Pirineos. Revista de Ecología de Montaña 179
Jaca, Enero-Diciembre, 2024, e086
ISSN-L 0373-2568, eISSN 1988-4281
https://doi.org/10.3989/pirineos.2024.179.003

WIND EFFECT AND PHENOLOGY OF POST BREEDING BIRD MIGRATION THROUGH THE WESTERN PYRENEES FOR A SELECTION OF SPECIES

Efecto del viento y fenología de la migración de aves post-reproducción a través de los pirineos occidentales para una selección de especies

Pablo Monroy[1], Alicia García-Serrano[2], Juan Herrero[3*], Luis Tirado[4]

[1] Area of Biodiversity, SARGA, Zaragoza, 50018, Spain.

[2] Ega Wildlife Consultants, Zaragoza, 50003, Spain.

[3] Area of Ecology, Department of Agrarian and Environmental Sciences, Technical School, University of Zaragoza, Huesca, 22718, Spain.

[4] SEO/Birdlife, Zaragoza, 50011, Spain.

Identificador ORCID de los autores y e-mail
Pablo Monroy: https://orcid.org/0000-0002-8196-0702. E-mail: pmonroym@sarga.es
Alicia García-Serrano: https://orcid.org/0000-0002-2474-7729. E-mail: aliciaega@gmail.com
Juan Herrero: https://orcid.org/0000-0001-8273-3141. E-mail: herreroj@unizar.es
Luis Tirado: https://orcid.org/0000-0002-6187-2422. E-mail: ltirado@seo.org
*Autor corresponsal: herreroj@unizar.es

Recibido: 26-10-2022. **Aceptado**: 26-11-2024. **Fecha de publicación on-line**: 30-01-2025

Citation/Cómo citar este artículo: Monroy, P., García-Serrano, A., Herrero, J., Tirado, L. (2024). Wind effect and phenology of post breeding bird migration through the western Pyrenees for a selection of species. *Pirineos*, 179 e086. https://doi.org/10.3989/pirineos.2024.179.003

ABSTRACT: Post-breeding bird migration along Western Pyrenean routes through two distinct mountain passes (Somport and Portalet) was studied during 2016 and 2017. A total of four species of two different groups were surveyed: (i) gliders or soaring birds (European Honey Buzzard *Pernis apivorus* and Black Kite *Milvus migrans*), (ii) flappers (Common House Martin *Delichon urbicum* and Barn Swallow *Hirundo rustica*). Swallows and martins used the central day hours to migrate due to thermal flows, whereas non-gliders avoided strong winds. The European Honey-Buzzard migrated from mid-August to mid-September, the Black Kite from mid-July to mid-August, the common house martin from late July to late September, and the barn swallow from late August to mid-October. Selection of wind direction was different for each species, and temperature was the most relevant explanatory meteorological factor related to the migrations.

KEYWORDS: gliders; flapping birds; Somport; Portalet; meteorology; soaring; flapping.

RESUMEN: Estudiamos la migración pos nupcial de aves a través de los Pirineos en los puertos de montaña de Somport y Portalet durante 2016 y 2017. Se siguieron cuatro especies: (aves planeadoras) abejero europeo *Pernis apivorus*, milano negro *Milvus migrans* y aves batiendo alas, aleteadoras o remeras (avión común *Delichon urbicum* y golondrina común *Hirundo rustica*). Las planeadoras utilizaron las horas centrales del día para migrar debido a los flujos térmicos. Las aleteadoras evitaron los fuertes vientos. El abejero europeo migra desde mediados de agosto hasta mediados de septiembre, el milano negro desde mediados de julio hasta mediados de agosto, el avión común desde finales de julio hasta finales de septiembre y la golondrina común desde finales de agosto hasta mediados de octubre. La selección de la dirección del viento es diferente en cada especie. La temperatura es el factor meteorológico más relevante que explica su migración.

PALABRAS CLAVE: aves planeadoras; aves aleteadoras; Somport; Portalet; meteorología; planeo; aleteo.

1 Introduction

Bird migration is defined as these animals' regular and seasonal movements (Bernis, 1966; Alerstam, 1990; Dingle, 2014). These voyages are undertaken by several species to face climate and resource seasonality (Alerstam, 1990) and are legally protected through several European initiatives, such as the Bird's Directive (79/409/EU) and the Bonn's Convention (82/461/EU).

Due to their flight ability and efficiency, migrations are widespread among birds (Newton, 2008; Dingle, 2014). Approximately half of the world's bird species migrate annually (Newton, 2008; Cox, 2010), and specifically 50 to 100 % of the ones living at mid-latitudes and polar environments do so (Somveille *et al*., 2013). These migrations typically follow north-south axis routes along temperature and primary production gradients, among other factors (Alerstam, 1990; Newton, 2008). There are two annual migrations: prenuptial — generally from S to N, during spring — and post-breeding — from N to S, during late summer and autumn (Alerstam, 1990).

Birds fly by either gliding or flapping their wings. This has produced a selection for structures and body systems (Alerstam, 1990; Berthold, 2001; Newton, 2008; Pennycuick, 1975, 2008). Gliding birds usually have a large wing surface and depend on airflows formed on the earth's surface to move with a small energetic expenditure (Onrubia, 2015). Several birds use upward flow to rise at a great speed in characteristic circular flights (Kerlinger, 1989; Newton, 2008). Because gliders use these airflows, these species concentrate their migration during the central hours of the day, when said airflows are available (Bildstein, 2006; Newton, 2008; Onrubia, 2015).

Migration between Africa and Europe corresponds with the Palearctic-African Migratory System, with 2,100-5,000 million birds of 215 species migrating annually (Moreau, 1972; Newton, 2008; Hahn *et al*., 2009). Important geographic barriers such as the Alps and the Mediterranean Sea largely condition these migrations, which has led to the formation of the eastern and western migration corridors. The later crosses the Iberian Peninsula and other western Mediterranean passes (Moreau, 1972; Mead, 1983; Berthold, 2001; Elphick, 2007; Newton; 2008; Filippi-Codaccioni *et al*., 2010), where several monitoring projects are being carried out (SEO/Birdlife 2000; Pérez-Tris & Santos, 2004; Filippi-Codaccioni *et al*., 2010; Isturiz *et al*., 2022).

The migratory phenology in the Iberian Peninsula has been previously studied (Filippi-Codaccioni *et al*., 2010; Onrubia, 2015; Isturiz *et al*., 2022), but what remains largely unexplored is the potential influence of meteorology on this phenomenon (Isturiz *et al*., 2022).

In this context, the aim of our work is to describe the post-breeding visible migration behaviour (below 400 m of height) of two gliding species (European Honey Buzzard *Pernis apivorus* and Black Kite *Milvus migrans*) and two flapping species (Common House Martin *Delichon urbicum* and Barn Swallow *Hirundo rustica*), and to study the effect of wind direction and speed on their passing through the Pyrenees. Non-visible migration was not considered (over 800 m of height). These species were selected for their abundance considering their taxonomic group allowing statistical analysis, and because they represent different flying strategies.

2. Study area

The Pyrenees are a mountain range located along the northern Iberian Peninsula. They represent the border between France and Spain and integrate the totality of Andorra, reaching elevations above 3000 m. The field work was carried out at two mountain passes of the Western Pyrenees: Somport and Portalet. Somport mountain pass (42º 47' 44,79" N, 0º 31' 33,08" W), is oriented NE-SO and has an elevation of 1,632 m. According to the Köppen (1900) classification, the climate is "Dfc, without a dry season and with a fresh summer".

During field work, weather was stable during summer, except for some storms, and rainy, cloudy, and windy in autumn. Fog was frequent due to the narrowness of the pass. The habitat is composed of Scots Pine *Pinus sylvestris*, Mountain Pine *Pinus uncinata* and Beech *Fagus sylvatica* in the lower areas and open subalpine grasslands in the higher ones. The Portalet mountain pass (42º 48' 21, 72" N, 0º 25' 6,35" W) has as N-S orientation and an elevation of 1,795 m. The climate is the same as in Somport, and so was the meteorology during field work, except for less fog.

3. Material and methods

Counts were performed simultaneously at both mountain passes from 7:00 to 17:00 h, between July 15th and November 15th of 2016 and 2017. At each mountain pass, five experienced ornithologists including one of us (Pablo Monroy) took individual turns to identify and count the passing birds using binoculars and spotting scopes. The following information was recorded: date, time, species, genus or taxonomic group, behaviour (migratory or non-migratory), number of birds per flock, age, and sex when possible.

The following meteorological parameters were recorded at the end of every census hour: wind direction (N, NE, E, SE, S, SE, W, NW), speed (km h^{-1}), and temperature (ºC), the latter two with an anemometer and a thermometer, respectively.

To study the effect of wind speed and direction on bird migration we used Somport 2017 data (AEMET https://www.aemet.es/es/portada) with 120 days and 1,023 h of field work. For the analysis of each species' behaviour, we only considered the ten days with a crossing over 5 % of total annual data. Wind effect was analyzed for the two mountain passes exclusively, not for Western or total Pyrenees.

Wind effect was studied using a Generalized Linear Model (GLM), that allows the dependent variable to have a non-normal distribution. Specifically, we used a log-lineal model, which is adequate when the dependent variable is count data, as is the case. When data showed overdispersion (variance larger than mean), we used the Negative Binomial regression (Doménech & Navarro, 2005; Karlsson, 2014; Alcaide, 2015). We used SPSS statistical package.

The dependent variable was the number of birds of a given species per hour. The independent variables were wind speed (0, 0-10 km h^{-1}; 1, 11-20 km h^{-1}; 2, 21-30 km h^{-1} and 3 >30 km h^{-1}), wind direction (N-NE, E-SE, S-SO, O-NO) and T in ºC.

4. Results

A total of 186,338 migrating birds were counted, 105,496 (56.6 %) at Somport and 80,842 (43.4 %) at Portalet.

Twenty-two percent of the detected birds belonged to gliding species and 78% to flapping ones. Among the gliders, 15.9 % were European honey buzzards and 20.1 % were black kites. Among the flapping species, 23.7 % were common house martins and 16.2 % were barn swallows (Table 1). Migration was not constant throughout the day and increased progressively from 9 to 11 h and then decreased until practically zero after 18 h. (Figure 1).

4.1. European Honey Buzzard

This species showed a unimodal distribution, with 48 % of birds passing between 11:00 and 13:59 h (Figure 3). The migration period started on August 14th and ended on September 12th (30 days) (Figure 2). The mean number of migrating birds per hour was 6.4 (SD 11.2), with a maximum of 76 birds per hour. Wind direction was the only explanatory variable that showed a significant effect on migration intensity (Tables 2, 3 and 10).

Table 1. Number of birds of the studied species and number of passage days.
Tabla 1. Número de aves de las especies estudiadas y número de días de paso.

	Total 2016	**Total 2017**	**Days (n) 2016**	**Days (n) 2017**
European honey buzzard	1,296	1,068	39	59
Black kite	2,049	24,150	33	48
Common house martin	13,617	22,915	59	76
Barn swallow	21,725	8,833	56	53

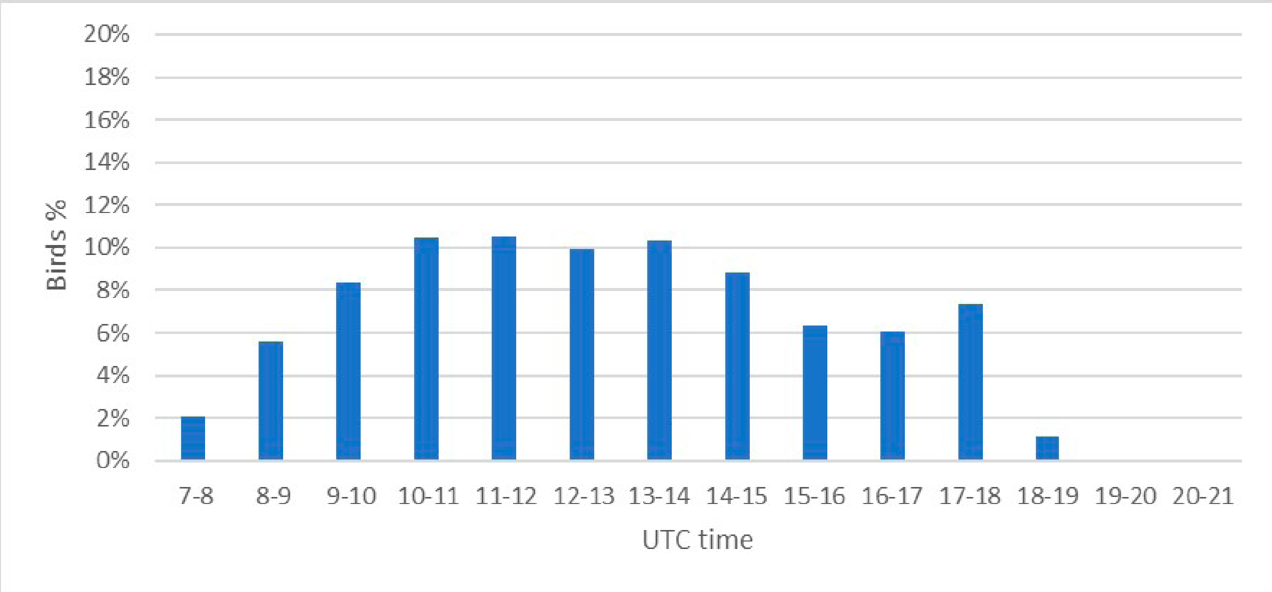

Figure 1. Percentage of birds observed in post-breeding migration per hour.
Figura 1. Porcentaje de aves en paso migratorio postnupcial observadas por hora.

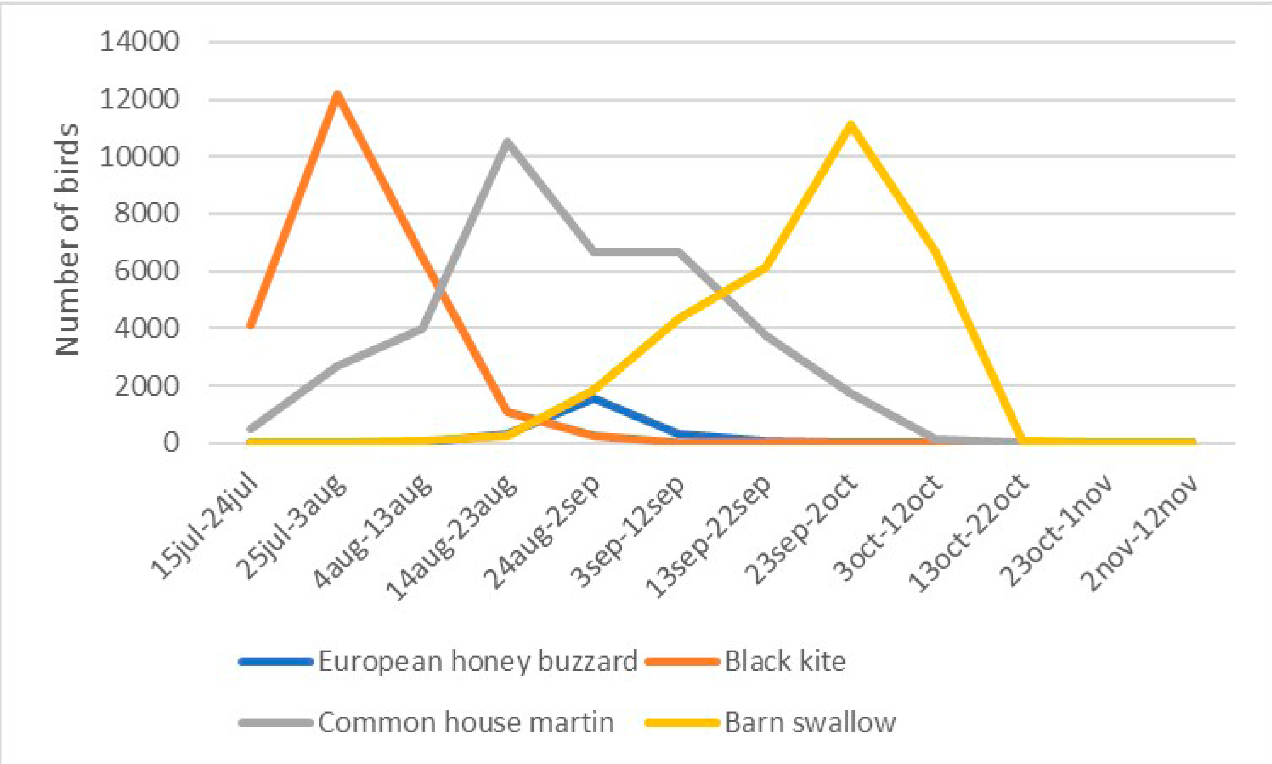

Figure 2. Passage of the four studied species through Somport and Portalet in 2016 and 2017.
Figura 2. Paso de las cuatro especies estudiadas por Somport y Portalet en 2016 y 2017. Con línea continua las aves planeadoras y con línea discontinua las no planeadoras.

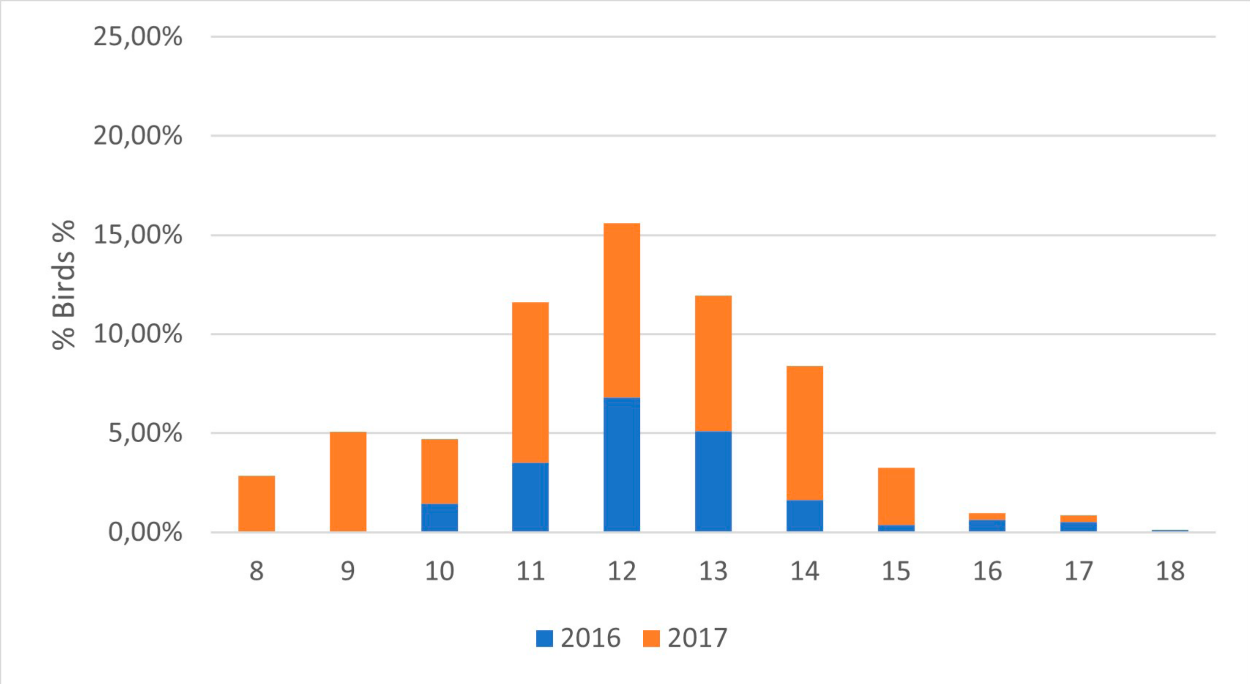

Figure 3. Percentage of Honey Buzzard observed per hour.
Figure 3. Porcentaje de abejeros europeos observados por hora.

Table 2. Tests of effects of the model for Honey Buzzard. Signification in bold.
Tabla 2. Pruebas de efectos del modelo para el abejero europeo. Significación en negrita.

Origin	X^2 likelihood ratio	df	p
Interceptation	18.75	1	**<0.001**
Wind speed	5.725	3	0.126
T	1.032	1	0.310
Wind direction	116.682	3	**<0.001**

Table 3. Estimation of parameters for Honey Buzzard. Signification in bold.
Tabla 3. Estimación de parámetros para el abejero europeo. Significación en negrita.

			95 % Wald confidence interval				95 % Wald confidence interval for Exp(B)	
Parameter	**B**	**SE**	**Lower**	**Higher**	**Wald X^2 test**	**Exp(B)**	**Lower**	**Higher**
Interceptation	-0.639	0.3698	-1.364	0.086	0.084	0.528	0.256	1.09
> 30 km h^{-1}	-0.647	0.5477	-1.721	0.426	0.237	0.523	0.179	1.531
21 a 30 km h^{-1}	-0.515	0.2336	-0.973	-0.057	0.027	0.597	0.378	0.944
11 a 20 km h^{-1}	-0.261	0.1791	-0.612	0.09	0.145	0.77	0.542	1.094
0 a 10 km h^{-1}	0	-	-	-	-	1	-	-
T	0.015	0.0149	-0.014	0.044	0.311	1.015	0.986	1.045
O-NW	2.44	0.2441	1.962	2.918	**0.000**	11.474	7.112	18.513
S-SW	1.77	0.2391	1.301	2.239	**0.000**	5.87	3.673	9.38
E-SE	1.059	0.3199	0.432	1.686	**0.001**	2.883	1.54	5.397
N-NE	0	-	-	-	-	1	-	-

4.2. Black kite

This species showed a unimodal distribution, with 40 % of birds passing between 13:00 and 14:59 h (Figure 4). The migration period started on July 15th and ended on August 23rd (40 days) (Figure 2). The mean number of migrating birds per hour was 156.75 (SD 360.16), with a maximum of 2,451 birds per hour and 7 days with over 500 birds per hour. Wind direction, speed and temperature showed a significant effect on migration intensity (Tables 4 and 5). The highest intensity of migration was detected with E-SE winds with a speed over 10 km h^{-1}. A positive effect of temperature was detected, with greater migration intensity observed with higher temperatures (Tables 5 and 10).

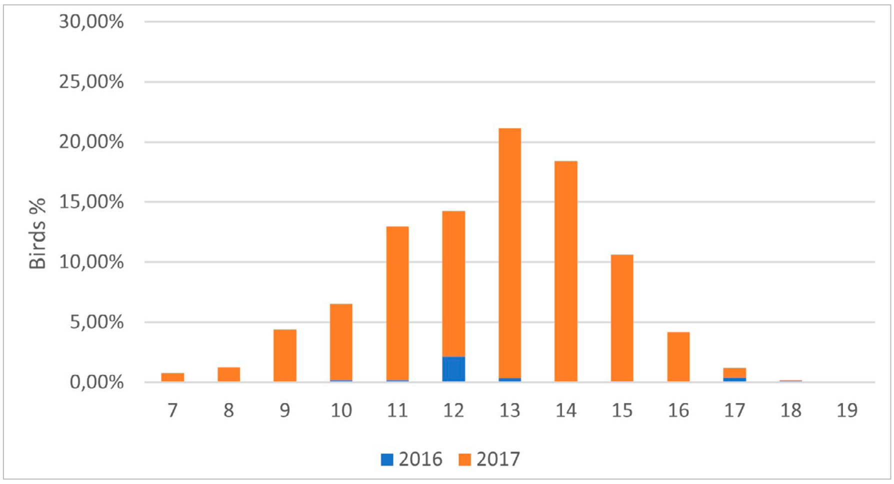

Figure 4. Percentage of Black Kites observed per hour.
Figura 4. Porcentaje de milanos negros observados por hora.

Table 4. Tests of the effects of the model for Black Kite. Significance in bold.
Tabla 4. Pruebas de efectos del modelo para el milano negro. Significación en negrita.

Origin	X^2 livelihood ratio	df	p
Interceptation	1,164.77	1	**<0.001**
Wind speed	83.357	3	**<0.001**
T	15.064	3	**<0.001**
Wind direction	287.882	1	**<0.001**

Table 5. Estimation of parameters for Black Kite. Signification in bold.
Tabla 5. Estimación de parámetros para el milano negro. Significación en negrita.

			95 % Wald confidence interval				95 % Wald confidence interval for Exp(B)	
Parameter	**B**	**SE**	**Lower**	**Higher**	**Wald X^2 test**	**Exp(B)**	**Lower**	**Higher**
Interceptation	-0.129	0.536	-1.180	0.922	0.810	0.879	0.307	2.514
> 30 km h^{-1}	1.068	0.323	0.434	1.702	**0.001**	2.910	1.544	5.485
21 a 30 km h^{-1}	1.448	0.259	0.940	1.955	**0.000**	4.253	2.560	7.067
11 a 20 km h^{-1}	1.832	0.193	1.453	2.212	**0.000**	6.249	4.277	9.130
0 a 10 km h^{-1}	0					1		
O-NW	-0.474	0.226	-0.916	-0.032	**0.035**	0.622	0.400	0.968
S-SW	-3.287	0.323	-3.919	-2.655	**0.000**	0.037	0.020	0.070
E-SE	0.659	0.301	0.069	1.249	**0.029**	1.933	1.071	3.488
N-NE	0					1		
T	0.113	0.029	0.056	0.169	**0.000**	1.119	1.058	1.185

4.3. Common house martin

This species showed a unimodal symmetrical distribution, with 52 % of birds crossing between 10:00 and 14:59 (Figure 5). The migration period started on July 25th and ended on September 12th (50 days). Data was gathered between 8:00 and 16:59 h (443 h), and sightings occurred in 53 % of the hours. The median was 26 birds per hour, with a maximum of 591 in 1 h. The variable number of common house martins per hour shows overdispersal (4,160 >29; n=443), with a CV of 143. The adjusted regression model using predictive variables (wind speed, direction, and T) differs significantly from the model without them. This means that including these three variables improves explanatory capacity compared to the model that only includes the constant (X^2=250; df=7; p <0.001). Table 6 shows the significance of each variable considering the likelihood ratio X^2. Wind speed and temperature are explanatory for the model. High values of the number of common house martins are negatively associated with winds over 21 km h^{-1}, as opposed to winds between 0-10 km h^{-1}. There is no signification for winds between 11-20 km h^{-1}. There is a positive association between the number of common house martins and temperature (Table 7 and 10).

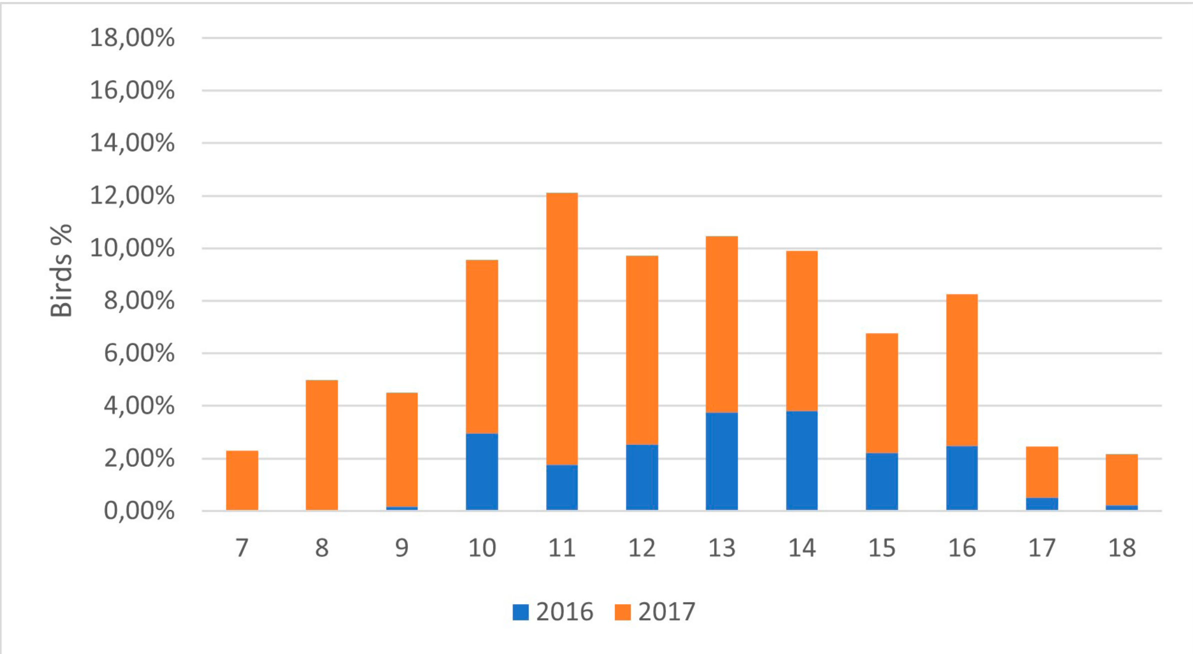

Figure 5. Percentage of Common House Martins observed per hour.
Figura 5. Porcentaje de aviones comunes observados por hora.

Table 6. Tests of effects of the model for Common House Martin. Signification in bold.
Tabla 6. Pruebas de efectos del modelo para el avión común. Significación en negrita.

Origin	X^2 livelihood ratio	df	p
Interceptation	2,104.324	1	**<0.001**
Wind speed	70.524	3	**<0.001**
T	120.156	1	**<0.001**
Wind direction	6.137	3	0.105

Table 7. Parameter estimations for Common House Martin. Signification in bold.
Tabla 7. Estimación de parámetros para el avión común. Significación en negrita.

			95 % Wald confidence interval				95 % Wald confidence interval for Exp(B)	
Parameter	**B**	**SE**	**Lower**	**Higher**	**Wald X^2 test**	**Exp(B)**	**Lower**	**Higher**
Interceptation	0.605	0.265	0.085	1.125	**0.023**	1.831	1.089	3.079
> 30 km h^{-1}	-1.851	0.258	-2.355	-1.346	**0.000**	0.157	0.095	0.260
21 a 30 km h^{-1}	-0.473	0.160	-0.786	-0.160	**0.003**	0.623	0.456	0.852
11 a 20 km h^{-1}	0.191	0.139	-0.080	0.462	0.168	1.210	0.923	1.588
0 a 10 km h^{-1}	0					1		
O-NW	0.070	0.147	-0.218	0.358	0.635	1.072	0.804	1.430
S-SW	0.177	0.156	-0.128	0.482	0.255	1.194	0.880	1.619
E-SE	-0.201	0.167	-0.527	0.126	0.228	0.818	0.590	1.134
N-NE	0					1		
T	0.127	0.012	0.104	0.150	**0.000**	1.135	1.110	1.162

4.4. Barn swallow

This species showed a unimodal asymmetrical distribution, with 31 % of birds crossing between 9:00 and 10:59 (Figure 6). The migration period started on September 13th and ended on October 12th (30 days). Data was gathered between 8:00 and 16:59 h (245 h). Sightings occurred in 33 % of the hours, with a median of 13.5 birds per hour and a maximum of 756 in 1 h. The variable number of common Barn Swallows per hour shows overdispersal (5.828 >23; n =245), with a CV of 253. The adjusted regression model using predictive variables (wind speed, direction, and T) differs significantly from the model without them. This means that including these three variables improves explanatory capacity compared to the model that only includes the constant (X^2 =301; df =7;

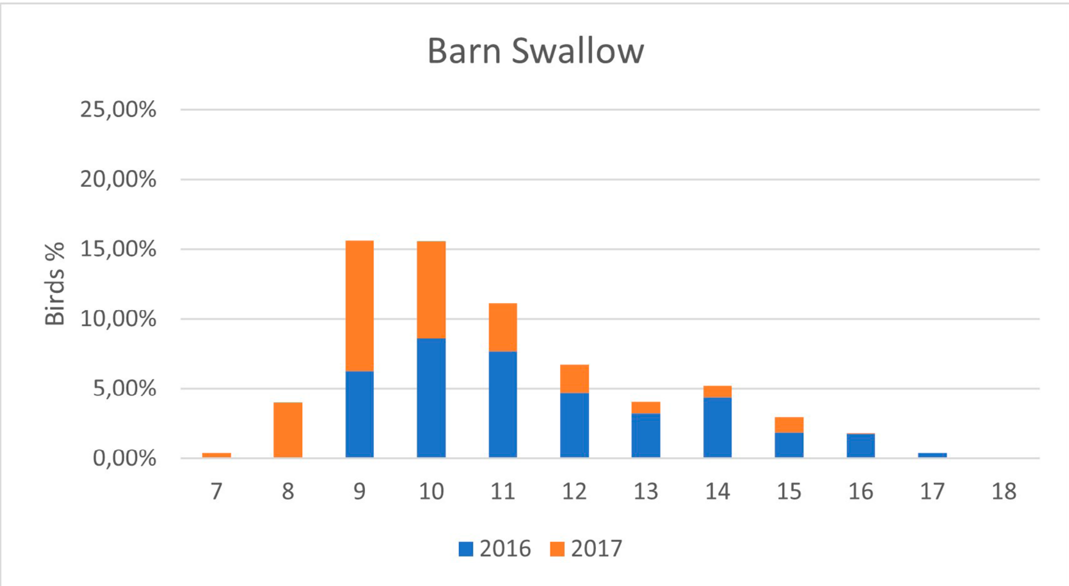

Figure 6. Percentage of Barn Swallows observed per hour.
Figura 6. Porcentaje de golondrinas comunes observadas por hora.

p <0.001). Table 8 shows the significance of each variable considering the likelihood ratio X^2. The three variables are explanatory for the model. Table 9 presents each estimated parameter (B coefficients of each category of the two categorical variables and of the quantitative variable T), the Standard Error (SE), the 95 % confidence interval, the signification with Wald test and the exponential. High values of the number of Barn Swallows are associated with strong N-NE winds. The rest of winds have less association, and this wind acts as reference category. High values of the number of Barn Swallows are associated with winds between 11 and 20 km h^{-1}, in contrast to those between 1-10 km h^{-1}, and to a lesser extent with weaker winds. There is no signification with winds over 30 km h^{-1}. There is a negative association between the number of common Barn Swallows and T (Table 10).

Table 8. Tests of effects of the model for Barn Swallow. Signification in bold.
Tabla 8. Pruebas de efectos del modelo para la golondrina común. Significación en negrita.

Origin	X^2 livelihood ratio	df	p
Intercept	77.89	1	**<0.001**
Wind speed	81.044	3	**<0.001**
T	4.667	1	**0.031**
Wind direction	220.016	3	**<0.001**

Table 9. Parameter estimation for Barn Swallow. Signification in bold.
Tabla 9. Estimación de parámetro para la golondrina común. Significación en negrita.

			95 % Wald confidence interval				**95 % Wald confidence interval for Exp(B)**	
Parameter	**B**	**SE**	**Lower**	**Higher**	**Wald X^2 test**	**Exp(B)**	**Lower**	**Higher**
Interceptación	3.516	.4887	2.558	4.474	**0.000**	33.645	12.910	87.686
O-NW	-3.487	.5420	-4.549	-2.425	**0.000**	.031	.011	.088
S-SW	-2.202	.2909	-2.773	-1.632	**0.000**	.111	.063	.195
E-SE	-.938	.1714	-1.274	-.602	**0.000**	.392	.280	.548
N-NE	0	-	-	-	**-**	1	-	-
T	-.062	.0286	-.118	-.006	**0.031**	.940	.889	.994
> 30 km/h $^{-1}$	-.306	.2083	-.715	.102	**0.141**	.736	.489	1.107
21 a 30 km/h $^{-1}$	1.050	.2203	.618	1.481	**0.000**	2.856	1.855	4.399
11 a 20 km/h $^{-1}$	2.571	.2165	2.147	2.996	**0.000**	13.085	8.560	20.001
0 a 10 km/h $^{-1}$	0	-	-	-	**-**	1	-	-

Table 10. Meteorological factors affecting birds in their post breeding passage in Somport during 2016 and 2017.
Tabla 10. Factores meteorológicos que afectan a las aves en su paso postnupcial en Somport durante 2017.

	Wind direction (Reference category N-NE)	**Wind speed (Reference category 0-10 km h^{-1})**	**T**
European Honey Buzzard	Larger number with W-NW, S-SW, E-SE	ns	ns
Black Kite	Larger number with E-SE	Larger number with winds > 0- 10 km h^{-1}	Positive effect
Common House Martin	ns	Smaller number with winds over 20 km h^{-1}	Positive effect
Barn swallow	Smaller number in any other direction	Larger with winds between 11- 20 km h^{-1} and to a lesser degree between 21-30 km h^{-1}	Positive effect

5. Discussion

The results of this work reveal the importance of the Portalet and Somport mountain passes during post-nuptial migration. Despite the fact that the number of birds to have crossed these passes is notably less than that recorded in other Pyrenean passes further west such as the Organbidexka (Filippi-Codaccioni *et al*., 2010) and Lindus (Isturiz *et al*., 2022) passes, more than 90,000 specimens per year constitutes a very high number, for which it seems necessary to establish an annual monitoring at the Portalet and Somport passes.

It has been possible to confirm that the start and end dates of migration are similar to those recorded in the westernmost Pyrenean mountain passes (Filippi-Codaccioni *et al*., 2010; Isturiz *et al.,* 2022), while the migration in the Strait of Gibraltar occurs some weeks later (Onrubia, 2015).

The apparently longer seasonal migration period detected in our work, compared to that of the Strait of Gibraltar, could possibly be related to a broader use of thermal flows, given their relevance in mountain environments (Agostini & Logozzo, 1997; Panuccio *et al.,* 2013).

The four species show different migration time patterns, as it also happens in the Alps (Agostini & Logozzo, 1997) or Gibraltar (Onrubia *et al.,* 2009; Panuccio *et al.,* 2013; Onrubia, 2015).

Gliding and flapping birds do not show a common time migration pattern, except for the number of passing days. Gliders pass in fewer days, maybe because they do it faster, even though there are species differences.

The Black Kite shows a similar time pattern as in Gibraltar (Panuccio *et al.,* 2013; Onrubia, 2015). The European Honey Buzzard has a similar time pattern as in the Alps (Agostini & Logozzo, 1997) and Gibraltar (Onrubia, 2015). This may be because both are large gliders with high flight speed.

Both flapping birds show different time patterns. The Common House Martin has a different time pattern compared with Gibraltar (Onrubia *et al*., 2009), which happens a month later. This species is small, has a less efficient glide. The Barn Swallow shows a similar pattern as the one observed in Gibraltar, with few days of delay to cross the Iberian Peninsula (Onrubia *et al*., 2009).

Gliders cross the Pyrenees during fewer days than flapping birds, as it also happens in the Alps and Gibraltar (Agostini & Logozzo, 1997; Onrubia *et al.,* 2009; Panuccio *et al.,* 2013; Onrubia, 2015). This may be due to their larger size and the use of thermal flows, which facilitate their migration by improving speed and energy saving (Kerlinger, 1989; Newton, 2008; Onrubia, 2015).

The concentration of sightings of both glider species during midday is possibly due to their use of thermal flows, which are produced more easily at that time of the day (Bildstein, 2006; Newton, 2008; Onrubia, 2015). However, the European honey buzzard does not show this pattern in Gibraltar, where the peak is in the early morning (Onrubia, 2015). Again, this could be facilitated by the effect of thermal flows, which help them cross the Pyrenees, as happens in Gibraltar to cross the sea (Onrubia, 2015).

The flapping birds weren't found to concentrate their crossing in the midday, as previously described (Alerstam, 1990; Berthold, 2001; Newton, 2008; Pennycuick, 1975, 2008). They seem not to depend on thermal flows to cross the Pyrenees.

Meteorological factors do not seem to make a clear difference for gliders and flapping birds. The factor that affected the European honey buzzard most was wind direction, as this species seems to avoid N-NE winds (Agostini, 1992), chooses wind directions different to its flight direction and can fly with lateral wind (Agostini, 1992). The black kite choses strong winds, skilfully flying with the worst winds, probably using thermal flows (Agostini & Logozzo, 1997). This choice could be the reason to select lateral E-SE wind rather than a NE tailwind. The meteorology associated with E-SE winds are Atlantic storms coming from the N and anticyclones from the S. Both can produce thermal flows and southward winds that may aid migration (García De Pedraza, 1972) and establish a positive association with T, again related with the use of thermal flows.

Regarding the flapping birds, both studied species show different patterns. The common house martin's avoidance of strong winds is probably due to its small size and inability to use these winds. This species also shows a positive association with temperature, as it uses a wide daily timeframe. On the other hand, the barn swallow selects moderate winds, which could be interpreted as a better flight ability with stronger winds due to its larger size. This species chooses N-NE tailwind and avoids high temperatures, which is probably why it crosses during the first hours of the day.

Finally, analysing wind effect on bird migration exclusively in these two mountain passes could have some limitations regarding this effect in Western Pyrenees. A simultaneous monitoring in this whole area would allow to have more consistent data and consequently sound interpretation.

References

Agencia Estatal de Meteorología (España) e Instituto de Meteorología (Portugal), 2011. *Atlas climático ibérico*. Catálogo General de publicaciones oficiales, 79 pp., Madrid.

Agostini, N., 1992. Spring Migration of Honey Buzzards (*Pernis apivorus*) at the Straits of Messina in Relation to Atmospheric Conditions. *Journal of Raptor Research*, 26(2): 93–96.

Agostini, N., & Logozzo, D., 1997. Autumn migration of Accipitriformes through Italy in route to Africa. *Avocetta*, 21: 174–179.

Alcaide Delgado, M., 2015. Modelo de regresión binominal negativa. Trabajo Fin de Grado en Matemáticas. Universidad de Sevilla, Seville.

Alerstam, T., 1990. *Bird Migration*. Cambridge University Press, Cambridge.

Bernis, F., 1949. Las estaciones ornitológicas, el estudio de las aves y su protección. Memorias de la Real Sociedad Española de Historia Natural: 109–140.

Bernis, F., 1966. *Migración en aves. Tratado teórico y práctico*. Sociedad Española de Ornitología, Madrid.

Berthold, P., 2001. *Bird Migration. A general survey*. Oxford University Press, Oxford. https://doi.org/10.1093/oso/9780198507864.001.0001

Bildstein, K.L., 2006. *Migrating raptors of the world: their ecology and conservation*. Cornell University Press, 327 pp., New York.

Cox, G.W., 2010. *Bird migration and global change*. Island Press, Washington.

Dingle, H., 2014. *Migration: The Biology of Life on the Move*. Oxford University Press, Oxford. https://doi.org/10.1093/acprof:oso/9780199640386.001.0001

Doménech, J.M. & Navarro, J.B., 2005. Regresión logística binaria, multinomial y de Poisson. Signo, Barcelona.

Elphick, J., 2007. *Atlas of Bird Migration*. Natural History Museum, Londreson.

Filippi-Codaccioni, O., Moussus, J.P., Urcun, J.P., Jiguet, F., 2010. Advanced departure dates in long-distance migratory raptors. *Journal of Ornithology*, 151: 687–694. https://doi.org/10.1007/s10336-010-0500-5

García De Pedraza, L., 1972. Vientos marítimos y terrales en España. En Calendario Meteoro-Fenológico. Servicio Meteorológico Nacional, Madrid, pp.161-171.

Hahn, S., Bauer, S., Liechti, F., 2009. The natural link between Europe and Africa–2.1 billion birds on migration. *Oikos*, 118(4): 624-626. https://doi.org/10.1111/j.1600-0706.2008.17309.x

Istúriz, A., Astráin, C., Ibarrola, I., Milon, É., Castegè, I., 2022. Aves terrestres y marinas en Pirineos Atlánticos. Cambio Climático, migración y evolución de poblaciones. GANNIK/CMB/POCTEFA NaturClima EFA 311/19. Available in https://naturclima-poctefa.eu/wp-content/uploads/2022/06/La-migracion-de-las-aves-en-Lindux.pdf

Karlsson, M., 2014. Modelling daily numbers of ringed birds with negative binomial generalized linear models. Bachelor Thesis in Mathematical Statistics. Stockholm University, Stockholm.

Kerlinger, P., 1989. *Flight strategies of migrating hawks*. Chicago, University Press.

Köppen, W., 1900. Versuch einer Klassifikation der Klimate, vorzugsweise nach ihren Beziehungen zur Pflanzenwelt. *Geographische Zeitschrift*, 6(11): 593-611.

Mead, C., 1983. *Bird Migration*. Facts on File Publications, New York.

Moreau, R.E., 1972. *The Palearctic-African Bird Migration Systems*. Academic Press, London.

Newton, I., 2008. *The migration ecology of birds*. Academic Press, London.

Onrubia, A., Muñoz Arroyo, G., Barrios, L., Muñoz, AR., de la Cruz, A., Ramírez, J., González, M., Cuenca, D., 2009. Migración diurna visible de pequeñas aves en el Estrecho de Gibraltar. Año 2008. *Migres* 1: 115-119.

Onrubia, A., 2015. *Patrones espacio-temporales de la migración de aves planeadoras en el estrecho de gibraltar*. PhD Thesis. Departamento de Biodiversidad y Gestión Ambiental. Universidad de León, León.

Panuccio, M., Agostini, N., Mellone, U., Bogliani, G., 2013. Circannual variation in movement patterns of the Black Kite (*Milvus migrans migrans*): A review. *Ethology, Ecology and Evolution*, 26(1): 1–18. https://doi.org/10.1080/03949370.2013.812147

Pennycuick, C.J., 1975. Mechanics of flight. In D.S.Farner & J.R.King (eds): *Avian Biology*, 5: 1-75. Academic Press, New York.

Pennycuick, C.J., 2008. *Modelling the flying bird*. Elsevier, Academic Press, Amsterdam.

Pérez-Tris, J., & Santos, T., 2004. El estudio de la migración de aves en España: Trayectoria histórica y perspectivas de futuro. *Ardeola*, 51(1): 71–89. Retrieved from https://www.ucm.es/data/cont/media/www/pag-33468/2004_Ardeola_51_71.pdf

SEO/Birdlife, 2000. *Programa MIGRES. Seguimiento de la migración en el Estrecho. Año 1999*. Madrid: SEO/Birdlife.

Somveille, M., Manica, A., Butchart, S.H.M., Rodrigues, A.S.L., 2013. Mapping Global Diversity Patterns for Migratory Birds. *PLoS ONE* 8(8): e70907. https://doi.org/10.1371/journal.pone.0070907

Spaar, R.,1997. Flight strategies of migrating raptors; a comparative study of interspecific variation in flight characteristics. *Ibis*, 139(3): 523–535. https://doi.org/10.1111/j.1474-919X.1997.tb04669.x

Data Availability Statement

Data can be shared with other researchers upon request of collaboration.

Acknowledgments

We would like to thank Héctor Bintanel, Marco Antonio Escudero, Marta Medrano and Pilar Jimeno for their strong implication in the field work, Ena Dack for English review and Sofía Morcelle for an early review of the manuscript.

Finantial support

This research is part of Lindus 2 research Project, financed by the European Regional Development Fund, Interreg Program V-A of Andorra, France, and Spain (POCTEFA 2014-2020). Partners were: Burguete/Auritz Municipality (Navarre, Spain), the Regional Government of Navarre, the

Ligue pour la protection des oiseaux (France) and SEO/Birdlife (Spain).

Author's contribution

PM. Writing the draft, formal analysis, investigation, review; AGS. Conceptualization, methodology, software, formal analysis, review and editing; JH. Conceptualization, review and editing, supervision; LT. Resources, reviewing; All authors have read and agreed to the published version of the manuscript.