak)	2010	28.19458	45.25285
2	Tichilești	2010	28.35126	45.26842
3	Niculitel	2010	28.47389	45.16464
4	Beștepe Hill	2010	29.05166	45.08848
5	Peceneaga	2010	28.20284	44.97399
6	General Praporgescu	2010	28.37554	45.00758
7	Iulia	2010	28.51352	45.02301
8	Denis Tepe Hill	2010	28.69117	45.00093
9	Agighiol Hill	2010	28.85762	45.03225
10	Hârșova	2010	27.92827	44.70125
11	Rahman	2010	28.32695	44.76902
12	Vasile Alecsandri	2010	28.49096	44.79445
13	Caugagia	2010	28.63109	44.77325
14	Enisala Castle	2010	28.83238	44.88173
15	Allah Bair Hill	2010, 2011	28.21040	44.52141
16	Capidava	2011	28.12127	44.48697
17	Pantelimon	2011	28.34644	44.54033
18	Cheile Dobrogei	2011	28.46300	44.48226
19	Gura Dobrogei	2011	28.57113	44.48529
20	Ostrov	2011	27.31235	44.10335
21	Bugeac	2011	27.41211	44.04844
22	Lipnița	2011	27.61661	44.10135
23	Ion Corvin	2011	27.81866	44.10583
24	Șipotele	2011	27.95121	44.05232
25	Negrești	2011	28.13066	43.98940
26	Amzacea	2011	28.37763	43.96381
27	Techirghiol	2011	28.59670	44.01359

Table S2. Total number of migrating raptors and non-raptors recorded in the Măcin Mountains between 2002–2007.

Species	2002 01/09– 29/10	2003 16/08– 21/10	2004 16/08– 17/10	2005 16/08– 23/10	2006 14/08– 21/10	2007 20/08– 19/10
Raptors						
European Honey Buzzard <i>Pernis apivorus</i>	1502	2828	2828	1591	1286	1487
Griffon Vulture <i>Gyps fulvus</i>	0	0	1	0	0	0
Egyptian Vulture <i>Neophron percnopterus</i>	0	1	0	0	0	0
Common Buzzard <i>Buteo buteo</i>	6088	3618	7959	6406	8802	4487
Long-legged Buzzard <i>Buteo rufinus</i>	61	54	21	14	23	9
Rough-legged Buzzard <i>Buteo lagopus</i>	7	0	4	17	5	0
Golden Eagle <i>Aquila chrysaetos</i>	0	1	0	2	3	0
Eastern Imperial Eagle <i>Aquila heliaca</i>	2	4	6	6	2	0
Steppe Eagle <i>Aquila nipalensis</i>	1	0	1	3	1	0
Booted Eagle <i>Aquila pennata</i>	45	57	65	63	49	30
Greater Spotted Eagle <i>Clanga clanga</i>	4	4	8	5	2	2
Lesser Spotted Eagle <i>Clanga pomarina</i>	1252	1416	1718	2268	288	1084
Western Marsh Harrier <i>Circus aeruginosus</i>	677	457	600	674	372	253
Hen Harrier <i>Circus cyaneus</i>	40	14	28	45	68	32
Montagu's Harrier <i>Circus pygargus</i>	36	273	119	111	137	57
Pallid Harrier <i>Circus macrourus</i>	18	20	24	19	24	26
Black Kite <i>Milvus migrans</i>	11	25	41	41	41	32
Northern Goshawk <i>Accipiter gentilis</i>	23	17	23	8	13	3
Eurasian Sparrowhawk <i>Accipiter nisus</i>	521	478	439	700	542	499
Levant Sparrowhawk <i>Accipiter brevipes</i>	16	56	15	12	66	12
Short-toed Eagle <i>Circaetus gallicus</i>	78	59	95	84	77	67
White-tailed Eagle <i>Haliaeetus albicilla</i>	10	8	13	12	12	4
Peregrine Falcon <i>Falco peregrinus</i>	5	16	5	6	14	2
Saker Falcon <i>Falco cherrug</i>	3	7	2	1	1	2
Common Kestrel <i>Falco tinnunculus</i>	53	35	28	34	29	29
Red-footed Falcon <i>Falco vespertinus</i>	22	28	6	179	18	26
Eurasian Hobby <i>Falco subbuteo</i>	89	137	25	40	41	34
Merlin <i>Falco columbarius</i>	6	3	5	7	3	0
Osprey <i>Pandion haliaetus</i>	9	7	10	20	11	6
Unidentified raptor	85	120	53	59	36	24
Total	10664	9743	14142	12427	11966	8207
Non-raptors						
White Stork <i>Ciconia ciconia</i>	746	25440	19603	9792	37894	14106
Black Stork <i>Ciconia nigra</i>	322	448	408	421	506	495
Total	1068	25888	20011	10213	38400	14601

Table S3. Total number of migrating raptors and non-raptors recorded in the northern part of Dobrogea in 2010.

	Măcin Mountains	Tichilești	Niculitel	Beștepe Hill	Peceneaga	General Praporgescu	Iulia	Denis Tepe Hill	Agighiol Hill	Hârșova	Rahman	Vasile Alecsandri	Caugagia	Enisala Castle	Allah Bair Hill
Raptors															
European Honey-buzzard <i>Pernis apivorus</i>	15	18	5	14	3	1	5	14	35	6	2	12	15	52	1
Common Buzzard <i>Buteo buteo</i>	187	844	532	1953	93	181	515	99	897	508	342	619	1969	1735	542
Long-legged Buzzard <i>Buteo rufinus</i>	3	7	1	3	1	4	1	2	3	5	0	2	2	10	10
Rough-legged Buzzard <i>Buteo lagopus</i>	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Eastern Imperial Eagle <i>Aquila heliaca</i>	1	0	0	0	0	0	0	1	0	0	4	0	4	1	0
Steppe Eagle <i>Aquila nipalensis</i>	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Booted Eagle <i>Aquila pennata</i>	4	4	7	2	6	7	6	14	22	6	3	1	4	4	2
Greater Spotted Eagle <i>Clanga clanga</i>	0	0	1	1	1	0	0	0	0	0	1	0	3	0	0
Lesser Spotted Eagle <i>Clanga pomarina</i>	1017	2584	1030	47	1224	111	468	75	122	3162	195	379	634	161	1636
Western Marsh Harrier <i>Circus aeruginosus</i>	22	50	45	28	6	40	28	37	56	42	27	19	40	38	37
Hen Harrier <i>Circus cyaneus</i>	0	1	2	0	0	1	0	0	0	1	0	0	0	0	1
Montagu's Harrier <i>Circus pygargus</i>	1	1	0	0	0	0	0	3	3	0	1	0	1	1	0
Pallid Harrier <i>Circus macrourus</i>	0	2	1	1	0	0	6	0	1	1	1	0	3	1	1
Black Kite <i>Milvus migrans</i>	1	2	4	0	0	0	0	1	0	0	4	1	2	1	1
Northern Goshawk <i>Accipiter gentilis</i>	2	0	2	0	0	2	0	0	0	2	0	2	0	1	2
Eurasian Sparrowhawk <i>Accipiter nisus</i>	54	89	86	61	10	51	94	19	45	115	63	69	100	62	52
Levant Sparrowhawk <i>Accipiter brevipes</i>	0	2	3	0	0	0	0	4	2	2	1	1	9	4	0
Short-toed Eagle <i>Circus gallicus</i>	19	80	1	11	14	33	18	6	17	28	30	13	37	4	23
White-tailed Eagle <i>Haliaeetus albicilla</i>	11	5	13	13	1	0	0	1	5	10	0	1	1	3	0
Peregrine Falcon <i>Falco peregrinus</i>	0	2	2	0	0	0	0	0	2	1	1	1	0	3	0
Saker Falcon <i>Falco cherrug</i>	1	1	0	0	0	0	0	1	0	0	0	0	3	0	1
Common Kestrel <i>Falco tinnunculus</i>	3	1	0	1	0	9	4	0	1	7	2	0	5	4	2
Red-footed Falcon <i>Falco vespertinus</i>	2	36	7	69	1	5	4	22	51	7	5	9	14	39	18
Eurasian Hobby <i>Falco subbuteo</i>	10	34	19	20	0	11	21	7	4	17	14	12	17	16	24
Osprey <i>Pandion haliaetus</i>	1	0	3	1	0	0	2	1	0	0	1	0	1	6	0
Unidentified raptor	15	8	4	9	1	53	7	12	9	10	8	59	14	3	36
Total	1369	3773	1768	2234	1361	509	1180	319	1275	3930	705	1200	2879	2149	2389
Non-raptors															
White Stork <i>Ciconia ciconia</i>	0	57	2	9	0	1	0	0	2	33	0	1	2	4	4
Black Stork <i>Ciconia nigra</i>	63	147	5	413	118	12	78	72	392	2049	156	80	193	201	142
Unidentified Stork <i>Ciconia</i> spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	2	21
Great White Pelican <i>Pelecanus onocrotalus</i>	0	172	84	688	0	0	117	220	2595	144	13	0	691	1664	1
Dalmatian Pelican <i>Pelecanus crispus</i>	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Unidentified Pelican <i>Pelecanus</i> spp.	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
Total	63	376	91	1110	118	13	195	292	2989	2232	170	81	886	1871	168

Table S4. Total number of migrating raptors and non-raptors recorded in the southern part of Dobrogea in 2011.

	Allah Bair Hill	Capidava	Pantelimon	Cheile Dobrogei	Gura Dobrogei	Ostrov	Bugeac	Lipnița	Ion Corvin	Șipotele	Negrești	Amzacea	Techirghiol
Raptor													
European Honey-buzzard <i>Pernis apivorus</i>	19	10	2	60	65	44	47	35	27	11	1	16	2
Griffon Vulture <i>Gyps fulvus</i>	1	0	0	0	0	1	0	0	0	0	0	0	0
Common Buzzard <i>Buteo buteo</i>	421	509	2279	1496	1116	264	279	225	910	639	1997	204	6
Long-legged Buzzard <i>Buteo rufinus</i>	12	3	0	17	1	1	5	3	1	14	3	8	0
Rough-legged Buzzard <i>Buteo lagopus</i>	0	0	0	1	0	0	0	0	0	0	0	0	0
Eastern Imperial Eagle <i>Aquila heliaca</i>	1	1	2	1	3	2	0	0	0	0	0	0	0
Steppe Eagle <i>Aquila nipalensis</i>	0	0	0	0	0	0	1	0	0	0	0	0	0
Booted Eagle <i>Aquila pennata</i>	10	5	10	15	3	2	8	5	15	8	3	1	0
Greater Spotted Eagle <i>Clanga clanga</i>	0	0	0	1	0	2	1	3	2	0	0	0	0
Lesser Spotted Eagle <i>Clanga pomarina</i>	29	48	27	37	7	831	1828	331	82	39	21	18	2
Western Marsh Harrier <i>Circus aeruginosus</i>	75	25	32	60	116	55	90	79	83	41	48	53	17
Hen Harrier <i>Circus cyaneus</i>	0	0	1	1	0	1	0	0	0	0	0	0	0
Montagu's Harrier <i>Circus pygargus</i>	3	3	0	0	4	4	0	0	0	2	1	0	0
Pallid Harrier <i>Circus macrourus</i>	2	3	0	6	0	2	3	5	0	0	2	3	0
Black Kite <i>Milvus migrans</i>	0	1	2	1	0	0	4	2	2	3	1	1	0
Northern Goshawk <i>Accipiter gentilis</i>	0	0	0	5	1	3	1	3	5	1	1	0	0
Eurasian Sparrowhawk <i>Accipiter nisus</i>	61	29	60	108	83	126	92	118	200	135	77	38	5
Levant Sparrowhawk <i>Accipiter brevipes</i>	4	6	2	1	0	22	3	6	0	1	1	0	2
Short-toed Eagle <i>Circus gallicus</i>	14	16	7	8	4	13	18	25	28	20	12	4	0
White-tailed Eagle <i>Haliaeetus albicilla</i>	0	1	0	0	1	1	2	1	0	0	0	0	0
Peregrine Falcon <i>Falco peregrinus</i>	0	2	1	10	2	0	1	0	0	1	0	1	0
Saker Falcon <i>Falco cherrug</i>	0	0	7	2	2	1	0	1	0	1	1	1	1
Eleonora's Falcon <i>Falco eleonora</i>	0	0	0	0	0	0	0	0	0	0	0	1	0
Common Kestrel <i>Falco tinnunculus</i>	4	4	8	18	6	7	2	0	19	7	0	3	0
Red-footed Falcon <i>Falco vespertinus</i>	326	172	59	429	549	82	65	77	147	236	299	105	11
Eurasian Hobby <i>Falco subbuteo</i>	5	12	10	54	18	11	14	22	31	6	19	8	6
Merlin <i>Falco columbarius</i>	0	0	0	1	0	0	1	0	0	0	1	0	0
Osprey <i>Pandion haliaetus</i>	2	0	0	0	4	4	6	7	3	0	5	1	1
Unidentified raptor	5	6	15	1	11	19	17	8	7	2	17	8	0
Total	994	856	2524	2333	1996	1498	2488	956	1562	1167	2510	474	53
Non-raptors													
White Stork <i>Ciconia ciconia</i>	0	3	2	0	1	3	6	5	6	2	2	1	0
Black Stork <i>Ciconia nigra</i>	42	137	234	67	8	419	299	831	802	98	169	3	0
Great White Pelican <i>Pelecanus onocrotalus</i>	5	16	166	513	6904	12	53	174	91	0	2146	7040	1590
Dalmatian Pelican <i>Pelecanus crispus</i>	0	16	17	22	43	253	7	9	0	0	1	6	0
Unidentified Pelican <i>Pelecanus</i> spp.	0	0	1	0	0	0	0	0	0	0	0	0	0
Total	47	172	420	602	6956	687	365	1019	899	100	2318	7050	1590