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Broad wintering range and intercontinental migratory divide within a core population of the near-threatened pallid harrier

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ABSTRACT

Aim To identify the migration routes and wintering grounds of the core populations of the near-threatened pallid harrier, *Circus macrourus*, and highlight conservation needs associated with these phases of the annual cycle.

Location Breeding area: north-central Kazakhstan; Wintering areas: Sahel belt (Burkina Faso to Ethiopia) and north-west India.

Methods We used ring recovery data from Kazakhstan and satellite tracking data from 2007 to 2008 on six adults breeding in north-central Kazakhstan to determine migration routes and locate wintering areas. In addition, one first-year male was tagged in winter 2007–2008 in India.

Results Data evidenced an intercontinental migratory divide within the core pallid harrier population, with birds wintering in either Africa or India. The six individuals tagged in north-central Kazakhstan followed a similar route (west of the Caspian Sea and Middle East) towards east Africa, before spreading along the Sahel belt to winter either in Sudan, Ethiopia, Niger or Burkina Faso. Spring migration followed a shorter, more direct route, with marked interindividual variation. The bird tagged in India spent the summer in central Kazakhstan. Half of the signal losses (either because of failure or bird mortality) occurred on the wintering areas and during migration.

Main conclusions Our study shows that birds from one breeding area may winter over a strikingly broad range within and across continents. The intercontinental migratory divide of pallid harriers suggests the coexistence of distinct migratory strategies within the core breeding population, a characteristic most likely shared by a number of threatened species in central Asia. Conservation strategies for species like the pallid harrier, therefore, require considering very large spatial scales with possibly area-specific conservation issues. We highlight urgent research priorities to effectively inform the conservation of these species.

Keywords
***Circus macrourus*, conservation, kazakhstan, migration strategy, migratory divide, satellite telemetry, wintering areas.**

INTRODUCTION

The study of migration is crucial for fully understanding the population ecology and conservation needs of migrant species (Webster & Marra, 2005). Bird populations of long-distance migrants breeding in Eurasia and wintering in sub-Saharan Africa have experienced stronger population declines than short-distance migrants or resident species (Sanderson *et al.*, 2006). Suggested causes include a combination of harsher climatic conditions and agricultural intensification in the

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wintering areas, leading to widespread land degradation and increased mortality during long migrations (e.g. Newton, 2008). Additionally, breeding success may be influenced both by the quality of the breeding habitat and by the carry-over influence of winter habitat quality on body condition and arrival dates (Norris *et al.*, 2003; Gunnarsson *et al.*, 2005). As a consequence, the effective conservation of migratory populations depends on the understanding of the factors that influence an individual's fitness through the entire annual cycle. Satellite tracking is a powerful tool for investigating large-scale animal movements and migratory pathways (Meyburg *et al.*, 1998; Kjellén *et al.*, 2001; Robinson *et al.*, 2010; see Guan & Higuelin, 2000 for a review), and increasingly available for smaller species (Strandberg *et al.*, 2009).

Many Eurasian species have their wintering quarters split between India and Africa (del Hoyo *et al.*, 1994), where they may experience different human and environmental pressures (Naidoo & Iwamura, 2007). However, the migratory pathways and connectivity between breeding and wintering areas are largely unknown for most populations. This is the case of the pallid harrier (*Circus macrourus*), a long-distance migrant whose core breeding populations (where the species is most abundant) are located in north-central Kazakhstan and south-western Siberia (del Hoyo *et al.*, 1994). Substantial population declines of this poorly known species have been reported in many breeding areas, particularly in peripheral populations west of the Ural River (Kostin, 1983; Nankinov *et al.*, 1991; Davygora & Belik, 1994; Birdlife International, 2003). As a result, this species is now classified as 'Near Threatened' (BirdLife International, 2000). The main limiting factors include breeding habitat degradation and reduced prey availability through land-use changes, as well as a decrease in the availability and quality of suitable wintering areas and illegal hunting on migration routes and bottlenecks (van Maanen *et al.*, 2001; Birdlife International, 2003). However, most information available to date essentially relates to breeding ecology (Bragin, 2003; Terraube *et al.*, 2009). Pallid harriers are highly dependent on small rodents during the breeding period, and core breeding populations may be vulnerable to recent land-use changes in central Asia, causing the loss of high-quality vole-rich habitats such as the natural steppe and set-asides (Terraube *et al.*, 2011). However, part of the negative trend observed in pallid harrier's populations during the last decades may be linked to 'wintering area effects'. It is, therefore, necessary to better understand pallid harrier ecology outside breeding areas, starting with the identification of migration routes and wintering areas.

To date, information on pallid harrier migration is mostly anecdotal (observations at bottleneck migration points; Corso & Cardelli, 2004; Panuccio & Agostini, 2006). Its main wintering grounds are open grasslands and agricultural areas throughout the Indian subcontinent, the savannah belt in Africa, south of the Sahara through to the eastern African savannahs. The migration routes and wintering areas of the core breeding populations remain enigmatic and of particular interest, with any or both of the African and Indian continents being potential wintering areas.

In this study, we first review Kazakhstan ringing recovery data to study pallid harrier migration patterns. Second, we report on satellite telemetry data and document for the first time the migration routes and wintering areas of pallid harriers from a known origin (north-central Kazakhstan, within the core breeding area). Finally, we discuss the implications of our findings for the conservation of this and other migratory species of conservation concern in central Asia.

METHODS

Ringing and recovery data of pallid harriers in and from Kazakhstan (hereafter KZ) were obtained from the Institute of Zoology, Almaty (KZ). For the satellite tracking study, we trapped breeding pallid harriers in the Naurzum and Turgai regions (51°N, 64°E), located in north-central KZ (Terraube *et al.*, 2009). One adult pallid harrier female was captured in July 2007 in the Turgai region, and eight adult pallid harriers (four males and four females) were captured in June and July 2008 in Naurzum (*c.*100 km north of Turgai). All birds were trapped using a mist net and a stuffed corsac fox (*Vulpes corsac*) as a decoy, placed at the proximity of active nests, or with a nest-trap placed above the nestlings when older than 10 days. In addition to the previous birds, one first-year male was captured in the Velavadar National Park near Bhavnagar, Gujarat State, north India, in March 2008 (Verma, in press), as part of a research project set-up in India, to study the winter ecology of this species.

Birds were fitted with a 11.5 g solar Northstar PTT transmitter attached using a Teflon harness. The transmitter and harness weighed approximately 4% and 3% of the male and female weights. This extra-weight could negatively impact on survival, but the same tags fitted onto the closely related and smaller Montagu's harrier (23% lighter than pallid harrier) did not have any noticeable effects on survival (Limiñana *et al.*, 2007; Trierweiler *et al.*, 2007; Terraube *et al.*, 2009). After release at the capture site, birds quickly resumed normal activities (foraging, provisioning of young, etc...).

Harrier movements were tracked using the Argos satellite system which provides location estimates coupled with nominal location accuracy, the location class ('LC') (Meyburg & Fuller, 2007). Location classes 0, 1, 2 and 3 indicate that the reported location lies (with 68.23% confidence) within >1, ≤1 km, ≤350 and ≤150 m of the true location, respectively (Hays *et al.*, 2001). Location classes A, B, C and Z are not associated with reported accuracy and may thus be less reliable, but may be also useful for long-distance tracks (Trierweiler, 2010). We used one location per day, selecting the highest accuracy class available (including lower class locations if they were the only available) after having excluded aberrant data via filtering (following Trierweiler & Klaassen, pages 112–123 in Trierweiler, 2010). When more than one location of similar accuracy was available for a given duty cycle, we selected the first one.

Of the nine birds tagged in north-central Kazakhstan, only six provided useful data to study migration (three stopped transmitting shortly after PTT set-up, possibly because of loss or transmitter failure). For all individuals, we reported here the first year of tracking data.

Birds were considered to initiate migration when leaving their breeding areas or wintering areas. The onset of migration trips was very obvious since, in all cases they were initiated with movements of >100 km day^{-1}. Similarly, the end of migration trip (and change to wintering behaviour) was very obvious as daily movements changed to <20 km day^{-1}. All results are presented as means ± SD.

Habitats (natural vs. agricultural or anthropized) in wintering areas were characterized using Google Earth (http://earth.google.com).

RESULTS

Ringing data

Analysis of the ringing recoveries from Kazakhstan birds suggested that central Asian pallid harriers used two alternative migration routes (Fig. 1). A 'western' route to the African wintering grounds was evidenced by three ring recoveries in central Kazakhstan from Tunisia and France (Fig. 1). An 'eastern' migratory route linking central Kazakhstan to the Indian wintering grounds could be identified by two ring recoveries in south-eastern KZ, and one in northern India (Fig. 1).

Satellite tracking data: migration routes and wintering areas

All of the six migrating birds from north KZ migrated west of the Caspian Sea, through Russia, Georgia, Armenia and then crossed countries of the Middle East (Turkey, Syria and Iraq; Fig. 2a). Two to three of these birds flew a route near the Batumi region, along the Georgian (east) coast of the Black Sea when crossing the Caucasus area (Fig. 2a). Subsequently, the routes used slightly differed, as some birds used a more 'terrestrial' route crossing Israel, Jordan and Egypt, whereas others crossed Saudi Arabia, then the Red sea, Egypt and Eritrea. The wintering areas of these birds were mainly located in sub-Saharan countries from western-central to eastern Africa (Table 1; Fig. 2a), with a large longitudinal spread of *c.* 4500 km. Two pallid harriers overwintered in Ethiopia, two others in Sudan, and two other birds arrived to Sudan and then shifted to central-western Africa, one settling at the Burkina Faso – Niger border and the other one in Niger (wintering in open, dry savannah habitats). In Sudan, pallid harriers wintered in open and dry grasslands with higher heterogeneity in vegetal cover. Birds wintering in Ethiopia spent the winter in the most anthropized habitats, a mix of pastures and agricultural areas at the vicinity of several villages.

Of the six tagged birds that migrated to Africa, only three transmitted until the following breeding season (two stopped transmitting in Sudan and Ethiopia during winter, and one in Syria during spring migration; Table 1).

Spring migration routes used by pallid harriers differed from the autumn ones by being more direct (Fig. 2b). The two birds wintering in western-central Africa came back via Egypt after a northward trip through the Sahara Desert, thereafter using a similar route to those taken during the autumn. The other two birds that wintered in eastern Africa (Sudan and Ethiopia) crossed the Red Sea, Saudi Arabia, one crossing the Caspian Sea and the other passing east of it (and not west, as did all the birds during the autumn migration).

The bird tagged in winter in India migrated through Pakistan, Afghanistan, Turkmenistan and Uzbekistan, to spend summer in central Kazakhstan breeding grounds, about 300 km away from the area where the other tagged birds bred in 2007–2008 (Fig. 2b).

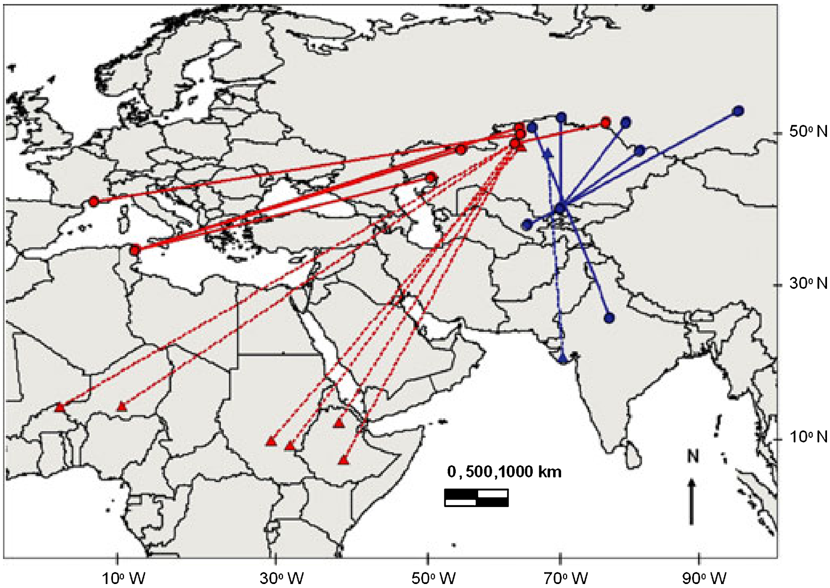

Figure 1 Migratory routes and wintering areas of pallid harriers as evidenced from ringing and recovery data from Kazakhstan (circles, solid lines) and from satellite tracking data (triangles, dashed lines). The western migratory routes (towards Africa) are shown in red, and the eastern routes (towards India) are shown in blue.

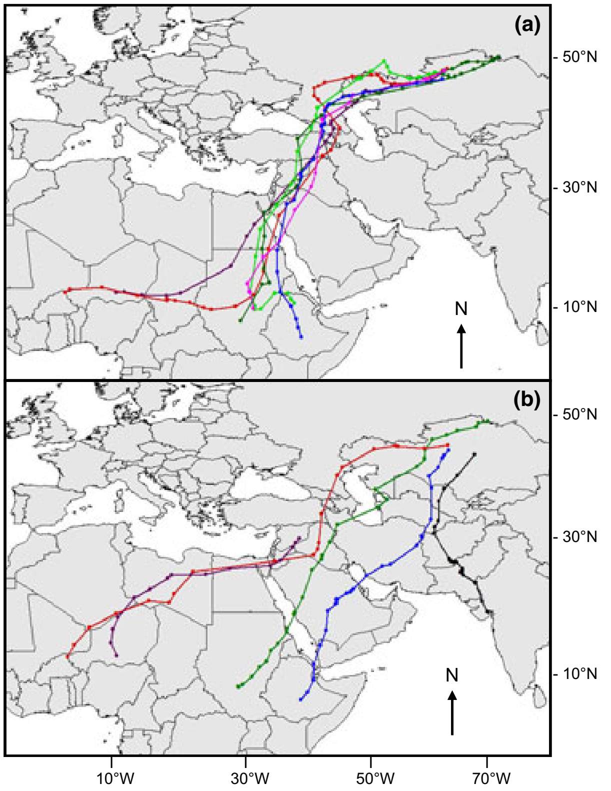

Figure 2 Autumn (a) and spring (b) migration routes of six pallid harriers breeding in north-central Kazakhstan and of one pallid harrier wintering in India.

Timing and duration of migration and wintering phases

The mean departure date from the breeding grounds was 28 July ± 6 days, and the mean arrival to the wintering areas was 29 October ± 11 days. Therefore, the mean duration of the autumn migration was 83 ± 31 days. Autumn migration was long because most birds (five of six) performed one long stopover (54 ± 10 days) in an area distant 1695 ± 610 km from the breeding area (all in Kazakhstan or Russia). During autumn migration, birds travelled a total of 7340 ± 1378 km. The average migration speed was thus 108 ± 67 km day^{-1} (or 164 ± 45 km day^{-1} when excluding the time spent in the stopover).

Birds stayed on the wintering grounds an average of 148 ± 15 days ($n = 4$). The mean departure date from the African wintering areas was 23 March ± 6 days ($n = 4$), and the mean duration of the northward migration was 28 ± 5 days ($n = 3$). The mean distance travelled was 6888 ± 1878 km, and average speed during spring migration was thus 258 ± 105 km day^{-1} ($n = 3$). Overall, the spring migration from Africa was shorter, faster and more direct than the autumn one for all three monitored birds. The first-year male captured in its wintering quarters in India travelled a distance of 3322 km until settlement in the breeding grounds (Table 1, see Verma, in press for more details).

DISCUSSION

This study documents for the first time the migration timing, routes and wintering areas of pallid harriers of known origin (north-central KZ). A main result was the existence of an intercontinental migratory divide for core breeding populations from central Kazakhstan (tagged birds wintered in sub-Saharan Africa and in north-west India using much differentiated paths). The simultaneous monitoring of several individuals originating from the same breeding area revealed a large longitudinal spread of the African wintering areas, an overall similarity in the initial autumn migration routes of birds going to Africa, but greater interindividual heterogeneity in spring migration routes, which are shorter (more direct) than the autumn ones.

Migration routes and wintering areas

Analyses of ringing data showed pallid harriers from Kazakhstan winter either in Africa or in the Indian subcontinent and could, therefore, use two different migration routes and wintering regions. In addition, the male pallid harrier tagged in India in winter migrated to central Kazakhstan, close to a breeding area where birds wintering in Africa were tagged. Together, these data confirm the existence of an intercontinental migratory divide for pallid harriers breeding in Kazakhstan and suggest that birds breeding in western and north-central KZ would migrate preferentially to east Africa and the Sahelian Belt, whereas those breeding in more eastern locations would have their wintering grounds in the Indian subcontinent. There is no obvious geographical barrier (mountain, desert, sea…) separating the breeding pallid harrier populations wintering in India from those wintering in Africa. Therefore, the origins of the evolution of divergent migration routes in this species remain to be investigated, for instance using molecular approaches (Pérez-Tris *et al.*, 2004). Pallid harriers seem to be more widely distributed in Africa than India (Birdlife International, 2003), but in the absence of reliable wintering population abundance estimates in Africa and India, the relative importance of each wintering area cannot be yet assessed. Further research would be, however, critical to ascertain this.

Our data indicate at least 4500 km of longitudinal extent in African wintering areas (from Ethiopia to Burkina Faso; Fig. 2) for birds from the same breeding origin (north-central Kazakhstan). This longitudinal variation is much greater than that reported in other raptor species tracked by satellite telemetry (e.g. Limiñana *et al.*, 2007; Gschweng *et al.*, 2009; Strandberg *et al.*, 2009).

Autumn migration routes towards Africa were consistent among individuals, at least during the first part of the migration (Fig. 1), whereas spring migration routes differed substantially from autumn ones and showed more interindividual variation, which was likely a consequence of the broad longitudinal range occupied by this species during winter, together with more direct routes used for the return migration.

Table 1 Life cycles and signal transmissions of 10 transmitters applied to pallid harriers and summarized migratory data for tracked individuals.

Harrier age/sex	Capture/nest site	Start of transmission/end of signals	Start autumn migration (departure breeding site)	Arrival wintering area	Total duration (days)	Total distance (km)	Average autumn migration speed (km day^{-1})	Wintering area location (Lat./long. in decimal degrees)
Adult male 1	Naurzum region	07 July 2008–19 April 2009	02 August	20 October	79	7301	92.42	Niger (14.68/8.64)
Adult female 1	Naurzum region	27 June 2008–03 August 2008	Signal lost*	–	–	–	–	–
First-year male	Gujarat, India	11 March 2008–21 September 2008	–	–	–	–	–	NW India (22.16/71.86)
Adult female 2	Naurzum region	27 June 2008–24 July 2009	30 July	08 November	101	9773	96.76	Front. Niger/Burk. Faso (14.5/0.21)
Adult female 3	Turgai region	09 July 2007–October 2009	03 August	16 November	105	7691	73.25	Sudan (9.40/29.27)
Adult female 4	Naurzum region	27 June 2008–10 December 2008	29 July	25 October	88	7184	81.64	Ethiopia (12.51/39.33)
Adult male 2	Naurzum region	28 June 2008–03 August 2008	Signal lost*	–	–	–	–	–
Adult male 3	Naurzum region	26 June 2008–11 November 2008	22 September	16 October	24	5828	242.83	Sudan (9.126/32.404)
Adult male 4	Naurzum region	30 June 2008–11 August 2008	Signal lost*	–	–	–	–	–
Adult female 5	Naurzum region	26 June 2008–present	18 July	28 October	102	6255	61.32	Ethiopia (7.266/39.985)

Harrier age/sex	Start spring migration	Arrival breeding grounds	Total duration (days)	Total distance (km)	Average spring migration speed (km day^{-1})
Adult male 1	30 March	Signal lost in Syria 19 April	20†	4262†	213†
Adult female 1	–	–	–	–	–
First-year male	1 April	26 April	25	3322	133
Adult female 2	16 March	7 April	22	8313	378
Adult female 3	23 March	24 April	32	6988	218
Adult female 4	Signal lost in Ethiopia	–	–	–	–
Adult male 2	–	–	–	–	–
Adult male 3	Signal lost in Sudan	–	–	–	–
Adult male 4	–	–	–	–	–
Adult female 5	23 March	23 April	30	5362	179

*Signal lost in the breeding area.

†Refers to partial data as signal lost in route (data not included for calculation of average duration or distance in text).

Additionally, climatic conditions (and particularly wind drift) could influence migration patterns (Klaassen *et al.*, 2010, 2011). Migrating raptors are subjected to easterly winds in Africa during both autumn and spring migration, with stronger winds in spring (Meyburg *et al.*, 2003), and there might be individual variation in responses to wind drift (Klaassen *et al.*, 2010, 2011). Finally, spring migration was overall faster than the autumn one. This was a combination of higher flight speed (with an additional 59 km travelled per day even when considering only moving days) and the lack of long stopovers. A faster migration in spring than in autumn has been reported in other raptors (e.g. McGrady *et al.*, 2002; Alerstam *et al.*, 2006) and could be related to a selection for earlier arrival, with fitness advantages for early breeders (Kokko, 1999).

Risks for migrating and wintering pallid harriers

From the six birds that started autumn migration, only three apparently survived to the following breeding season. The location of signal losses could indicate where mortality occurred.

Signal from one bird was lost during migration in Syria. Additionally, one of the birds that survived the first year was also lost during migration in Iraq the following year. The convergence of the routes used by tagged birds migrating from central Asia to Africa means a potential vulnerability of birds wintering in Africa to threats like illegal hunting on the migratory pathways or habitat degradation in stopover areas. Widespread capture and shooting of raptors, commonly including harriers, have been reported on migration corridors in Georgia, along the Black sea coast and in other Middle East countries (van Maanen *et al.*, 2001). Our data show that a large proportion of the tagged birds from central Kazakhstan transit through this region, while estimates based on local counts suggest that more than 1500 pallid harriers can be recorded every autumn in the Batumi area (http://www.batumiraptorcount.org). These estimates point out the critical importance of this watchsite for monitoring central Asian pallid harrier populations wintering in Africa. Although comprehensive information is lacking on current shooting and trapping levels on migration routes, a recent report indicates that migratory birds are facing considerable hunting and trapping pressure in Syria (Attar, 2005). Priority should be given to assessing the sensitivity of pallid harrier and other raptors' populations to illegal hunting along the migration routes, and mitigation effort should be maintained and reinforced meanwhile.

Additionally, signals for two birds were lost in winter, highlighting the potential importance of this stage of the annual cycle for populations. In particular, birds were lost in Sudan and Ethiopia in 2008–2009, when a severe drought occurred (NASA: http://earthobservatory.nasa.gov/NaturalHazards): low rainfall levels in the Sahel have been associated with reduced survival rates in other migratory raptors and birds (Schaub *et al.*, 2005; Grande *et al.*, 2009; Mihoub *et al.*, 2010).

Overall, different threats may be associated with each of the wintering areas, both intra- and intercontinent. The whole Sahelian and Sudanian biogeographical zones of the pallid harrier wintering range have suffered much habitat degradation (Thiollay, 2006a). Ethiopian grasslands and savannahs have been recently described as threatened by changes in the patterns of extensive seasonal grazing (involving transhumance, use of wet-and dry-season pasturing and the control of encroaching scrub by fire), as sedentarization is associated with a clear pattern of biodiversity loss (Western *et al.*, 2009; Donald *et al.*, 2010). Land degradation seems to be widespread in Ethiopia as a result of rapid population increase, erosion, deforestation and reduced vegetation cover (Tadesse, 2001). Nevertheless, the impact these changes could have on wintering pallid harriers remains largely unknown.

Western Africa has been reported to suffer a huge loss of biodiversity outside the protected areas in recent decades, associated with the dramatic increase in human pressure: deforestation, overgrazing and erosion, increase in pesticide use and overhunting (Sanderson *et al.*, 2006). These changes were associated with large decline in raptor abundance outside protected areas in west Africa between the 70s and the 2000s and a significant decline in wintering pallid harrier numbers during this period (Thiollay, 2006a,b, 2007).

Finally, results of an ongoing research project in India on the winter ecology indicate that pallid harriers depend on natural grasslands for both roosting and foraging (T. Cornulier, F. Mougeot, C. Krishna & M. Madders, unpublished data; del Hoyo *et al.*, 1994). Natural grasslands in India have suffered considerable reduction and fragmentation, and remnant grasslands are now essentially restricted to protected areas and governmental reclaimed land, with ongoing degradation because of overgrazing and encroachment by invasive trees *Prosopis juliflora* (Joshi *et al.*, 2009).

Further research is needed to better understand winter habitat use and foraging ecology of pallid harriers, as information on the diet in the different wintering areas remains scant. Contrary to the closely related Montagu's harrier, trophic relationships between pallid harriers, grasshoppers or other prey in Africa are still poorly understood. This could have crucial conservation implications as many western European migratory raptors, mainly locust and grasshopper consumers, have suffered severe declines in recent decades, possibly related to climate change and pesticide use to control insects (Newton, 2004; Sánchez-Zapata *et al.*, 2007).

Intercontinental migratory divide and conservation implications

We identified two main migration routes and a wide variety of wintering areas over two continents for the core populations of the pallid harrier breeding in central and north Kazakhstan. Such an intercontinental migratory divide appears to exist in other threatened species from central Asia (including sociable lapwing *Vanellus gregarius*, demoiselle crane *Anthropoides virgo*, steppe eagle *Aquila nipalensis*; del Hoyo *et al.*, 1994; BirdLife International, 2006; Meyburg *et al.*, 2003), although conservation implications are still little understood. Populations with individuals using different migratory pathways and scattered wintering areas are likely vulnerable to contrasted threats. Different wintering areas may be characterized by different levels of environmental and anthropic pressures, such as droughts, habitat destruction or illegal hunting. As a result, the existence of different wintering areas for birds using the same breeding area will impact heterogeneously on the demography of that population, which further complicates the design of effective conservation strategies. While wide wintering ranges have the potential to buffer populations against temporary adverse conditions in one particular wintering site, permanent differences in the quality of migration routes or wintering areas have the potential to constitute source or sink sub-populations. To inform global conservation strategies for species like the pallid harrier, it is important for future research to (1) determine the proportion of the global population wintering in India vs. Africa and among the different areas within Africa, (2) identify the specific threats associated with different migratory pathways and wintering areas using a combination of satellite data and detailed field studies, to develop appropriate targeted conservation programmes for the species in its wintering areas, and (3) estimate the spatial, genetic structuring and exchanges between sub-populations exhibiting different migration and wintering strategies.

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