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SHORT COMMUNICATION

Evidence of long-distance dispersal of a gray wolf from the Chernobyl Exclusion Zone

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Abstract
The Chernobyl Exclusion Zone (CEZ) is a ~4300 km^2 area in Belarus and Ukraine that remains heavily contaminated with radiation from the nuclear accident of 1986. Long standing controversy persists on the fate of wildlife within the CEZ following human abandonment of the area. Human residency remains extremely sparse, and the CEZ has become a refuge for some populations of wildlife, including gray wolves (*Canis lupus*). Using GPS telemetry, we documented the first long-distance movements of a young (1–2 years) male wolf from the CEZ into the surrounding landscape. The wolf traveled 369 km from its home range center over a 21-day period in February 2015. In the 95 days prior to dispersal, the wolf maintained a home range of ~28 km^2, with daily displacements rarely exceeding 5 km. With the onset of dispersal, daily displacement increased to a mean of 16.8 km. The dispersal of a young wolf is an important observation because it suggests that the CEZ may serve as a source for some wildlife populations outside of the CEZ, and raises questions about the potential spread of radiation-induced genetic mutations to populations in uncontaminated areas.

Keywords Animal movement · *Canis lupus* · Chernobyl · Contamination · Dispersal · GPS telemetry

Introduction

The 1986 accident at the Chernobyl Nuclear Power Plant released large amounts of radioactive material into the atmosphere, much of which settled throughout the surrounding landscape. In response, humans were evacuated from a ~4300 km^2 area surrounding the reactor. This area, the Chernobyl Exclusion Zone (CEZ), straddles the present day border of Belarus and Ukraine, and much of the landscape remains devoid of human habitation. Despite the contamination, the removal of humans from the CEZ created a de facto wilderness reserve, and in the years since the accident, numerous studies have attempted to quantify the effects of radioactive contamination on the wildlife of the CEZ. While some studies suggest detrimental effects of radionuclide exposure on local wildlife (e.g., Møller et al. 2006, Møller and Mousseau 2011), there is evidence wildlife populations, particularly those of large mammals, have grown substantially and are widely distributed within the CEZ, including highly contaminated areas (Deryabina et al. 2015, Webster et al. 2016).

Gray wolves (*Canis lupus*) are one species which appear to have benefited from the lack of human disturbance, with estimated population densities in the CEZ that exceed those observed in other uncontaminated reserves in the region (Deryabina et al. 2015). Like many large carnivores, gray wolves are known to disperse up to several hundred kilometers from natal areas (Kojola et al. 2006). Given the relatively high density of wolves in the CEZ, it is expected that some portion of young born within the zone would disperse into surrounding landscapes. However, the spatial ecology of this population remains largely unstudied and, to our knowledge, no dispersal events have been directly observed. As part of a larger study linking wolf movements and external radiation

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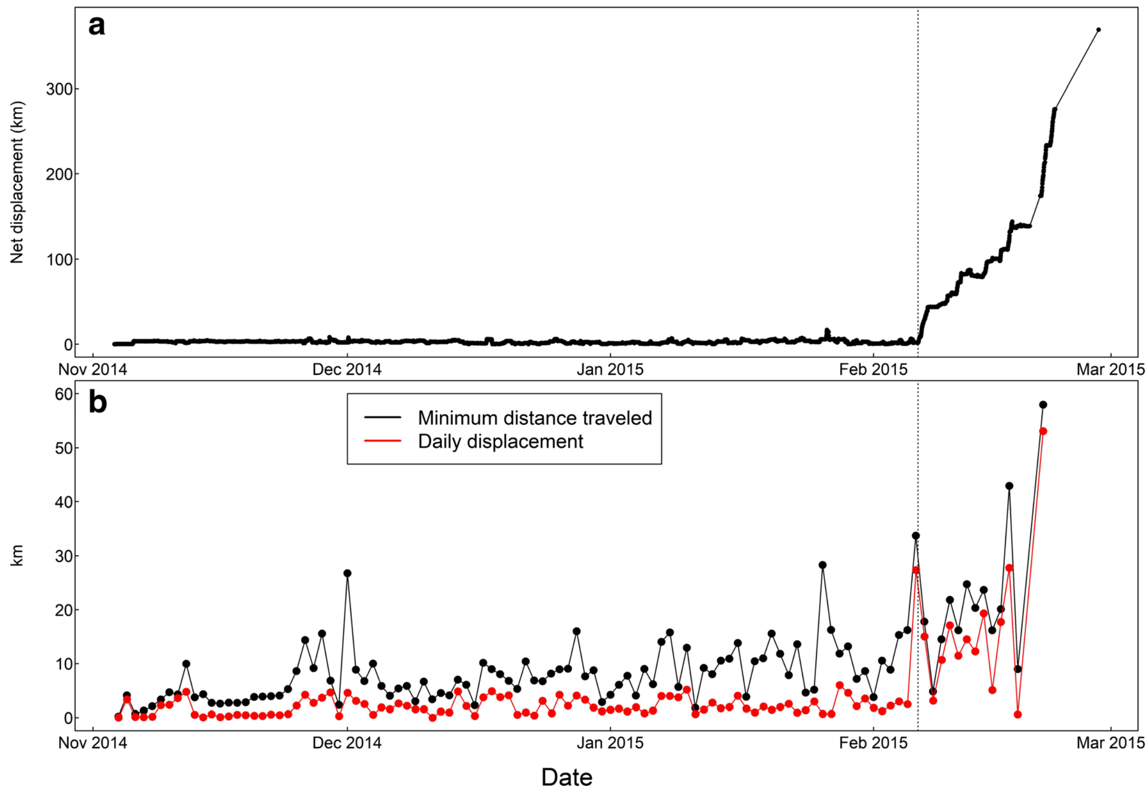

Fig. 1 Net displacement (**a**) of GPS fixes from tagging location, and minimum total daily distance traveled and daily displacement (**b**) of a male gray wolf fit with a GPS collar in the Chernobyl Exclusion Zone. Vertical dotted line in both panels (6 Feb 2015) represents the day the wolf left its home range and began dispersal movements

exposure within the CEZ, we documented the movements of a young male wolf from the CEZ into the surrounding landscape via GPS telemetry. Here we provide a detailed account of this observation and provide comments on the potential implications of the CEZ to regional wildlife populations and areas of future research.

Methods

On 3 November, 2014 we captured a male wolf with a modified foothold trap (Minnesota Brand, Minnesota Trapline Products, Inc., Pennock, MN, USA) within the Polesie State Radioecological Reserve (PSRER), which encompasses the Belarussian portion of the CEZ. We anesthetized the wolf with medetomidine at approximately 0.06 mg/kg. The wolf weighed 32.8 kg at the time of capture, and based on toothwear (Gipson et al. 2000), we estimated its age to be between 1 and 2 years. We fit the wolf with a GPS collar (Vectronic Aerospace GmbH, Berlin, Germany) equipped with an integrated electronic dosimeter (Mirion Technologies; Hinton et al. 2015). We programmed the collar to collect a GPS location every 35 min and transmit data remotely through the Globalstar satellite communication network, with an automatic drop-off mechanism set to release 1 May 2015. The wolf was released at the capture location following collar attachment. Animal capture and handling was carried out in accordance with University of Georgia Animal Care and Use protocol A2015 05–004-Y2-A1.

We plotted displacement (Euclidean distance - km) from the tagging location to each GPS fix to identify when the wolf began its dispersal movements, and to quantify how far the wolf moved from its home range as a function of time. We calculated two metrics to quantify the wolf’s daily movement behavior. First, we calculated minimum distance traveled daily by summing the distances between all GPS locations received within each 24-h period (midnight–midnight). For this analysis, we excluded 5 days with < 30 successful GPS fixes. The second metric, daily displacement, was calculated as the straight-line distance between the first location received each day (within 35 min of midnight) and the first location of the next day. We excluded days in which there was no successful GPS fix recorded within 35 min of midnight ($n = 7$). We used autocorrelated kernel density estimation (AKDE; Fleming et al. 2015) to estimate the home range size (95% UD contour) of the wolf prior to dispersal. The AKDE incorporates movement effects through the autocorrelation function of a fitted continuous-time movement model (Fleming et al. 2014). We fit a movement model and estimated the AKDE using the “ctmm” package (Calabrese et al. 2016) in R (R core team 2015). To visualize the landscape, the wolf traversed after leaving the CEZ, we plotted GPS locations on the European Space Agency 300 m land cover product (http://www.esa-landcover-cci.org). We combined land cover classifications into four broad habitat-types; forested, non-forested/agricultural, urban, and water.

Results and discussion The GPS collar reported 4236 GPS fixes between 3 November 2014 and 27 February 2015. Based on the net displacement plot (Fig. 1a) and visual inspection of the movement path (Fig. 2), the wolf began consistent movements away from its home range on 6 February 2015. GPS fixes were reported regularly during the first few days of dispersal; however, there was a 1.25-day period in which no fixes were reported between 19 February–20 February, and a 5.12-day period of missing fixes between 22 February and 27 February (Fig. 2). After leaving the CEZ, the wolf initially traveled east before moving in a southeastern direction (Fig. 2). Only a single location was received on 27 February, 369 km from the original capture location. No GPS fixes were reported again until 29 August 2015, when the collar began consistently reporting from a static position in a small forest patch, 176 km from the last GPS fix and 330 km from the original capture location (Fig. 2). This date was well after the programmed collar drop-off date of 1 May 2015. Unfortunately, we were not able to physically retrieve the collar, and thus the cause of the long gaps in data transmission (collar malfunction or satellite communication issues) are unknown. Similarly, we could not confirm whether the wolf had died in this location, or if this was the location in which the collar dropped off. Wolves have been documented engaging in dispersal movements lasting > 1 year before settling (Wabakken et al. 2007), and as such, we cannot say where this wolf eventually settled if it did survive.

In the 95 days prior to the onset of dispersal movements on 6 February, the wolf maintained a home range of 28.1 km^2 (95% CI 23.3–33.4 km^2), during which daily displacement rarely exceeded 5 km (mean = 2.0 km; Fig. 1b). The onset of dispersal corresponded to a marked shift in daily movement behavior, with increases in both minimum distance traveled as well as daily displacement (Fig. 1b). The difference was most pronounced for daily displacement, which increased to a mean of 16.8 km during dispersal as the wolf moved in a directed manner away from its home range in the CEZ (Fig. 1b, Fig. 2).

Gray wolves have been documented engaging in long distance dispersal through human dominated landscapes in both Europe and North America (Mech et al. 1995, Wabakken et al. 2007, Ciucci et al. 2009, Gula et al. 2009, Andersen et al. 2015), which may partially explain how the species is able

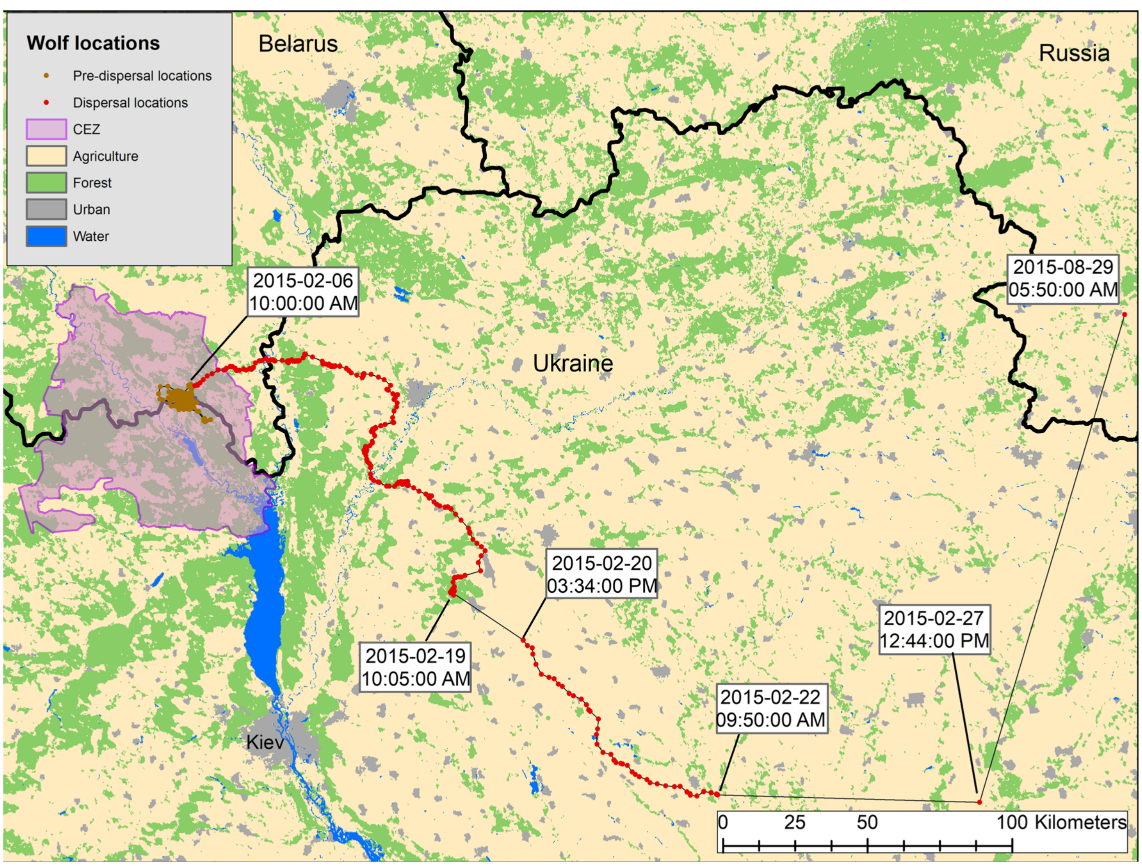

Fig. 2 Movement path (GPS fixes) of dispersing male wolf fit with a GPS collar in the Chernobyl Exclusion Zone, 3 Nov 2014–29 Aug 2015. Dates on the figure illustrate the start of dispersal, date of the last received location, and dates associated with considerable data gaps

to maintain such a large geographic distribution. The dispersal movements we observed (6 February–22 February) primarily traversed an agriculturally dominated region east of the CEZ, and the wolf generally avoided traveling through urban areas (Fig. 2). When the collar began transmitting again in August 2015, it did so from a small (< 2 km^2) patch of forest surrounded by agricultural fields.

Given the wolf's age (1–2 years) and the fact it maintained residence within a limited range for several months prior to leaving the CEZ, it is likely that this was a resident individual born within the CEZ. Young wolves in other regions have been observed making long distance exploratory movements beyond their natal region prior to true dispersal (Boyd and Pletscher 1999, Merrill and Mech 2000). Because of communication issues with the collar, it is impossible for us to say definitively if the movements we observed represented an exploratory excursion (i.e., the wolf eventually returned to its range in the CEZ) or a permanent dispersal. In either case, our observations demonstrate that wolves birthed in the CEZ have the potential to interact with populations in surrounding landscapes during exploratory and dispersal events. Given that the CEZ provides refuge from human disturbance, and the seemingly positive impacts this has had on mammal populations (Deryabina et al. 2015), our observations suggest it is worth exploring how the CEZ may serve as a source for some wildlife populations rather than a sink as has been previously suggested (Møller et al. 2006). Considering the high population density of wolves specifically relative to neighboring uncontaminated reserves (up to seven times greater; Deryabina et al. 2015), it is appropriate to speculate that wolves born in the CEZ regularly disperse into surrounding populations.

Thirteen adult wolves (4 male, 9 female) > 2 years (based on size and tooth wear) were also tracked with similarly programmed GPS collars from November 2014 to May 2015 ($n = 7$), and November 2016–August 2017 ($n = 6$). All tracked adult wolves maintained ranges within the CEZ for the duration of their respective tracking periods (Byrne et al., unpublished data), suggesting movements outsize the CEZ boundary may be infrequent except during dispersal events. Quantifying the relationships between wolves and other mammals, in the CEZ and surrounding populations is a fruitful area of future research that would provide additional insight into the long-term effects of Chernobyl, and other nuclear disasters, on regional wildlife populations. For example, as previous studies have documented mutations to wildlife within the CEZ (Ellegren et al. 1997, Møller et al. 2005, Ryabokon and Goncharova 2006), the potential for large mammals to disperse extensively within the surrounding landscape may facilitate the spread of genetic mutations to populations in uncontaminated areas (Møller and Mousseau 2011). However, genetic damage from the Chernobyl accident is a controversial topic (Chesser and Baker 2006, Beresford et al. 2016) with many conflicting results published in the literature. In contrast to the research cited above, numerous studies have found little evidence of genetic change in animals living within the CEZ (Baker et al. 1996, Baker et al. 2001, Wickliffe et al. 2002, Meeks et al. 2009). Research into the magnitude and impact of genetic flow between mammal populations in the CEZ and the surrounding landscape is needed to better understand the role of the CEZ within the context of regional wildlife populations.

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