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Pre-migratory movements of adult Montagu's Harriers *Circus pygargus*

Ruben Limiñana[1,*], Alvaro Soutullo[1], Pascual López-López[1,2] & Vicente Urios[1]





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Pre-migratory and migratory movements of Montagu's Harrier *Circus pygargus*, a long-distance migrant, are poorly documented by ring recoveries and observations. In the present study, we tagged 10 adult Montagu's Harriers in NE Spain with satellite transmitters and tracked their movements until their arrival on the wintering grounds. To identify the end of the breeding season and the onset of the migration based on our satellite-telemetry data we developed and applied a statistical approach, defining the time period between these two events as the pre-migratory stage. We then compared habitat preferences during the breeding season and the pre-migratory stage. The duration of the pre-migratory stage averaged 42 days, with harriers leaving the breeding areas between 4 June and 27 July, and the onset of the migration taking place between 25 July and 4 September. Staging areas used during pre-migration were located at higher altitudes than the breeding grounds, and were characterized by the presence of shrublands and cultivated areas, mainly cereals. Montagu's Harriers' use of these sites is likely to be related to food availability: at higher altitudes, peak abundance of Orthoptera, their main prey source, occurs later in the season than in the lowland breeding area. Pre-migratory movements may also play an important role in the search for suitable breeding sites for future use.

Key words: compositional analysis, migration onset, pre-migration, satellite telemetry, staging areas

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INTRODUCTION

The Montagu's Harrier *Circus pygargus* is a long-distance migrant, breeding in Europe and Asia, and wintering in Africa, the Indian subcontinent and Sri Lanka (Clarke 1996). The species is not globally threatened (BirdLife International 2004) but is considered vulnerable in Spain and France, the strongholds of the western European population (Salamolard *et al.* 1999, García & Arroyo 2003). In West Africa, the wintering population has declined in recent decades (Thiollay 2006). The main nesting habitat for the species in West Europe is cereal crop, although some populations

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still breed in natural habitats (Cramp & Simmons 1980, Clarke 1996, Limiñana *et al.* 2006a). Main threats for the species in Europe are loss of natural habitats, loss of clutches and broods due to harvesting activities in agricultural land, human persecution, and the use of pesticides, which reduce prey populations (Arroyo *et al.* 2004).

The Montagu's Harrier is a generalist predator that feeds on a range of taxa, including small mammals, birds, lizards and large insects (Underhill-Day 1993, Corbacho *et al.* 1995, Arroyo 1997). In our study area, the species breeds in shrublands (Limiñana *et al.* 2006a, 2006b), and mostly feeds on grasshoppers and other medium-sized insects (e.g. 77% of 197 pellets collected between 2001 and 2006 contained grasshoppers or other insects; Limiñana, pers. obs.). Both in natural habitats and croplands the peak of grasshopper abundance occurs later at higher altitudes (Bonnet *et al.* 1997). In croplands, this peak occurs after harvesting (Tella *et al.* 1998, Franco & Sutherland 2004, Ursúa *et al.* 2005), which in our study area takes place in June in the lowlands and at the end of the breeding season (July–August) at higher altitudes.

Many bird species are known to store energy reserves before initiating migration (Blem 1990, Jenni & Jenni-Eiermann 1998, Newton 1998, Berthold 2001). This involves movements from breeding grounds to areas where food availability is higher (e.g. Drewien *et al.* 1999, Trierweiler *et al.* 2007). To test whether Montagu's Harriers disperse to areas at higher altitudes after breeding (where food is more abundant), we used satellite telemetry to compare habitat use during the breeding season and the pre-migration stage.

Despite satellite telemetry being widely used in the study of bird migration (see Guan & Higuchi 2000 for review), onset and close of migration are generally chosen subjectively. There is a need to develop and use standardized methods that enable the objective identification of these events, making studies comparable and replicable. In this study, we describe and apply a method to establish onset of migration using movement patterns of tracked birds.

METHODS

In 2006, we tagged Montagu's Harriers from a breeding population of inland Castellón (NE Spain), where the c. 130 breeding pairs nest in sclerophyllous Mediterranean shrublands composed mainly of Kermes Oaks *Quercus coccifera*, Gorse *Ulex parviflorus* and Rosemary *Rosmarinus officinalis* (Limiñana *et al.* 2006a, 2006b, Soutullo *et al.* 2006a). Ten adult birds (six males, four females) were captured between May and June 2006 using dho-gaza nets and a stuffed Eagle Owl *Bubo bubo* as a decoy. Birds were sexed, weighed and ringed. A Microwave Telemetry's 9.5 g solar-powered PTT-100 platform transmitter terminal (PTT) was fixed to their backs using a Teflon harness (Kenward 2001, Soutullo *et al.* 2006b). Harriers were captured in the late incubation stage or when they had very small nestlings. Birds were released within 30 minutes of capture. For the first three months of operation the PTTs were programmed on a 6 hours ON / 16 hours OFF duty cycle, and reset to a 10 hours ON / 56 hours OFF duty cycle for the following months. Locations were obtained using the Argos system, and birds were tracked until all birds had arrived on their wintering grounds (see Limiñana *et al.* 2007 for details on how the end of the migration was established). To avoid excessive autocorrelation, positions obtained less than an hour after the previous one were excluded from the analyses. All data were retrieved and managed with the Satellite Tracking and Analysis Tool (STAT, Coyne & Godley 2005). Tagged harriers are identified by the ID number of the PTT throughout the paper.

For the present study, we only considered the period encompassing the breeding season and the pre-migratory stage. The 'pre-migratory stage' is defined as the period between the last record on the breeding grounds and the first record of migration. To establish these dates we employed a modification of the method used by Soutullo *et al.* (2006c; see also Cadahía *et al.* 2007). The method is based on the idea that, regardless of the differences among individuals in their movement patterns, for each individual the transition between

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the more restricted movements undertaken during the breeding season and the wider-ranging movements undertaken during the pre-migratory stage shows as a peak in the variability of the distance covered between consecutive locations. The same applies to the transition between pre-migratory and migratory stages. Hence, for each location we calculated the distance (in km) to the previous one, and then the accumulated coefficient of variation (CV) of the distances between consecutive locations. Starting with the distances between the first three records, we calculated the CV for an increasing number of records, adding a new record each time. To identify the transitions between the breeding season and the pre-migratory stage, and between pre-migratory stage and migration, we then calculated the difference between each pair of consecutive CVs (ΔCV). We assumed that the larger the increase in CV (i.e. the larger the positive value of ΔCV) resulting from the inclusion of a new record, the larger the difference with the pattern of movements performed until then (i.e. the last recorded movement represents an abrupt change of the scale of the distances covered by the birds in their daily movements). Thus, we considered the date midway of each pair of dates with the two largest ΔCVs as the dates of the onset of the pre-migration stage (the first of those events in chronological terms) and the onset of migration (the second). As changes in CVs are smoothed by the inclusion of all previous records in every calculation, abrupt changes in the pattern of movements should be evident as sharp peaks in the ΔCV values when the full range of ΔCV values is observed (Fig. 1). Note that when one of the two largest ΔCV values corresponds to the value calculated with the distances between the first three locations, this was not considered as an indicator of the onset of the pre-migratory stage, as that peak is an artifact of the method that results from subtracting an initial CV = 0 from the CV calculated from the first two movements (i.e. for the first three records).

For bird ID 39706, it was not possible to estimate the onset of the pre-migratory stage, given the small number of locations obtained while in Spain. This resulted in the second higher peak appearing just at the end of the migration, which had been estimated in a previous study (Limiñana *et al.* 2007). Thus, for this individual we considered the largest ΔCV value as indicative of the onset of the migration, not the pre-migration.

Once the onset of the pre-migratory stage was determined for each individual, we used all locations obtained between the date of tagging and the end of the breeding season to determine the breeding area used by all the individuals studied. To do so, we calculated the 95% fixed kernel including all birds' locations (Worton 1989, Kenward 2001) using ArcView's Animal Movement Extension (Hooge & Eichenlaub 1997). Following Hooge & Eichenlaub (1997) we used the least squares cross validation (LSCV) procedure (Silverman 1986, Kenward 2001, but see Hemson *et al.* 2005) to calculate the smoothing parameters (H). Argos assigns a measure of the estimates' accuracy (Location Class, LC) to each calculated position (see Soutullo *et al.* 2007 and references therein). To determine the breeding area we only used locations in LCs 3, 2, 1 or 0.

We then calculated the proportion of different habitat types within that area using the Corine Land Cover map for Spain. For those individuals for which we had at least 10 locations in LCs 3, 2 and 1 (i.e. with nominal accuracies between 150 and 1000 m) during the breeding season, we estimated their home range as the minimum convex polygon including these locations. Although this is only an approximation of their actual home range, we proceeded in this way because 10 locations are too few to calculate reliable kernels, and also because locations with other LCs are inappropriate for analyses on habitat use (see Soutullo *et al.* 2007). To explore individual differences in habitat preferences, the proportion of different habitat types within each home range was compared with that observed for the whole breeding area using compositional analysis (Aebischer *et al.* 1993).

Finally, we used Monte Carlo tests (Manly 1997) to evaluate whether pre-migratory Montagu's Harriers prefer habitat types that differ from those preferred during the breeding season, and

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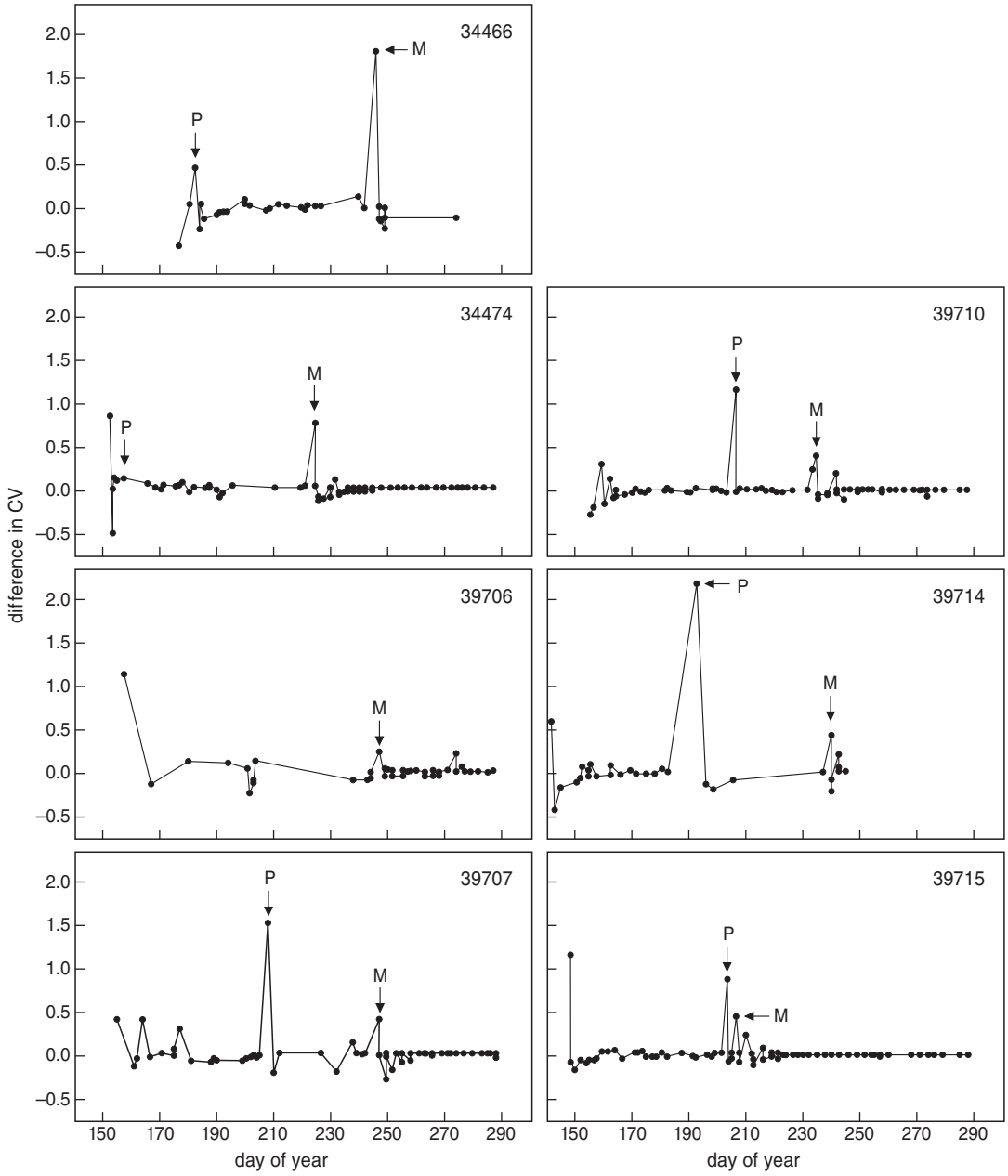


Figure 1. Differences in the CV of the distance covered in consecutive movements by Montagu's Harriers during the breeding season, pre-migration and autumn migration. ΔCV was calculated as the difference between consecutive CVs. Changes in movement patterns can be recognized as peaks in the ΔCV graphs, with the largest two corresponding to the onset of the pre-migration ('P') and migration stages ('M'). Each graph corresponds to an individual bird identified by PTT ID number.

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whether they use areas located at higher altitudes, as expected if the abundance of Orthoptera is an important driving force during this stage. To compare median altitude and the proportion of different habitat types in both areas, we generated 1000 random points within the breeding areas using ArcView's Random Point Generator (Jenness 2005). For each point we recorded habitat type (from the Corine Land Cover map) and altitude (Baumgartner & Mate 2005). As suggested by Soutullo *et al.* (2007) only locations in LCs 3, 2 and 1 were considered for these analyses. Given Montagu's Harriers' capability of moving several km in a few minutes, and the countrywide scale of the habitat data we used, we considered locations with an accuracy <1 km as reliable descriptors of the birds' differential use of habitat types in our study area (see also Soutullo *et al.* in press). Altitudes were obtained from USGS' 30-arc-second SRTM digital elevation model (available at http://www.landcover.org).

Data of all individuals were pooled to compare the altitude of the breeding area with the altitude of the areas used during the pre-migratory stage. We compared the median of the altitudes obtained during the pre-migration stage with the confidence interval including the central 95% of the values (two-tailed test) obtained from choosing at random without replacement the same number of random points (i.e. the number of locations obtained during the pre-migration) from the breeding area. To calculate the confidence interval, a total of 1000 randomizations were performed using Excel's Poptools add-in (Hood 2006). To compare habitat use in relation to their availability (i.e. preference), we pooled the data and counted the number of observations in each habitat type during the pre-migratory stage. This was compared with the number of random points in different habitat types in the breeding areas using the same Monte Carlo procedure (see Soutullo *et al.* in press).

RESULTS

Montagu's Harriers left the breeding areas between 4 June and 27 July. The pre-migratory stage took on average 42 days and onset of the migration took place between 25 July and 4 September (Table 1). For three individuals (ID # 39707, 39714 and 39715) we obtained enough locations (i.e. more than 10 locations in LCs 3, 2 or 1) during the breeding season to calculate home-ranges, which varied between 14 and 88 km^2 (Table 2).

During the breeding season, harriers used some habitat types more often than expected from their

Table 1. Dates of the onset of the pre-migratory and migratory stages of seven Montagu's Harriers breeding in natural habitats in northeastern Spain.

ID #	Sex	Pre-migratory onset	Pre-migratory duration (days)	Migration onset
34466	F	1 July	62	1 September
34474	M	4 June	68	11 August
39706	F	-	-	4 September
39707	F	27 July	39	4 September
39710	M	26 July	28	23 August
39714	M	7 July	52	28 August
39715	M	22 July	3	25 July
Mean ± SD		10 July ± 20	42 ± 24	23 August ± 15

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Table 2. Percentage of habitat types in the breeding area of a population of Montagu's Harriers in northeastern Spain (first data column) and in the home ranges of three individuals (n = number of locations used in the calculation).

	Breeding area	HR 39707	HR 39714	HR 39715
Fruit tree plantations	15.7	11.0	14.9	20.8
Complex cultivation patterns	30.3	24.9	29.4	44.8
Sclerophyllous vegetation	38.3	36.8	51.3	34.3
Other	15.7	27.3	4.5	0.1
Area (km^2)	482.06	87.51 (n = 10)	52.51 (n = 15)	13.89 (n = 18)

Table 3. Montagu's Harriers' habitat use during the breeding season and the pre-migratory stage. Indicated is the number of locations obtained in each habitat type during the pre-migratory stage. Data obtained from the breeding area (randomizations) are expressed as mean number of records in each habitat type.

		Breeding (randomizations)		
	Pre-migration	Mean	SD	P
Non-irrigated arable land	21	0.47	0.48	<0.001
Fruit trees plantations	5	16.94	13.55	<0.001
Complex cultivation patterns	20	31.32	21.57	<0.01
Sclerophyllous vegetation	24	36.54	22.36	<0.01
Other	27	11.63	10.28	<0.001
Altitude (m)	717.50	305.03	114.36	<0.001

availability ($\chi^2_3 = 16.737$, $P < 0.001$), although they showed differences in their preferences (Table 2). Overall, they seemed to prefer complex cultivation patterns and sclerophyllous vegetation to fruit trees plantations, and these to other habitats types in the breeding area.

Pre-migratory Montagu's Harriers used areas located at higher altitudes than those used during the breeding season (Table 3; Fig. 2). These areas also had a lower proportion of sclerophyllous vegetation, complex cultivation patterns and fruit tree plantations. In contrast, they used a higher percentage of non-irrigated arable land and other habitat types (Table 3).

DISCUSSION

Montagu's Harriers did not depart to their wintering grounds immediately after breeding, but performed pre-migratory movements of varying duration and direction (all directions except East), with one of the birds moving to SW France (Fig. 2; see also Trierweiler *et al.* 2007). The high variability in the duration of the pre-migratory stage might be related to differences in body condition after the breeding season, timing of the breeding cycle (early breeders are expected to disperse earlier), and breeding success (failed pairs may prematurely leave the breeding areas).

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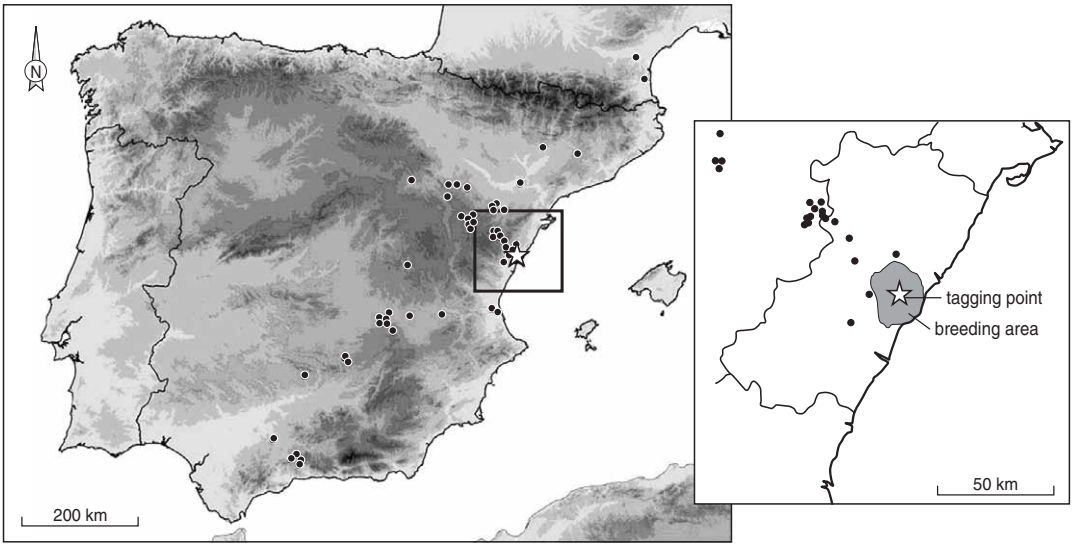


Figure 2. Locations of seven adult Montagu's Harriers obtained by satellite telemetry in northeastern Spain during the pre-migratory stage. Darker areas indicate higher altitudes. The staging areas can be recognized by the clusters of points in inland Spain. The breeding area is shown in the inset (95% fixed kernel).

Pre-migratory movements give birds the chance to gather information on productivity in different areas that can then be used as a clue to select a breeding area in the future (Arroyo *et al.* 2002). Visiting other colonies or breeding areas could aid in making settling decisions for the next year (Boulinier & Danchin 1997, Danchin *et al.* 1998). In fact, the bird that travelled to France did visit areas where the species breeds (Thiollay & Bretagnolle 2004) and in Spain, some birds were pinpointed in an area of La-Mancha where the species is known to breed (García & Arroyo 2003).

In our study area, Montagu's Harriers use sclerophyllous Mediterranean shrublands for nesting, which explains the overall preference for sclerophyllous vegetation during the breeding season (Table 2). These breeding areas are surrounded by, and interspersed with, dry crops (mainly olive and almond plantations), with a lesser coverage of cereals (Limiñana *et al.* 2006a, 2006b). Spanish Montagu's Harriers have a diet based on Orthoptera (e.g. Corbacho *et al.* 1995; Limiñana pers. obs.), and therefore prefer hunting in open cultivations where prey availability and prey access are high (Martínez 1994, Martínez *et al.* 1999, Moreira 1999, Clere & Bretagnolle 2001).

The areas used by harriers during the pre-migratory stage were located at higher altitudes than the breeding areas, and were characterized by the presence of shrublands and extensive cultivation areas, mainly cereals like Wheat *Triticum* spp., Barley *Hordeum vulgare*, Oats *Avena* spp., Rye *Secale cereale*, and leguminoseae species like Alfalfa *Medicago sativa*. These areas are maintained by a traditional pattern of crop rotation, resulting in higher availability of Orthoptera than in lowland breeding areas (Bonnet *et al.* 1997), accounting for the presence of Montagu's Harriers after breeding. Furthermore, right after harvesting the abundance and availability of arthropods reach a peak in this type of habitat (Tella *et al.* 1998, Ursúa *et al.* 2005, Franco & Sutherland 2004), contrasting with lowland breeding areas where food peaks occur in May–June (time of hatching).

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The areas used by Montagu's Hariers prior to migration are shared with other steppe-inhabiting birds like Dupont's Lark *Chersophilus duponti*, Little Bustard *Tetrax tetrax*, Great Bustard *Otis tarda*, Black-bellied Sandgrouse *Pterocles orientalis*, Pin-tailed Sandgrouse *Pterocles alchata* and other endangered species like Lesser Kestrel *Falco naumanni* (Martí & Del Moral 2003, García *et al.* 2006), which highlights the conservation importance of these habitats. In fact, the European Union subsidizes traditional cultivation practices in these areas to safeguard steppe habitats for birds (e.g. García *et al.* 2006).

Finally, the dates of the onset of the pre-migration and the migration stages calculated with our method were consistent with our subjective calculations. The large variation in onset of the pre-migratory stage and migration probably reflects a mixture of successful and failed breeders. The accuracy of these dates further depends on the number of reliable fixes that are obtained (see bird ID 39706); if accounted for, our method is standardized and replicable when dealing with satellite telemetry data (Soutullo *et al.* 2006c, Cadahía *et al.* 2007, Limiñana *et al.* 2007).

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SAMENVATTING

Tussen het einde van het broedseizoen en het vertrek naar Afrika zwerven Grauwe Kiekendieven *Circus pygargus* eerst een tijdje rond. De aanvang en duur van deze zwerftochten zijn slecht bekend, maar met behulp van satelliettelemetrie is het nu mogelijk hierover meer aan de weet te komen. Dit Spaanse onderzoek van gezenderde Grauwe Kiekendieven beoogt een objectieve methode te geven die de start van de dispersie en de wegtrek ondubbelzinnig en reproduceerbaar vastlegt. De methode is gebaseerd op abrupte veranderingen in de dagelijks afgelegde afstand. De eerste scherpe verandering (grotere afstand afgelegd) na het uitvliegen van de jongen leidt de zwerffase in, de tweede het moment waarop de trek serieus van start gaat. De periode van zwerven omvatte gemiddeld 42 dagen, waarbij de broedplaatsen tussen 4 juni en 27 juli werden verlaten. De start van de trek viel tussen 25 juli en 4 september. In de tussenliggende periode verbleven de Grauwe Kiekendieven in hoger gelegen terreinen dan waar ze hadden gebroed. Die terreinen worden gekenmerkt door een open structuur, een minder intensieve landbouw en een groot aanbod van sprinkhanen in de periode dat de Grauwe Kiekendieven er aanwezig zijn. De Grauwe Kiekendieven lijken de zwerftochten ook te gebruiken om de stand van zaken in omliggende gebieden in ogenschouw te nemen. Daarbij passeren ze geregeld andere broedplaatsen. Eén vogel zwierf zelfs van Noordoost-Spanje naar Zuidwest-Frankrijk. Mogelijk zijn deze zwerftochten op te vatten als een vergelijkend habitatonderzoek, dat het volgende broedseizoen van pas kan komen bij het kiezen van een broedplaats. (RGB)

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