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Short communication

Golden jackal expansion in Europe: First telemetry evidence of a natal dispersal

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ABSTRACT

The Eurasian golden jackal (*Canis aureus*) is currently undergoing a rapid range expansion. Originally restricted to small coastal areas of the Mediterranean and Black seas, this highly adaptive and generalist species is now reproducing throughout Southeastern and Central Europe. In addition, individuals are being seen further to the North and West. This continental-scale phenomenon is receiving high interest among the public and policy makers. Although dispersal is a key determinant of the species expansion, little is known about the dispersal ecology of the species. Here we report the first direct evidence of the golden jackal dispersal ability by presenting the natal dispersal of a yearling female monitored by GPS-telemetry in Southwestern Hungary. We used a cluster-based path segmentation analysis to identify the different movement sequences: pre- and post-dispersal home ranges, dispersal event as well as explorative forays. The yearling female left her natal home range before the mating season, in January and settled 61.2 km to the North, where she successfully bred. The dispersal transience lasted for 12 days, with a cumulative travelled distance of 223.7 km through a human-dominated landscape (including two crossings of a motorway). The dispersal movements were characterized by much longer step lengths than observed during the home ranging behavior, and a high propensity for nocturnal movements. Noticeably, the dispersal event followed a period of numerous explorative forays. Our GPS telemetry study confirms the golden jackal's ability to disperse long distances through human-dominated landscapes, and the potential for the species to expand further in human-dominated landscapes of Central Europe.

The Eurasian golden jackal (*Canis aureus*) is currently undergoing a remarkable range expansion. Restricted to small coastal areas of the Mediterranean and Black seas in the Holocene (Sommer and Benecke, 2005), this highly adaptive and generalist species is now reproducing throughout Southeastern Europe (Arnold et al., 2012; Trouwborst et al., 2015). In addition, vagrant individuals are being noticed further to the North and West – as far as the Baltic countries, in Denmark, Switzerland and The Netherlands (Rutkowski et al., 2015; Trouwborst et al., 2015). The species expansion could potentially have important consequences on communities and ecosystems (Lanszki et al., 2006; Ćirović et al., 2016), and is already receiving high interest from the public and policy-makers (Trouwborst et al., 2015). Uncovering the processes underlying the species range expansion and forecasting its future developments are therefore of ecological interest and management priorities.

Dispersal affects the redistribution of organisms, and is thus a key determinant of species range expansions (Jønsson et al., 2016). Insights on golden jackal dispersal ecology are scarce, and have largely relied on indirect approaches. First, opportunistic detection of vagrant individuals, and in some cases the development of geographically isolated populations, illustrate the species dispersal abilities (Arnold et al., 2012; Rutkowski et al., 2015). Second, large-scale genetic investigations in Europe support the occurrence of long-distance dispersal in the species (Rutkowski et al., 2015). With development of new tracking methods such as GPS-telemetry, opportunities arise to investigate animal dispersal in a more direct manner (Jønsson et al., 2016). For example, such data have recently

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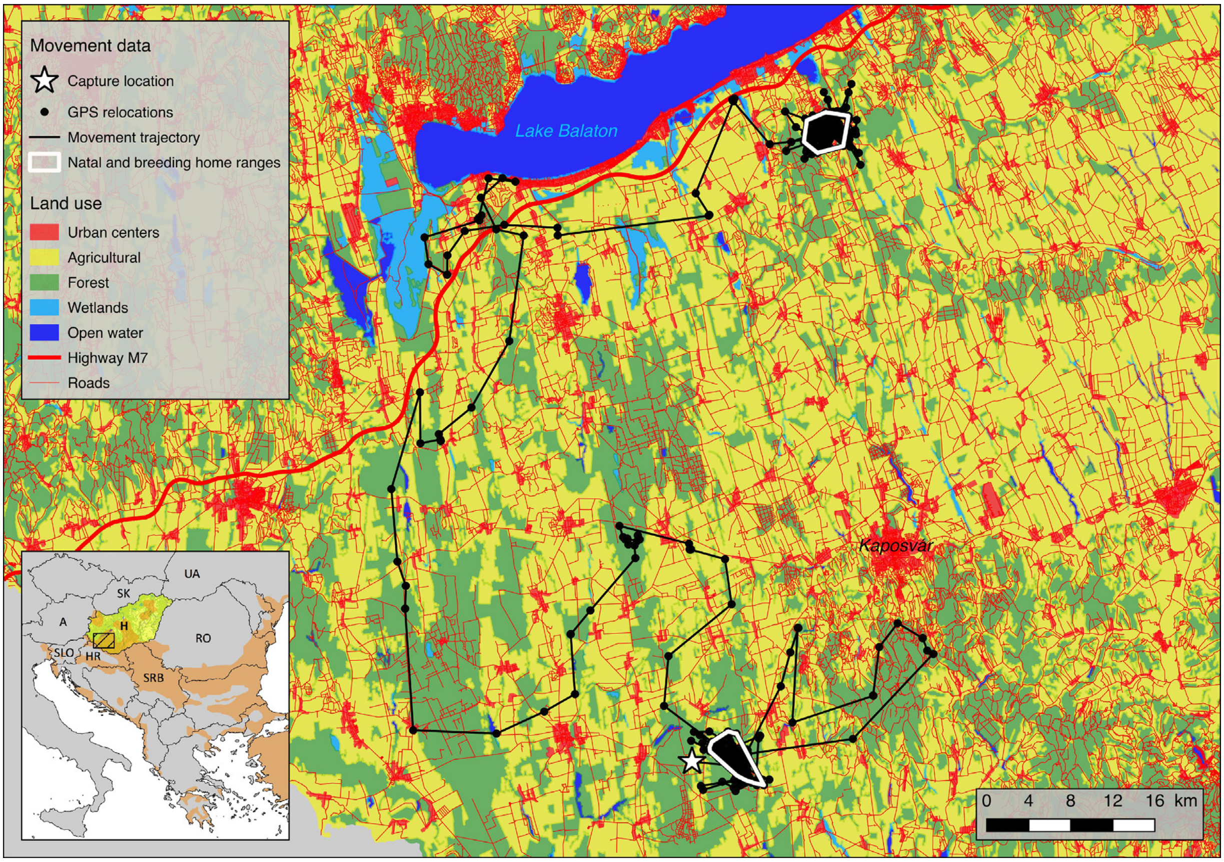

Fig. 1. Dispersal event of Zsuzsi, a GPS-collared female golden jackal in SW Hungary. Zsuzsi was captured (white star) close to her natal home range (bottom white polygon). She dispersed (trajectory: black dotted line) to her breeding home range (top white polygon), 61.2 km away. During the dispersal transience, she crossed the M7 motorway (thick red line). Bottom-left overview panel: the study area (black hatched rectangle) is located on the Northern edge of the golden jackal distribution (pale orange; Trouwborst et al., 2015) in Hungary (H). Neighboring countries are as labeled as follow: Austria (A), Slovakia (SK), Ukraine (UA), Romania (RO), Serbia (SRB), Croatia, (HR) and Slovenia (SLO). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

shed light on this phenomenon in European grey wolf (Ciucci et al., 2009; Ražen et al., 2016; Wabakken et al., 2007). Here we report the first direct evidence of the golden jackal dispersal ability by presenting the long-distance natal dispersal of a yearling female monitored by GPS-telemetry.

The study was conducted in south-western Hungary (Fig. 1), an area of lowland and low hills characterized by a temperate continental climate. The landscape is composed of broadleaf woodlands (mean cover within the county: 29%) interspersed within an agricultural matrix (53%) and small settlements. It is traversed by the M7 motorway. Golden jackal presence has been continuous in the study area since 1995 and the population is currently expanding northwards (Heltai et al., 2000; Szabó et al., 2009).

On 21 October 2013, we captured a female golden jackal (nicknamed "Zsuzsi") near Lábod village (N46.196, E17.513) using a box trap baited with big game viscera. We immobilized the animal using 0.1 ml DexDomitor (agent: 1 mg/ml dexmedetomidine hydrochloride, *i.m.*). She was estimated to be 1.5 years-old, mature, non-breeding, intact, weighed 10.1 kg and was in good body condition. We fitted Zsuzsi with a GPS Plus Mini (270 g; Vectronic Aerospace) collar programmed to acquire relocations at 00:00, 03:00, 06:00, 12:00, 18:00, 21:00 and 22:00 (CET), and to relay data via Global System for Mobile Communications (GSM). We monitored her movements for 238 days, she was legally shot on 16 June 2014.

We used a path segmentation analysis to objectively identify the dispersal event. To this end, we first subsampled the movement trajectory to a homogeneous fix interval of 6 h between GPS relocation attempts (i.e., at 00:00, 06:00, 12:00 and 18:00). We used MigrO (Damiani et al., 2015, 2016), a spatiotemporal clustering-based segmentation algorithm, to categorize the movement path into three distinct phases: residence (i.e., pre- and post-dispersal home ranges), excursion forays (i.e., movements away from and returning to a single home range) and dispersal event (i.e., transience movements between the pre- and post-dispersal home ranges). MigrO relies on two density criteria – the threshold distance ϵ defining neighbor locations and the number of neighbors n to classify a point as a core point. A cluster is formed by an ensemble of core points (and all other locations within their radii ϵ) and is classified as a dense region when the animal's minimum continuous presence within the cluster exceeds δ (see Damiani et al., 2015 for details). We defined points as neighbors if they were closer than the average distance covered by the animal during 6 h (ϵ = median step length, i.e. 474 m) in order to link the definition of neighborhood distance to the movement capacity of the animal. We classified points as core points if there was at least one full day of activity within their neighborhood radius ϵ ($n = 4$). Finally, we categorized a cluster as a dense region if the animal was present for at least a month (δ = 30 days) – a duration that was set a priori to capture home range phases but omit restricted use areas resulting from the exploitation of localized resources.

We delineated the pre- and post-dispersal home ranges as the minimum convex polygons (MCP) encompassing all relocations identified by MigrO for the respective dense regions. We measured the net dispersal distance as the Euclidean distance between departure and settlement locations, defined as centroids of the pre- and post-dispersal home ranges, respectively. The centroids were computed as the arithmetic means of the relocations in both MCPs. The minimum distance travelled was calculated as the sum of all step lengths between departure and settlement locations (i.e., it included the relocations taken at 03:00, 21:00 and 22:00). Instead, the movement rates were based on the trajectory subsampled to a homogeneous 6-h fix schedule. We employed a similar approach to evaluate net and cumulative distances of excursion forays. All analyses were conducted using the package adehabitatLT (Calenge, 2006) in R (R Core Team, 2016) and Quantum GIS (QGIS Development Team, 2016).

Overall, the proportion of successful fix acquisition was relatively high (mean = 83.8%). It was, however, noticeably smaller between the 24th of April and the 27th of May 2014 (mean = 22.7%) than during the rest of the monitoring period (mean = 93.7%). The path segmentation analysis revealed two dense regions of residence separated by a dispersal event (Fig. 1). The pre-dispersal home range was occupied between the 21/10/2013 and the 05/01/2014 (i.e., 76 days) whereas the post-dispersal home range was occupied between the 17/01/2014 and the 16/06/2014 (i.e., 150 days). Both home ranges were estimated to be c. 12 km^2 and were separated by a net Euclidean dispersal distance of 61.2 km (Fig. 1).

Based on the clustering procedure, the dispersal event stated on the 6 January 2014, when Zsuzsi left her home range to move northwards. She covered a minimum cumulative distance of 223.7 km in 12 days. Zsuzsi travelled an average of 3.24 km every 6 h (standard deviation $\sigma = 3.94$, n = 38), which is significantly more than step lengths within either the pre- or post-dispersal home ranges (mean = 0.63 km, $\sigma = 0.72$, n = 554; Mann-Whitney *U* test, W = 7806, p-value = 0.008). When dispersing, she moved much larger distances at night, between 18:00 and 06:00 (6-h mean distance = 6.09 km, $\sigma = 3.74$, n = 19), than during the day (mean = 0.39 km, $\sigma = 0.86$, n = 19; W = 8, p-value <0.001). During the dispersal transience, she crossed several primary and secondary major roads, as well as twice the M7 motorway. Zsuzsi also undertook short explorative forays (i.e., roundtrip movements outside a single dense region) lasting less than a day and taking her less than 6 km away from residence areas. These occurred before dispersing (n = 6, including the location of her capture; Fig. 1) and in the few weeks after settling in her post-dispersal home range (n = 7). Noticeably, the week before the dispersal (29/12/2013–01/01/2014), she undertook a long explorative foray characterized by a minimum cumulative distance of 73.8 km and taking her at least 20.4 km away from her home range.

Although the species dispersal ability was demonstrated by both genetic relatedness analyses and detection of dispersing individuals (Rutkowski et al., 2015), this study provides the first movement-based analysis of a golden jackal natal dispersal event. Evidence suggests that Zsuzsi, a yearling, sexually mature female jackal, dispersed from her natal home range to establish a successful breeding home range. First, field investigations in the pre-dispersal home range revealed her association to a resident jackal group, where she was presumably a helper – a common strategy for yearlings (Moehlman, 1987). Second, field investigations in the post-dispersal home range showed that Zsuzsi attended a den occupied by a litter. In addition, the very low rate of successful fix acquisition between 24 April and the 27 May 2014 is coherent with maternal underground activity inside the den (Moehlman, 1987).

The characteristics of Zsuzsi dispersal are consistent with previous studies. Yearling seems to be the most common dispersing age class in East African jackals (Moehlman, 1987), where subadults may remain in the family group as helper. The high propensity of yearling dispersal has also been noted in grey wolf (Gese and Mech, 1991; Mech and Boitani, 2003). Winter dispersal is typical in coyote *Canis latrans* (Gese et al., 1996), but has rarely been observed in wolf, for which it seems to peak in autumn and spring (Gese and Mech, 1991; Kojola et al., 2006). Interestingly, Zsuzsi dispersal was preceded by multiple extra-territorial forays, a behavior frequently observed in wolf (Gese and Mech, 1991; Wabakken et al., 2007) and red fox *Vulpes vulpes* (Woollard and Harris, 1990).

In general terms, dispersal propensity depends both on external information and on the individual internal state (Clobert et al., 2009). In golden jackals, resource depletion has been shown to increase dispersal in yearlings (Kapota et al., 2016). In addition, strong social pressures may be an important underlying factor, as shown in coyote (Gese et al., 1996). In the present case, the dispersal took place from an area of high jackal density (mean density = 28 groups/100 km^2, Lanszki et al., 2015) to an area of relatively low conspecific density (5 groups/100 km^2, Lanszki unpublished), at the expansion front of the species in Hungary.

Dispersing jackals have been observed several hundreds of kilometers from the closest source population e.g., in the Baltic countries or Switzerland (Rutkowski et al., 2015), and more recently in Denmark. As a result, we cannot consider the present case as an extreme dispersal event. Nevertheless, daily traveled distance and total dispersal distance of Zsuzsi are larger than those generally observed in red fox (Trewhella et al., 1988; Gosselink et al., 2010), and comparable to data on wolf dispersal (Gese and Mech, 1991; Wabakken et al., 2007; Ciucci et al., 2009; Ražen et al., 2016). Additional research is critically needed to characterize golden jackal dispersal pattern and biological determinants.

Despite the sample size limitation, our study demonstrates the capacity of the species to disperse rapidly across human-dominated landscapes, and to overcome important movement barriers (e.g., motorway). Such high dispersal ability, combined with the adaptability of the species to anthropogenic landscapes, strongly suggests that the ongoing expansion of golden jackal in Europe could reach large parts of Western Europe in the near future.

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References

Arnold, J., Humer, A., Heltai, M., Murariu, D., Spassov, N., Hackländer, K., 2012. Current status and distribution of golden jackals Canis aureus in Europe. Mamm. Rev. 42, 1–11.
Calenge, C., 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecol. Model. 197, 516–519.
Ciucci, P., Reggioni, W., Maiorano, L., Boitani, L., 2009. Long-distance dispersal of a rescued wolf from the northern apennines to the western alps. J. Wildl. Manage. 73, 1300–1306.
Clobert, J., Le Galliard, J.-F., Cote, J., Meylan, S., Massot, M., 2009. Informed dispersal, heterogeneity in animal dispersal syndromes and the dynamics of spatially structured populations. Ecol. Lett. 12, 197–209.
Ćirović, D., Penezić, A., Krofel, M., 2016. Jackals as cleaners: ecosystem services provided by a mesocarnivore in human-dominated landscapes. Biol. Conserv. 199, 51–55.
Damiani, M.L., Fotino, G., Ranc, N., Cagnacci, F., 2015. MigrO: a plug-in for the analysis of individual mobility behavior based on the stay region model. Proc. ACM GIS, 2015.
Damiani, M.L., Issa, H., Fotino, G., Heurich, M., Cagnacci, F., 2016. Introducing presence and stationarity index to study partial migration patterns: an application of a spatio-temporal clustering technique. Int. J. Geogr. Inf. Sci. 30, 907–928.
Gese, E.M., Mech, L.D., 1991. Dispersal of wolves (Canis lupus) in northeastern Minnesota, 1969–1989. Can. J. Zool. 69, 2946–2955.
Gese, E.M., Ruff, R.L., Crabtree, R.L., 1996. Social and nutritional factors influencing the dispersal of resident coyotes. Anim. Behav. 52, 1025–1043.

Gosselink, T.E., Piccolo, K.A., van Deelen, T.R., Warner, R.E., Mankin, P.C., 2010. Natal dispersal and philopatry of red foxes in urban and agricultural areas of Illinois. J. Wildl. Manage. 74, 1204–1217.
Heltai, M., Szemethy, L., Lanszki, J., Csanyi, S., 2000. Returning and new mammal predators in Hungary: the status and distribution of the golden jackal (Canis aureus), raccoon dog (Nyctereutes procyonoides) and raccoon (Procyon lotor) in 1997–2000. Beiträge zur Jagd- und Wildforsch 26, 95–102.
Jønsson, K.A., Tøttrup, A.P., Krabbe Borregaard, M., Keith, S.A., Rahbek, C., Thorup, K., 2016. Tracking animal dispersal: from individual movement to community assembly and global range dynamics. Trends Ecol. Evol. 31, 204–214.
Kapota, D., Dolev, A., Bino, G., Yosha, D., Guter, A., King, R., Saltz, D., 2016. Determinants of emigration and their impact on survival during dispersal in fox and jackal populations. Sci. Rep. 6, 24021.
Kojola, I., Aspi, J., Hakala, A., Heikkinen, S., Ilmoni, C., Ronkainen, S., 2006. Dispersal in an expanding wolf population in Finland. J. Mammal. 87, 281–286.
Lanszki, J., Heltai, M., Szabó, L., 2006. Feeding habits and trophic niche overlap between sympatric golden jackal (Canis aureus) and red fox (Vulpes vulpes) in the Pannonian ecoregion (Hungary). Can. J. Zool. 84, 1647–1656.
Lanszki, J., Kurys, A., Heltai, M., Csányi, S., Aícs, K., 2015. Diet composition of the golden jackal in an area of intensive big game management. Ann. Zool. Fennici 52, 243–255.
Mech, D.L., Boitani, L., 2003. Wolf social ecology. In: Mech, D.L., Boitani, L. (Eds.), Wolves: Behavior, Ecology, and Conservation. The University of Chicago Press, Chicago & London, pp. 1–34.
Moehlman, P.D., 1987. Social organization in jackals. Am. Sci. 75, 366–375.
QGIS Development Team, 2016. Quantum GIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.
R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria URL https://www.R-project.org/.
Ražen, N., Brugnoli, A., Castagna, C., Groff, C., Kaczensky, P., Kljun, F., Knauer, F., Kos, I., Krofel, M., Luštrik, R., Majić, A., Rauer, G., Righetti, D., Potočnik, H., 2016. Long-distance dispersal connects Dinaric-Balkan and Alpine grey wolf (Canis lupus) populations. Eur. J. Wildl. Res. 62, 137–142.
Rutkowski, R., Krofel, M., Giannatos, G., Ćirović, D., Männil, P., Volokh, A.M., Lanszki, J., Heltai, M., Szabó, L., Banea, O.C., Yavruyan, E., Hayrapetyan, V., Kopaliani, N., Miliou, A., Tryfonopoulos, G.A., Lymberakis, P., Penezić, A., Pakeltytė, G., Suchecka, E., Bogdanowicz, W., 2015. A European concern? Genetic structure and expansion of golden jackals (Canis aureus) in Europe and the Caucasus. PLoS One 10, 1–22.
Sommer, R., Benecke, N., 2005. Late-Pleistocene and early Holocene history of the canid fauna of Europe (Canidae). Mamm. Biol. 70, 227–241.
Szabó, L., Heltai, M., Szucs, E., Lanszki, J., Lehoczki, R., 2009. Expansion range of the golden jackal in Hungary between 1997 and 2006. Mammalia 73, 307–311.
Trewhella, W.J., Harris, S., Mcallister, F.E., Mcallistert, F.E., 1988. Dispersal distance, home-range size and population density in the red fox (Vulpes vulpes): a quantitative analysis. J. Appl. Ecol. 25, 423–434.
Trouwborst, A., Krofel, M., Linnell, J.D.C., 2015. Legal implications of range expansions in a terrestrial carnivore: the case of the golden jackal (Canis aureus) in Europe. Biodivers. Conserv. 24, 2593–2610.
Wabakken, P., Sand, H., Kojola, I., Zimmermann, B., Arnemo, J.M., Pedersen, H.C., Liberg, O., 2007. Multistage, long-range natal dispersal by a global positioning system–collared scandinavian wolf. J. Wildl. Manage. 71, 1631–1634.
Woollard, T., Harris, S., 1990. A behavioral comparison of dispersing and non-dispersing foxes (Vulpes vulpes) and an evaluation of some dispersal hypotheses. J. Anim. Ecol. 59, 709–722.