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Unusual clockwise loop migration lengthens travel distances and increases potential risks for a central Asian, long distance, trans-equatorial migrant, the Red-footed Falcon *Falco vespertinus*

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ABSTRACT

Capsule: Red-footed Falcons *Falco vespertinus* migrating from northern Kazakhstan proceed west before heading south to Africa; their northbound travel follows a different route with passage close to shooting hotspots in the Mediterranean.
Aim: To use tracking and ringing data to document for the first time the migration of globally threatened Red-footed Falcons from northern Kazakhstan.
Methods: Light-level geolocators were deployed on breeding adults in Kazakhstan and recovered one year later. Ringing and observational data from more than 100 years of Russian-language and other literature were summarized and mapped alongside the geolocator data.
Results: Geolocator, ringing and observational data together demonstrate that Red-footed Falcons from northern Kazakhstan have a clockwise loop migration that begins with a long and unusual westward trek around eastern Europe's large inland seas before continuing to extreme southern Africa. Return migration is farther west and requires crossing two major migratory barriers: the Sahara and the Mediterranean.
Conclusion: The loop migration we describe requires an extensive longitudinal movement, exposes central Asian Red-footed Falcons to multiple desert, mountain and marine crossings, and, at outbound and return Mediterranean bottlenecks, crosses sites where raptor shooting is common.

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Conservation of migratory birds is challenging because it may be necessary year-round, on summer breeding grounds, on wintering grounds and on migration (Faaborg *et al.* 2010). However, the vast majority of research or conservation action for northern hemisphere migrants has occurred on either their summering (Vickery *et al.* 2014) or wintering (Keast & Morton 1980) areas. Nonetheless, it is generally well understood that for many species the vast majority of deaths occurs during migration (Newton 2008, Klaassen *et al.* 2014).

In the absence of human activity, mortality on migration is generally associated with either predation or the high energetic demands of long-distance flight, often across large ecological barriers (Newton 2008, Klaassen *et al.* 2014). Many large birds, including raptors, face additional anthropogenic risks when on migration, especially from shooting (Pannuccio 2005). For example, every year thousands of raptors are shot when passing via the island of Malta (Fenech 2010). Other hotspots of shooting of migratory raptors are on the eastern Black Sea coast in the Republic of Georgia (Van Maanen *et al.* 2001, Vansteelant *et al.* 2014), Lebanon and northern Syria (Magnin 1991, Bildstein *et al.* 1993).

Some long-distance migrants follow a similar trajectory for both their autumn and their spring movements (Miller 2012). However, many others undertake an elliptical or 'loop' migration, using different outbound and return routes. To date, loop migration has been recorded for at least two North American raptor species (Kerlinger 1989, Martell *et al.* 2014) and at least seven Eurasian raptors (Meyburg *et al.* 2003, Corso & Cardelli 2004, Bildstein 2006, Klaassen *et al.* 2010, Agostini *et al.* 2011, Limiñana *et al.* 2012, Mellone *et al.* 2013a, 2013b). In fact, recent

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work has suggested that loop migration may be the rule for many Palearctic migrants faced with the dual barriers presented by the Mediterranean Sea and the Sahara Desert (Schmaljohann *et al.* 2012, Klaassen *et al.* 2014). The evolution of loop migration is likely tied to adaptive wind drift (Alerstam 1990, Klaassen *et al.* 2011) and the improved odds of surviving difficult barrier crossings when weather makes them seasonally more or less challenging.

The globally threatened Red-footed Falcon (*Falco vespertinus*) breeds across European steppes, from Hungary through to Kazakhstan and winters in southern Africa (Ferguson-Lees & Christie 2001). Southbound migration of the species is known along the Mediterranean (probably in a wide front; Galea & Massa 1985, Iankov *et al.* 2007, Roth 2008), but subsequent movements are unclear. Some reports suggest a broad-front migration across the Mediterranean (Béltekiné *et al.* 2010, Birdlife International 2014) although others suggest a funnelled flight through the Levant (Leshem & Yom-Tov 1996, 1998). However, there is currently no knowledge of the migration behaviour of Red-footed Falcons that breed in central Asia and the limited data that are available are not accessible to those unable to read Russian.

We tracked migration of Red-footed Falcons tagged with light-level geolocators on summer breeding grounds in north-central Kazakhstan and we reviewed Russian-language literature on ring recoveries and field observations of this species on migration. Our goals were: (a) to describe the migratory behaviour of Red-footed Falcons in terms of routes, timing, distance and wintering destinations and (b) to evaluate that behaviour in the context of threats and potential conservation management for the species.

Methods

We monitored Red-footed Falcons on breeding grounds in the Kostanay Oblast of north-central Kazakhstan. Shortly after arrival in Kazakhstan in May, Red-footed falcons lay an average of 3.5 eggs in Corvid nests or nest boxes; on average 2.4 chicks/nest fledge in late July or early August (Bragin 2011). During the breeding season, Kazakhstan's Red-footed Falcons forage on insects, reptiles, small birds and mammals (Bragin 1989).

We captured falcons near the village of Kievka (approximately 51°43′13″N 64°20′0″E) with mist nets set near nests or with nooses in the nest. We collected standard morphological measurements, colour ringed the birds and fitted them with 1.5–2 g Mk-14 series light-level geolocators with a 20 mm stalk (British Antarctic Survey and BioTrack Ltd, UK) by a 2 mm-wide teflon ribbon harness over the hips (Bally Ribbon Mills, USA).

Falcons were recaptured the following year. Geolocator data were downloaded and post-processed using the manufacturer's BASTRack Decompressor, TransEdit2 and Locator software. We followed the manufacturer's instructions to handle equinox periods, light thresholds (set at 16) and sun elevation angles (for which final choices were made by comparing accuracy against known summering locations; Beason *et al.* 2012). We estimated the start and end of migration following Jahn *et al.*'s (2013) protocol and we estimated centroids for winter locations by averaging locations between 15 December and 15 January, a time period when we were reasonably certain that the birds were not migrating.

We plotted midnight fixes from the geolocators (Beason *et al.* 2012) within a Geographical Information Systems package (ARCGIS 10.1; ESRI, Redlands, CA, USA) for subsequent analysis. We accounted for clock drift (which affects longitudinal accuracy) by measuring the distance between recorded summering grounds after deployment and before recapture and, per manufacturer instructions, correcting for that difference by assuming that drift was constant (linear) over the year the unit was deployed. We accounted for location error by correcting every data point by the difference between the centroid of our calibration period (a 2–4-week period when we knew the birds were breeding) with the known nest location for each bird. We followed the BASTrack instructions for confidence levels but we retained and flagged in our maps apparently reasonable geolocator data from the equinox period (confidence < 9). This approach helped us identify a most probable general course of migration during this critical but hard to measure period. Finally, we calculated the measurement error from our calibration periods and used that distance to illustrate potential error around geolocator-measured migration routes. We also report ringing return data from a 30+ year ringing effort conducted at our study site and from an extensive manual survey of records in Russian-language scientific literature.

Results

Geolocator tracking

We deployed 5 geolocators in 2011 (one on an adult male, four on adult females) and 15 geolocators in summer 2012 (four on adult males, 11 on adult females). We colour ringed all tracked birds as well as an additional 16 adults and 209 nestlings. We recovered two geolocators in summer 2013 that had been deployed in 2012 on females. This low geolocator recovery rate (2/20 = 10%) is consistent with or higher than the recovery rates we observed from colour ringing alone (in 2013 we saw only two other colour-ringed falcons, both ringed as adults and neither with geolocators; 4/245 = 1.6%).

Both of the Red-footed Falcons we tracked engaged in clockwise loop migration that started with an unusual anticlockwise longitudinal movement (Figure 1(a,b)). Departure from breeding grounds occurred between 5 and 11 September. Southbound routes took the birds north of the Caspian Sea and towards the Middle East. It is not obvious from our data if these birds passed through the Caucasus or west of the Black Sea. Trans-equatorial migration occurred at approximately the same time as the autumn equinox (20 September), and so we recorded few useful geolocator data points in this period. Those data that do exist suggest a passage route through the Middle East and northeastern Africa. Total time on migration was approximately 30 days, with arrival in Angola, southern Africa, during the first week of October.

Both birds then took approximately one month to move through Angola into Botswana and Namibia. Winter locations of these birds were centred in east-central Namibia (Tag #166033) and west-central Botswana (Tag #17372). From February into March, one bird (#166033) began drifting north, into Angola, while the other drifted south, into South Africa.

Return migration also occurred close to the equinox and precise departure dates therefore were difficult to estimate. Estimated dates of the onset of return migration were between 10 and 30 March (probably closer to the end of the month in both cases) and birds arrived in northern Kazakhstan on 5 (#17372) and 6 (#166033) May. This northbound trek was far west of the southbound route and it appeared close to the coast, through Congo, Gabon, Cameroon, then inland through Nigeria, Niger and Libya, to a Mediterranean crossing near Italy. Migration continued west and then north of the Black Sea, over the Caspian and then back to Northern Kazakhstan. Both birds appeared to stop for 1–2 weeks south of the Sahara, a behaviour consistent with refuelling before the subsequent difficult desert and open water crossings.

Straight-line (orthodrome) distance between northern Kazakhstan breeding grounds and the centre of wintering grounds was 9224 km (#17372) and 9436 km (#166033). Estimated minimum overland distance between these sites was 9518 km (#17372) and 9666 km (#166033), but the southbound route our birds took was at least 9550 km (via the Caucasus) or 11 275 km (via Ukraine and Bulgaria). Because we collected few data points during the equinox, true migration distance is likely longer than estimated. The northbound route was approximately 13 200 km. Thus, the actual migration route these falcons took was at least 103–143% of a straight-line route between breeding and wintering grounds.

Ring recovery and literature review

During 1978–87 and 1992–93, one of the authors (EAB) fitted 402 aluminium rings on Red-footed Falcons, nearly all nestling birds. Three ringed nestlings were recovered, all of them during southbound migration (Figure 1(c)). One bird, ringed on 30 July 1978 was recovered shot in November 1979 in Lebanon. A second was ringed on 14 July 1980 and recovered 11 September 1980 when found injured in the south Ural region of Russia. A third bird, ringed on 25 July 1983, was recovered on 5 November 1984 in the Rostov Region of Russia, northeast of the Azov Sea.

Our focal population breeds in northern Kazakhstan and neighbouring Russia, and there are only a few records of this species that suggest significant migration south along a direct overland route, through central Asia (Figure 1(c)). These include autumn records from east of the Caspian Sea (Isakov & Vorobyov 1940, Mitropolskii *et al.* 1987) and from the north and east of the Aral Sea (Bostanzhoglo 1911, Zarudnii 1916, Varshavckii 1957, Korelov 1962, Berezovskii 1983). Farther east, Red-footed Falcons have been recorded near the Ili River and the Tien Shan Mountains in extreme southeastern Kazakhstan (Korelov 1962, Kovshar and Berezovikov 1999, Gavrilov *et al.* 2002), in the Kyzyl-kum Desert (Bogdanov 1882) and near Tashkent (Ivanov 1940).

In contrast, the vast majority of observations of autumn migration of Red-footed Falcons are from north of the Caspian and Black Seas (Figure 1(c)). Thousands of birds have been observed in the mid-level reaches of the Ural River (Bostanzhoglo 1911) as well as in the North Caucasus region of Russia (Dagestan and Stavropol; Malovichko *et al.* 2003). From there, the most likely migratory route for the majority of falcons is north of the Black Sea, where thousands of birds have been observed over the lower reaches of the Dnieper River near the towns of Cherson and Ochakov (Petrovitch & Redinov 2008). In contrast, few birds have been observed near the Caspian Sea (Komarov 1985, Mikheev 1985, Polivanov *et al.* 1985) and only a few hundred have been seen crossing the Caucasus (Abuladze *et al.* 2003). Likewise,

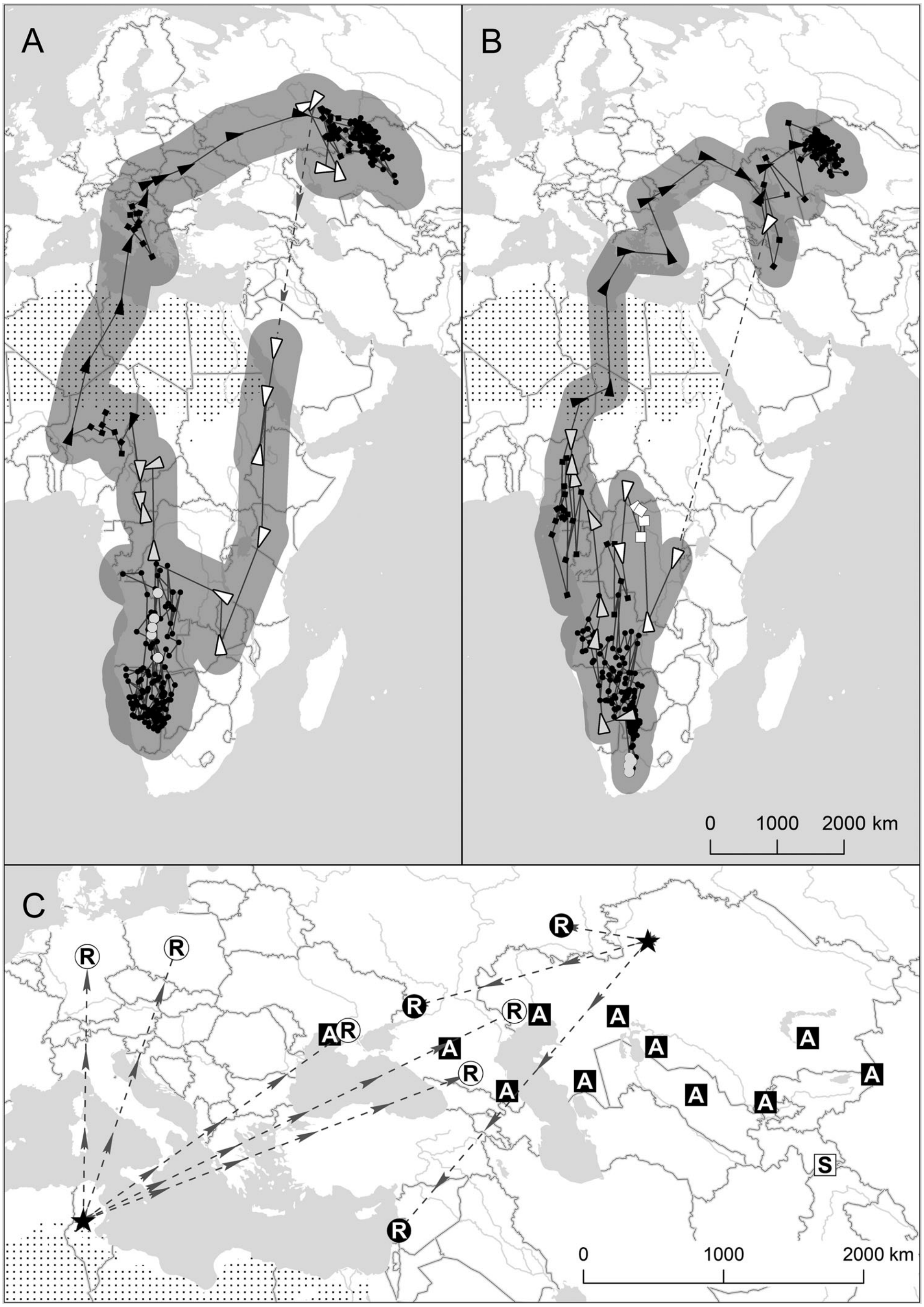

Figure 1. Migration routes, ring recoveries and Russian-language literature records of Red-footed Falcon migration in Eurasia. (a) and (b) show geolocator data from two female Red-footed Falcons (A = tag #166033; B = #17372) tagged in north-central Kazakhstan. Circles are summer and winter locations, triangles show directionality of migration travel, squares are times when direction of travel is not clear, dotted lines are periods with no data. In all cases, open shapes (unfilled circles, squares and triangles) represent data with less confidence (those recorded during the equinox). The buffer around the lines is the average error from known locations estimated during the breeding period; see text for details. The area of the Sahara Desert is illustrated by dots on the map. Inset (c) shows ring recovery and Russian-language literature records. Circles show locations of recoveries from birds ringed in northern Kazakhstan and northern Africa (both ringing sites represented by stars). Squares show published sightings during autumn (A) and spring (S). In all cases, filled shapes with white letters are autumn data, unfilled shapes with black letters are spring data.

Red-footed Falcons have been seen in the tens or hundreds at Batumi (Verhelst *et al.* 2011), Eilat (Shirihai & Christie 1992) and the Bosphorus (Fülöp *et al.* 2014). Finally, Leshem & Yom-Tov (1998) report greater numbers of Red-footed Falcons in autumn than in spring in Israel.

The limited data on spring migration of this species consist of older records that suggest the possibility of a secondary migratory flyway across the Altai and Hindu Kush in Afghanistan (Meinertzhagen 1938, as cited in Ivanov 1969). Published records of ring recoveries of birds ringed in northern Tunisia occurred from Germany, Poland and regions north of the Black and Caspian Seas and in the northern Caucasus (Haratchi 1982; Figure 1(c)).

Discussion

Our data and literature review describe a remarkable clockwise loop migration whose length suggests that these Red-footed Falcons travel westward to avoid desert and mountain crossings south of their breeding grounds. Although our sample size is small, the clockwise nature of this movement is unexpected, as many other species that migrate elliptically, do so in an anticlockwise direction (e.g. Eleonora's Falcon *Falco eleonorae*, Mellone *et al.* 2013a; Marsh Harrier *Circus aeruginosus*, Klaassen *et al.* 2010), or enter and leave Africa in the northeast (Steppe Eagles *Aquila nipalensis*, Meyburg *et al.* 2003). Of published migration tracks we reviewed, only the Common Cuckoo *Cuculus canorus* has a similar clockwise migration, but they enter and leave Africa with a Mediterranean crossing (Willemoes *et al.* 2014). The falcons we monitored entered Africa by land but departed across the Mediterranean.

Our data suggest that Red-footed Falcons from Russia, Ukraine and Central Asia follow one of at least two autumn migration tracks. One passes through the Caucasus into Turkey and the Middle East. However, the one that is probably used more frequently passes north of both the Black and Caspian Seas, south through the Bosphorus, Turkey and into the Middle East. We saw no evidence for a southbound open water crossing (this contrasts with tracked Hungarian birds that make such a crossing in the eastern Mediterranean; Béltekiné *et al.* 2010). Unpublished and incomplete satellite-monitored migration routes of Red-footed Falcons from our study area were similar (P. Palatitz, unpubl. obs.).

If birds from northern Kazakhstan head directly south from breeding grounds, they would need to cross multiple central Asian and Middle Eastern deserts before reaching the Sahara. In contrast, by migrating due west, through Russia, falcons remain in habitats similar to those in which they breed. Presumably this provides them better forage and the opportunity to make desert crossings in better condition (Alerstam 2001). However, the cost of this behaviour is the addition of up to 40% greater distance travelled than a direct, overland flight. The northbound route, which is longer than required and involves an open water crossing, possibly is enabled by refuelling in the Sahel and springtime trade winds from behind. Thus the Red-footed Falcon clockwise loop migration strategy appears not to be focused on minimizing travel distance but instead on the maintenance of energetic reserves that may be essential to survival when crossing extended barriers such as the Mediterranean Sea and the Sahara Desert.

The loop migration of these falcons also demonstrates the geographic extent over which local shooting or other threats migrant raptors face may impact populations. Kostanay Oblast is approximately 4300 km from Malta, 2800 km from the western Black Sea and similarly far from other shooting hotspots in the Middle East. Nevertheless, birds that breed in this part of central Asia are exposed to many risks across migration routes that go east-west as well as north-south. Although the low geolocator and ring recovery rates in this study may be due to low breeding site fidelity, they may also reflect the risks these birds face on migration. If the latter is true, then the threats birds face in Europe and the Middle East have the potential to impact birds that breed long distances away. Therefore, conservation of central Asian migrants involves addressing threats they face on their long-distance migration, not just on steppe breeding grounds or Afro-tropical wintering grounds.

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