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Migration patterns of breeding Hen Harriers *Circus cyaneus* in Spain

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ABSTRACT

Capsule: Tracked Hen Harriers *Circus cyaneus* breeding in Spain winter either in the southern parts of the Iberian Peninsula or in Morocco, although migration timing and distances did not differ between birds using different wintering regions.

Aims: To study, for the first time, the migratory patterns of Hen Harriers breeding in Spain.

Methods: Eight breeding adult Hen Harriers were tagged in Spain with GPS/GSM transmitters between 2019 and 2022 to study autumn and spring migration between breeding areas in central or northern Spain, and wintering quarters in southern Spain and Morocco.

Results: Males and females did not differ significantly in their patterns of migration (dates for start and end of migration, duration, daily distance, and total distance) in either migratory period. Individuals started the autumn migration between July and January, with the peak migration in mid-October. Spring migration took place from February to April and peaked in mid-March. Mean (± sd) distances travelled were: daily distance 168.99 ± 80.10 km/day and total distance 995.07 ± 402.90 km in autumn, and 141.74 ± 41.41 km/day and 1035.26 ± 593.51 km in spring. Two types of migration patterns were found: intra-peninsular migration and migration to Morocco. Migration dates and distances did not differ significantly between individuals with intra-peninsular migration strategies and those migrating to Morocco.

Conclusion: These results are the first to describe the migratory behaviour of Spanish breeding Hen Harriers using satellite telemetry. Knowledge of migratory routes and behaviour are important for planning the conservation of species.

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The Hen Harrier *Circus cyaneus* is distributed across the Western Palearctic. Europe holds approximately 34% of the world population, with 56,300–86,600 breeding females – equivalent to 112,000–174,000 mature individuals (BirdLife International 2021). At the European level, the conservation status is Least Concern (BirdLife International 2021).

Spain is located at the southern end of the Hen Harrier's breeding distribution (García & Arroyo 2001). In Spain, the species is found mainly in the Atlantic strip and the northern plateau of the Iberian Peninsula, while it is absent as a breeding species in the southern peninsular and the Mediterranean coast (García & Arroyo 2001). According to the latest census, in 2017, the breeding population in the Iberian Peninsula is estimated to be around 500–800 pairs (Arroyo *et al.* 2019), which represents a decrease of 34–45% compared to the previous census of 2006 (Arroyo & García 2007). This decline can be attributed to habitat loss, including changes in cultivation, deforestation, and degradation of scrubland areas (Arroyo *et al.* 2019). In Spain, the conservation status of the Hen Harrier is listed as Endangered (López-Jiménez & Arroyo 2021).

In eastern and northern Europe and Asia, most Hen Harrier populations are migratory and move long distances to avoid severe winters (Ferguson-Lees & Christie 2001). However, in western Europe, including the Iberian Peninsula, Hen Harriers are partial-migrants and often perform short-distance movements. These areas host some of the wintering individuals from northern Europe (Del Hoyo *et al.* 1994, Arroyo 2012, Agostini 2021). In the Iberian Peninsula, breeding Hen Harriers are mainly sedentary, with nomadic or dispersive movements depending on the climate (Redpath *et al.* 2002, Arroyo 2022), and the wintering population has been estimated at 3000 individuals (Arroyo 2012). Some birds from the Iberian Peninsula move to areas such as the Duero and Guadalquivir valleys (400–900 km south of the breeding areas), where

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they prefer open agricultural fields rather than mountainous areas (Arroyo 2012, 2022).

An understanding of the annual cycle and migratory movements is necessary for effective conservation planning, but most of the knowledge about the Hen Harrier has been provided by studies from northern Europe, especially from Ireland and the United Kingdom, where there has been research on feeding behaviour (Balfour & McDonald 1970, Redpath *et al.* 2002), reproduction (Picozzi 1984a, 1984b, Amar *et al.* 2008, Irwin *et al.* 2011, Baines & Richardson 2013, Fernández-Bellon *et al.* 2017), population dynamics (Meek *et al.* 1998, Amar & Redpath 2002, Wotton *et al.* 2018) and conservation (Watson & Thirgood 2001, Arroyo *et al.* 2009, Thompson *et al.* 2009). There is a paucity of studies on the Hen Harrier population in Spain, which is an area characterized as a warm environment with limited rainfall compared to the rest of the range, which tends to be colder and wetter (Keller *et al.* 2020, Arroyo 2022). There are also differences in habitat use between northern Europe (Britain and Ireland or the Scandinavian Peninsula), where Hen Harriers breed in semi-natural upland areas, including gaps in forest plantations (Amar & Redpath 2005), and southern Europe (France and Spain) where they breed in pseudo-steppe landscapes, predominantly in cereal crops but with a small (decreasing) number in grassland/scrubland (Amar *et al.* 2008, Arroyo 2022).

Here, we report for the first time on the migratory movements of Hen Harriers from the Spanish breeding population. Using high-precision global positioning system (GPS) telemetry, the main objectives were: (1) to study variation in the non-breeding range of the Hen Harrier (moving within the Iberian Peninsula or to Morocco) and (2) to quantify the variation in the timing, duration and distances of migration before and after breeding.

Methods

Tagging and tracking

The movements of eight adult or sub-adult Hen Harriers (six females and two males) from different regions of Spain (mainly from central and northern Spain) were monitored with GPS/GSM transmitters (Table 1). Between 2019 and 2022, the Hen Harriers were lured with a Eurasian Eagle-Owl *Bubo bubo* and captured with dho-gaza nets. During the marking process, individuals were ringed and morphometric measurements were taken. Sexing was based on the clear sexual colour dimorphism of the species (Ferguson-Lees & Christie 2001). Individuals were fitted with satellite tracking transmitters (10 g OrniTrack-E10 3G GPS/GSM, Ornitela, $n = 7$; and 9 g Milsar u9 3G GPS/GSM, Milsar, $n = 1$), back-mounted using thoracic Teflon harnesses. Following established guidelines, the weight of the backpacks was less than 3% of the body weight of each individual (Kenward 2001). The handling time until release of captured individuals was less than one hour to avoid stressing the animals. The devices were set to collect locations every 15–60 min, depending on battery voltage, season, and time of day. Data packages were transmitted via the digital cellular network.

Capture of individuals was carried out by expert licenced ringers from the Spanish Ornithological Society (SEO/BirdLife) and Natural England, complying with ethical standards in the capture and tagging of Hen Harriers. The location data of all individuals were provided by SEO/Birdlife and Natural England to the Vertebrate Zoology Research Group of the University of Alicante.

Migratory variables

Latitudinal movements of more than 400 km were classified as long migratory movements (Kerlinger 1989). Spring migration was defined as the movement from wintering areas to breeding areas and autumn migration was defined as the movement from breeding grounds to wintering grounds.

Prior to the analysis, the frequency of GPS locations was down-sampled to one-hour frequency to help fulfil the assumptions of statistical tests. For each migration period (spring or autumn), we identified the onset and end dates, and the migration duration. The migration starting day (MSD) was estimated from the sharp change in the latitudinal position of each individual. The migration arrival day (MAD) was estimated from the stabilization of an individual's latitude after migration. The mean duration (MD) of each migration period was the number of days between MSD and MAD.

The hourly distance travelled was calculated as the Euclidian distance between two consecutive points (step length) an hour apart. All hourly distances for each day were summed to obtain the accumulated daily distance (DD). We calculated the mean daily distance excluding the stopover days (when a bird moved less than 25 km per day; Strandberg *et al.* 2009, García-Macía *et al.* 2022). The total migration distance (TMD) was calculated as the distance between the first and last migration points following the step length of each migration period but excluding the movements on stopover days. The analysis was split between Hen Harriers which migrated within the Iberian Peninsula and those which crossed the Strait of Gibraltar and migrated to Morocco.

Table 1. Information on the migrations of individually tracked Hen Harriers.

ID	Province	Age	Sex	Year	Pattern	Migration
190217	Salamanca	Adult	Female	2020	Morocco	Autumn
				2021	Morocco	Spring
200426	Salamanca	Adult	Male	2021	Iberian Peninsula	Spring
				2021	Iberian Peninsula	Autumn
				2022	Iberian Peninsula	Spring
				2022	Iberian Peninsula	Autumn
200437	Segovia	Adult	Female	2021	Iberian Peninsula	Spring
				2021	Iberian Peninsula	Autumn
200438	Asturias	Adult	Female	2020	Iberian Peninsula	Autumn
				2021	Iberian Peninsula	Spring
200452	Toledo	Adult	Female	2022	Morocco	Autumn
216507	Toledo	Adult	Male	2022	Morocco	Autumn
				2023	Morocco	Spring
216522	Toledo	Adult	Female	2022	Morocco	Autumn
1B8D731E	Salamanca	Subadult	Female	2019	Iberian Peninsula	Autumn
				2020	Morocco	Spring
				2020	Morocco	Autumn
				2021	Morocco	Spring

Statistical analysis

Statistical analyses were performed with R software version 4.2.1 (R Core Team 2021), and the level of significance was set at $P < 0.05$. QGIS software version 3.22.6 (QGIS Development Team 2022) was used to visualize the position and routes of each individual, as well as for the creation of the maps. The coordinate reference system used was UTM (Universal Transverse Mercator) 30N grid: EPSG:32630. We used the *amt* (Signer *et al.* 2019) package in R to calculate the migratory variables. All the previous variables (MSD, MAD, MD, DD, and TMD) were used to test for differences between sexes within each migration period. We also compared MD, DD, and TMD between prenuptial and postnuptial migrations. Comparisons used Kruskal–Wallis analysis (Vargha & Delaney 1998) due to the absence of normality in the data, as tested by a Shapiro–Wilk test (Royston 1992). Thus, MSD, MAD, MD, DD, and TMD were the response or dependent variables, while migratory period or sex were fixed factors. Means are reported with their standard deviation.

Results

From the eight tagged Hen Harriers, data were recorded for 10 autumn migrations. After the autumn migration towards the south-east, the areas where the Hen Harriers over-wintered were mainly within the Iberian Peninsula (five times) and crossing the Strait of Gibraltar to Morocco (five times) (Figures 1 and 2). After wintering, there were eight spring migrations recorded from these areas (five from the Iberian Peninsula and three from Morocco) to the centre or north of the Iberian Peninsula or southern France (Figures 1 and 2). Mean total distances travelled between the winter quarters to breeding areas, or vice versa, ranged from 410 km (an individual that travelled after breeding between Spanish provinces from Segovia to Badajoz) to 2347 km (an individual that migrated from Morocco to the Spanish province of Salamanca).

Migration dates and speed

Hen Harriers started the autumn migration ($n = 10$ routes) on a mean date of 21 October ± 56.39 days (range: 18 July–12 January). They reached their wintering areas in the south of the Iberian Peninsula or Morocco on 11 November ± 45.49 days (range: 7 September–21 January). Hen Harriers travelled for 20.10 ± 37.88 days to complete the autumn migration (range: 4–127 days), the DD was 168.99 ± 80.10 km/day (range: 91.73–355.87 km/day) and the TMD was 995.07 ± 402.90 km (range: 410.41–1667.41 km) (Figure 1; Table 2).

Hen Harriers started the spring migration ($n = 8$ routes) on 13 March ± 15.78 days (range: 15 February–5 April). They reached their breeding areas in the Iberian Peninsula and southern France on 4 April ± 23.93 days (range: 2 March–25 May), travelled for 19.25 ± 32.81 days to complete the spring migration (range: 5–100 days), the DD was 141.74 ± 41.41 km/day, (range: 86.70–203.80 km/day), and the TMD was 1035.26 ± 593.51 km (range: 493.07–2347.00 km) (Figure 2; Table 2).

Differences between sexes and between migration periods

There were no significant differences between males and females for their migration variables in either migration period (Kruskal–Wallis analysis, $P > 0.05$ in all comparisons; Table 2). Also, there were no differences in migration variables between the two migration periods (Kruskal–Wallis analysis, $P > 0.05$ in all comparisons; Table 2).

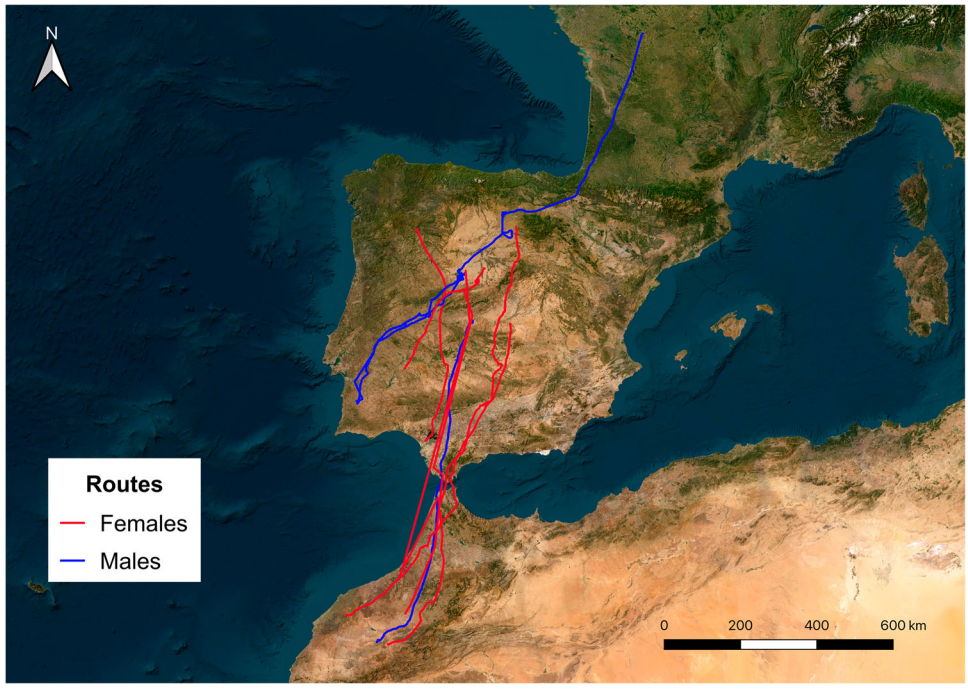


Figure 1. Autumn migration routes ($n = 10$) of eight Hen Harriers tracked by GPS from the breeding areas in southern France or northern/central Iberian Peninsula to the wintering quarters in the southern Iberian Peninsula or Morocco. Red lines show the routes of females and blue lines those of males.

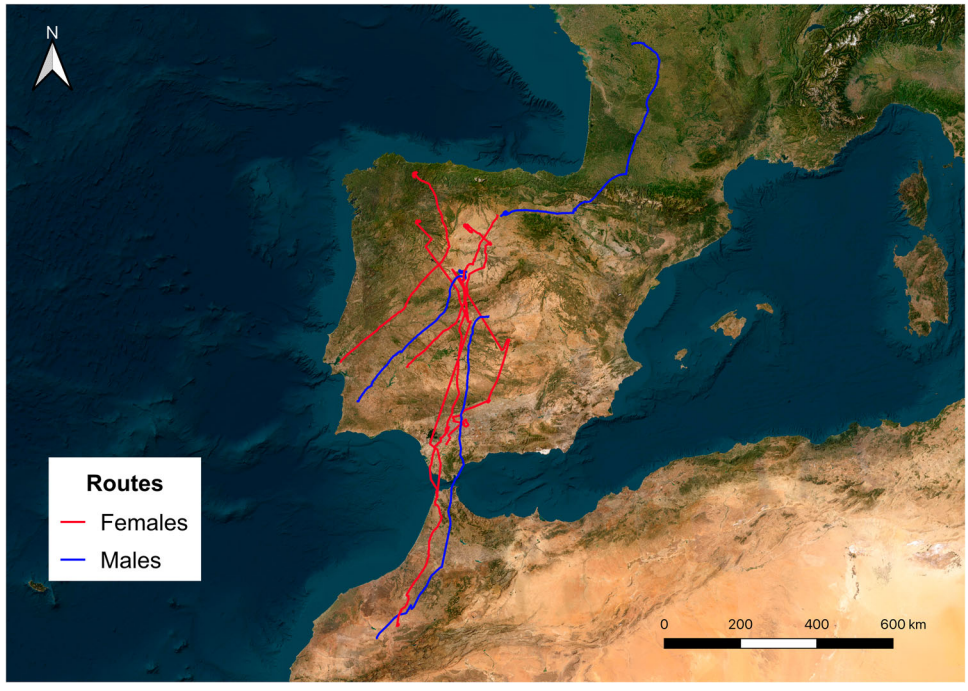


Figure 2. Spring migration routes ($n = 8$) of six Hen Harriers tracked by GPS from the wintering quarters in Morocco or southern Iberian Peninsula to the breeding areas in central or northern Iberian Peninsula. Red lines show the routes of females and blue lines those of males.

Discussion

We provide the first description and analyses of the migration of Hen Harriers breeding in Spain based on GPS telemetry. We highlighted the main migratory routes used by this population, as well as the seasonal differences found.

Previously, the migration of this species has been studied mainly from ring recoveries, visual surveys,

Table 2. Mean values of the migratory variables in relation to sex and migration pattern in the autumn and spring migrations.

Migration	Sex	Pattern	*N*	MSD	MSD sd (days)	MSD range	MAD	MAD sd (days)	MAD range	MD (days)	MD sd (days)	MD range (days)	DD (km/day)	DD sd (km/day)	DD range (km/day)	TMD (km)	TMD sd (km)	TMD range (km)
Autumn	Females	–	7	16 Oct	58.13	18 Jul–9 Jan	10 Nov	42.49	7 Sep–12 Jan	23.57	45.64	4–127	177.68	84.87	91.73–355.87	964.91	369.29	410.41–1467.66
Autumn	Males	–	3	1 Nov	62.43	18 Sep–12 Jan	12 Nov	62.40	22 Sep–21 Jan	12.00	8.19	5–21	148.71	79.90	94.51–240.47	1065.45	557.44	567.08–1667.41
Autumn	–	Intra-peninsular	5	4 Nov	73.91	18 Jul–12 Jan	6 Dec	38.68	26 Oct–21 Jan	33.40	52.76	4–127	116.96	26.93	91.73–155.90	947.24	575.96	410.41–1667.41
Autumn	–	Morocco	5	7 Oct	35.06	30 Aug–15 Nov	17 Oct	39.50	7 Sep–30 Nov	6.80	1.64	5–9	221.02	83.32	147.27–355.87	1042.90	166.69	883.60–1317.06
Spring	Females	–	5	10 Mar	14.55	15 Feb–22 Mar	10 Apr	25.36	25 Mar–25 May	27.60	40.63	6–100	121.94	35.27	86.70–164.36	1160.95	733.47	493.07–2347.00
Spring	Males	–	3	17 Mar	20.13	25 Feb–5 Apr	22 Mar	19.08	2 Mar–9 Apr	5.33	0.58	5–100	174.75	30.00	143.88–203.80	825.77	227.17	575.54–1019.01
Spring	–	Intra-peninsular	5	17 Mar	18.52	15 Feb–5 Apr	10 Apr	25.44	24 Mar–25 May	25.60	41.69	5–100	128.52	40.07	86.70–176.55	1082.98	717.26	575.54–2347.00
Spring	–	Morocco	3	6 Mar	9.24	25 Feb–12 Mar	21 Mar	17.79	2 Mar–6 Apr	8.67	4.62	6–14	163.78	40.31	82.39–170.38	955.73	434.50	493.07–1355.12

MSD: migration starting day; MAD: migration arrival day; MD: migration duration; DD: daily distance; TMD: total migration distance; sd: Standard deviation. *N*: number.

and radio-tracking (Etheridge & Summers 2006, Agostini 2021, Panuccio *et al.* 2021) but there are very few satellite-tracking studies (Panuccio *et al.* 2021). Individual Hen Harriers have frequently been recorded crossing the Strait of Gibraltar to overwinter in the northern and eastern coasts of Morocco (Finlayson 1991, Pinilla *et al.* 1994, Arroyo 2012, Agostini 2021) and long-distance migration has been reported from cold areas in the north of the Western Palearctic to more temperate areas in southern Europe or Asia, including Spain (Arroyo *et al.* 2019). However, the Hen Harriers tracked in this study breed in temperate Spain, and migrate to even more productive areas in winter, such as the south of the Iberian Peninsula or Morocco. Until now it was thought that individual Hen Harriers breeding in Spain were sedentary or short-distance migrants (Del Hoyo *et al.* 1994, Pinilla *et al.* 1994, Agostini 2021).

In southern areas, such as Iberia, the behaviour of Hen Harriers differs from those in northern regions due to climatic conditions (Redpath *et al.* 2002): the Iberian environments are generally warmer and less humid than northern Europe. The distribution of resources over the annual cycle in Iberia, especially in the south, allows species to be sedentary around the breeding area or to perform shorter movements, in contrast to northern populations, which are compelled to make long-distance migrations to more southerly latitudes to avoid harsh winter conditions. Thus, some birds of prey often perform long-distance migrations when they breed in northern areas, but the populations which breed within the southern distribution limit may perform short-distance migrations or wandering movements after the reproductive period (García-Macía *et al.* 2022b). Long-distance migration requires a great amount of energy and time, and individuals face a broad range of threats (Klaassen *et al.* 2014); however, as a strategy, it increases the likelihood of resources being available during the entire annual cycle (Newton 2007). The outcome of cost–benefit trade-offs, as well as genetic variability, environmental conditions, and interspecific relationships could trigger one type of strategy or another in raptor populations or individuals.

The migration across the Strait of Gibraltar, from Europe to Africa, is not frequent in the Hen Harrier: only a small fraction of the European populations is expected to select Africa as wintering destination. This is supported by our tracking data and also by visual surveys in the Strait of Gibraltar: a mean (± sd) of 4.33 ± 5.13 (range: 0–13; $n = 9$ years) Hen Harrier crossings each spring, with the peak of

migration in late March, and a mean of 12.7 ± 10.3 (range: 1–30; $n = 23$ years) birds crossing each autumn, with the peak migration around mid-November (De la Cruz *et al.* 2011; unpublished data from Migres Fundation). Only a small fraction (5%) of previously tracked individuals migrated to Morocco, and standardized visual censuses estimated about a dozen individuals per year crossing the Strait of Gibraltar in both during spring and autumn (De Juana & Garcia 2015). The Hen Harrier may prefer northern areas to spend the winter, such as France or Spain (Panuccio *et al.* 2021), but the infrequent migration to Morocco has a special biological interest and should be considered in future management plans.

The migration phenology of Hen Harriers is similar to those of other Iberian raptors which breed in the Iberian Peninsula and overwinter in Africa. Furthermore, the movement metrics estimated for migration fall within the predicted ranges: the Hen Harriers in our study covered daily distances similar to those of other trans-Saharan soaring-gliding raptors breeding in Spain, such as the Booted Eagle *Aquila pennata* (Mellone *et al.* 2013), the Red Kite *Milvus milvus* (Gracía-Macía *et al.* 2021) or the Montagu's Harrier *Circus pygargus* (Limiñana *et al.* 2007, 2012a, 2012b). The main difference with those species is that the Hen Harriers performed a shorter migration and only needed a few days to complete their journeys.

In contrast with the Hen Harrier, the Montagu's Harrier exhibits distinct long-distance migratory behaviour from Spain (Limiñana *et al.* 2007, 2012a, 2012b) and elsewhere in its breeding range (Panuccio *et al.* 2021). Another clear example is the Black Kite *Milvus migransn* with a well-marked migratory behaviour (Panuccio *et al.* 2014), which also contrasts with the Red Kite which shows with much variation in its migratory ecology (García-Macía *et al.* 2022, 2022, 2022).

The sample size of this study is small but convincing for having discovered this previously undocumented behaviour. We have expanded current knowledge on the migration behaviour of the Hen Harrier, and further studies could be carried out with a larger sample size to better understand the migration variability of the species.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Authors' contributions

S.M., J.G.M., and V.U. conceived the ideas and designed the methodology, A.O. and S.L. collected the data. S.M. and J.G.M. analysed the data. S.M., J.G.M. and V.U. wrote the manuscript. S.M., J.G.M., S.L. and V.U and contributed critically to the drafts. S.L. and V.U. gave final approval for publication.

Data availability statement

All data used in this study are publicly available upon request to data managers in the online data repository Movebank (www.movebank.org). The projects are *Hen Harrier in Spain – Migra Program in Spain* (project ID: 1169461367) and *Hen Harriers in Spain* (project ID: 1135251191).

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