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Research Note

Short-term tracking of three red foxes in the Simpson Desert reveals large home-range sizes

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Abstract. The red fox (Vulpes vulpes) is probably the most intensively studied introduced predator in Australia, but little is known about its movements in arid areas. Here, we report on the home-range sizes of one male and two female red foxes that were tracked for 2–8 months using collars fitted with ARGOS transmitters in the Simpson Desert, central Australia. Based on the 100% Minimum Convex Polygon method, home-range sizes were 5723 ha, 50 158 ha, and 12 481 ha, respectively. Based on the 95% kernel contour method, home-range sizes were 3930 ha, 26 954 ha, and 12 142 ha, respectively. These home-range sizes are much larger than any recorded previously from elsewhere in Australia, suggesting that red foxes in the Simpson Desert need to roam over extensive areas to find enough resources to meet their energetic needs. Given that predation by red foxes poses a key threat to many small and medium-sized native mammals, we suggest that red fox control operations may need to be undertaken at very large spatial scales to be effective in arid areas.

Additional keywords: invasive species, mesopredator, spatial ecology.

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Introduction

Red foxes (*Vulpes vulpes*) were introduced into mainland Australia by humans following European settlement in 1788, and by the 1940s they had colonised about two-thirds of the continent (Saunders *et al*. 1995). They are considered a significant agricultural pest because they depredate livestock, particularly sheep (Lugton 1993; Molsher *et al*. 2000). Red foxes also prey on a variety of native species (Glen *et al*. 2006), and they have contributed to the declines and extinctions of a suite of medium-sized (450–5000 g) mammals, ground-nesting birds and turtles (Dickman 1996).

Because of the deleterious impacts that red foxes inflict, they are often subject to control by humans (Greentree *et al*. 2000; McLeod *et al*. 2010). However, red foxes remain populous in many regions despite intensive and extensive management efforts to control them (Newsome *et al*. 2014). Carter *et al*. (2012) argued that information on home-range size can be used to determine whether control efforts for the red fox are employed at an appropriate spatial scale. However, despite being the subject of intensive ecological studies (Saunders *et al*. 2002), red fox home-range sizes have been quantified in relatively few studies, and some systems are greatly under-represented (Moseby *et al*. 2009; Carter *et al*. 2012).

In particular, only two published studies have quantified red fox home-range sizes in arid regions of Australia. These include Moseby *et al*. (2009), who provided data on the home-range size of one male and two female red foxes in South Australia, and Burrows *et al*. (2003), who provided data on the home-range size of one male red fox in Western Australia. In those studies, red fox home-ranges varied from 830 ha to 3322 ha based on the 95% Minimum Convex Polygon (MCP) method. These home-range sizes are the largest recorded in Australia according to reviews by Moseby *et al*. (2009) and Carter *et al*. (2012), although post-dispersal areas up to 7690 ha have been reported recently from GPS-collared red foxes in remnant forest habitats in New South Wales (Towerton *et al*. 2016). Nonetheless, our ability to make management decisions based on home-ranges recorded in arid regions is limited because red foxes have been sampled in only two locations, and arid regions in Australia do differ greatly in terms of landforms and climatic conditions.

In this research note, we begin to fill this knowledge gap by providing home-range sizes for three red foxes that were tracked in a spinifex sand plain region of the Simpson Desert, central Australia. The region exemplifies the definition of arid, receiving, on average, ~300 mm of rainfall per year. The three red foxes were tracked during a period when conditions were extremely

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harsh. Indeed, in the year preceding this study the region received only ~160 mm of rainfall, and during the study there were no major rain events (Bureau of Meteorology 2016). The fact that we were able to collect data on red foxes during this period was extremely fortuitous: virtually nothing is known about the movements of red foxes during extreme drought conditions in arid Australia.

Methods

In April 2014 in the Simpson Desert, central Australia (23°16′S, 138°17′E), one male and three female red foxes were caught with #1.5 Victor Soft-Catch rubber-jaw, leg-hold traps (Oneida Victor Ltd, OH, USA) baited with lures (mainly red fox urine). The trapping was undertaken over an eight-day period and involved setting up to 21 leg-hold traps ~500 m apart on the edge of a dirt vehicle track. All traps were fitted with swivels attached to a chain tethered to a heavy log. Traps were set each afternoon and checked at first light the next morning. Upon successful capture, red foxes were restrained using a ketch-all pole (1.8-m-long pole with an adjustable noose at one end; Ketch-all, CA). They were then placed on a holding board with straps fitted around the waist, shoulder and neck. All red foxes caught were weighed, sexed and inspected for trap-related injuries. One of the female red foxes had chewed its foot and was therefore killed. No other injuries were apparent on the other three red foxes. Collars that housed an ARGOS transmitter (Sirtrack, Havelock North, New Zealand) were fitted to these animals. All of the collars had a thin leather insert that would degrade over time and thus allow the collar to drop off.

The ARGOS collars were programmed to transmit to a satellite at least one fix (location) every 24 h between 20 : 00 and 02 : 00 hours. This fix rate was chosen to maximise the amount of time the collar remained on the animal; a more intensive transmission rate would have drained the battery more quickly. Fixes were obtained at night when red foxes are typically most active (Saunders *et al*. 1995). The ARGOS system was chosen because it allowed for remote collection of data via an online platform.

The ARGOS data were downloaded via the online platform at least every 21 days. The ARGOS system provides a quality estimate for each fix based on a radius of error. For each 24-h period we selected the fix with the lowest radius of error and excluded the others. We also excluded data where no radius of error estimate was given. Furthermore, we visually assessed the location of fixes that had a radius of error >1.5 km. We excluded fixes that were well away (typically >5 km) from the other fixes retrieved.

For each red fox we estimated a home-range size using the 100% MCP and 95% MCP method, as well the 95% kernel contour and 85% kernel contour method. We chose these metrics so that comparisons could be made with other studies that have estimated red fox home-ranges. The MCPs were estimated using the software Home Range Tools ver. 2.0 (Rodgers *et al*. 2015). The kernel contours were estimated using the software Geospatial Modelling Environment (Beyer 2014). We used a fixed kernel rather than an adaptive kernel, as the latter may overestimate home-range size (Seaman and Powell 1996). We also used the least-squares cross-validation method for the smoothing as it performs well on a range of data distributions, and it provides the least-biased estimates of the 95% home-range area (Seaman *et al*. 1999). Finally, for discussion purposes, the travel paths of each animal were mapped by joining consecutive fixes with a straight line using GIS software (ArcMap ver. 10.1, Environmental Systems Research Institute Inc., Redlands, CA, USA).

Results

Home-range sizes were calculated for the three red foxes fitted with ARGOS collars (Table 1). Female 1 had a very large home-range compared with the other two red foxes (Fig. 1). However, the movement path of Female 1 suggests that the animal undertook an exploratory foray for a distance of over 20 km before eventually dying or dropping her collar (Fig. 2). This stands in contrast to Female 2 and Male 1 that generally lived within a core area for the duration of the tracking (Fig. 2). Although large numbers of fixes were obtained for each individual (Table 1), the total number includes duplicates and fixes with large radiuses of error (Table 1). On the basis of the exclusion criteria, there was generally one fix for each 24-h period that was eligible for inclusion in the home-range estimates, leading to many fewer fixes being used.

Discussion

The three red foxes tracked in the Simpson Desert had much larger home-range sizes than any previously recorded in the arid zone, or elsewhere, in Australia. The largest home-range was that of Female 1, which had a 95% kernel home-range about eight times larger than the largest previously recorded by Moseby *et al*. (2009), and ~10 times larger than that recorded by Burrows *et al*. (2003). In other regions of Australia red fox home-range sizes are usually much smaller. For example, Saunders *et al*. (2002) tracked 59 female and 96 male red foxes in a temperate agricultural area in New South Wales, and found that 95% MCP home-ranges ranged from 309 to 428 ha and 186 to 723 ha, respectively. Similar-sized home ranges have been recorded in

Table 1. Home-range and tracking attributes of red foxes studied in the Simpson Desert, central Australia

ID	Date collared	Last fix	Days	Fixes	Used	MCP (ha)		Kernel (ha)	
						100%	95%	95%	85%
Female 1	22 April 2015	19 June 2015[A]	58	1798	58	50 158	41 207	26 954	16 677
Female 2	22 April 2015	9 December 2015	231	2996	209	12 481	8726	12 142	8068
Male 1	26 April 2015	25 December 2015	243	2617	220	5723	3967	3930	2626

[A]Female 1 was presumed dead or to have shed her collar after 19 June 2015 because all additional fixes received for the five months after this were derived from within a 2-km radius. Female 1 also undertook an exploratory foray before 19 June 2015 (see Fig. 2), and before this had a 100% MCP home-range of 8127 ha.

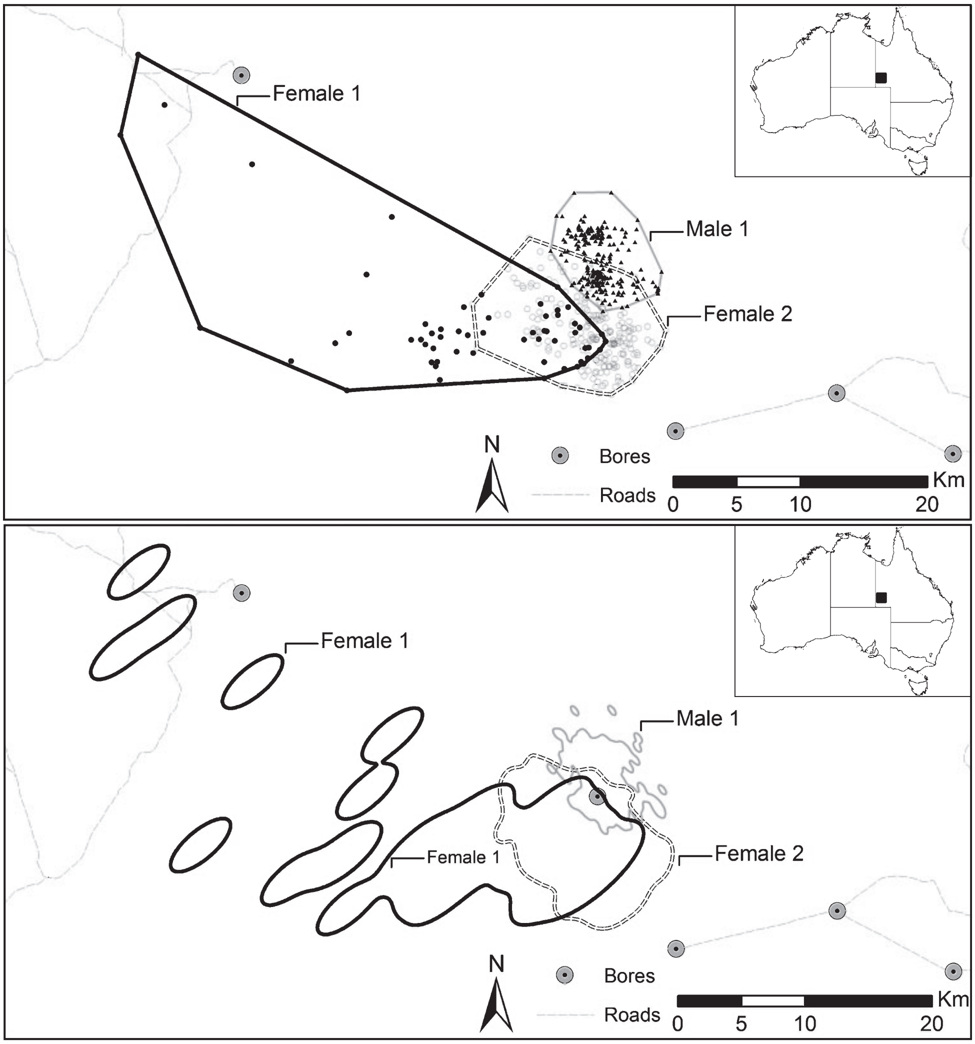

Fig. 1. 100% Minimum Convex Polygon home-ranges (top) and 95% kernel contour home-ranges (bottom) for three red foxes fitted with ARGOS collars in the Simpson Desert, central Australia. Free-standing water was not available at the bores during the study period.

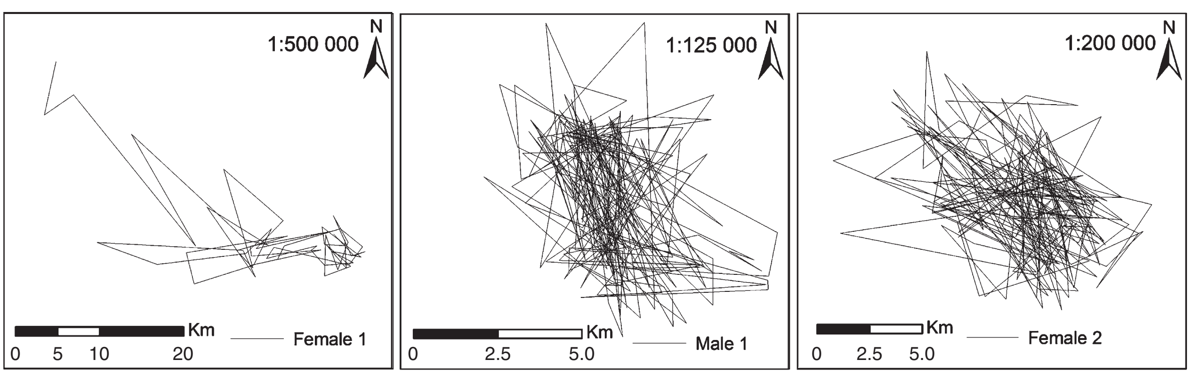

Fig. 2. Movement paths for three red foxes fitted with ARGOS collars in the Simpson Desert, central Australia. Scales are different on each map to aid visual interpretation.

coastal regions (Phillips and Catling 1991), while slightly smaller home ranges were documented in semiurban and urban areas (Marks and Bloomfield 2006). The largest home-range areas outside arid regions were reported by Towerton *et al*. (2016) from remnant forest in central New South Wales. Here, 95% MCP home ranges averaged 420 ha for VHF-tracked red foxes and 4462 ha for GPS-tracked animals.

Home-range areas in carnivores, and in red foxes in particular, are often governed by the dispersion of resources (Macdonald 1983). Large home ranges often reflect poor-quality, widely dispersed resources, whereas small ranges are more likely to occur where resources are rich and densely packed. Because of the very dry conditions that prevailed during the course of our study, resource availability was probably low and animals had to range far to meet their resource requirements. Towerton *et al*. (2016) invoked a similar explanation to account for the relatively large ranges that they recorded, although consistently high levels of imposed mortality from poison baiting in that study may also have contributed to the results.

On the basis of the movement path of Female 1, this individual undertook a large exploratory foray 53 days after capture (Fig. 2). As this foray was undertaken well after capture, it is unlikely that it was associated with capture stress. However, the likely death (or possibly dropped collar) of Female 1 on day 58 suggests that the foray may have been related to this event. Long-distance movements by red foxes have been recorded previously. Carter *et al*. (2012) recorded a male red fox moving 10 km in a single evening. Similarly, Meek and Saunders (2000) recorded multiple forays by red foxes, including a male red fox that moved 3 km from the outer limits of its home-range and a female red fox that moved over 10 km. Most of the forays recorded by Meek and Saunders (2000) were for a few hours, or for one or two days at a time, although the female that moved over 10 km established a new home-range area for a few months before returning. The foray by Female 1 herein lasted at least five days and went for a distance of at least 20 km from the main areas of previous activity (Fig. 2).

It is not known whether the foray by Female 1 was a dispersal event away from a core home-range area, but red foxes commonly undertake dispersals. For example, a global review by Trewhella *et al*. (1988) found that red foxes disperse distances of up to 346 km, with an average dispersal distance of 20.79 ± 0.98 km. Red foxes are also known to drift their territories in the order of 30–40 ha per year (Doncaster and Macdonald 1991), and they can rapidly fill vacated territories (Meek and Saunders 2000; Newsome *et al*. 2014). Further investigations are required to determine whether red foxes in the Simpson Desert exhibit similar behaviours.

Both Female 2 and Male 1 remained in core home-range areas for the tracking period (Fig. 2). Despite displaying such behaviour, these red foxes maintained relatively big home-ranges, with 95% kernel estimates of 12 142 ha and 3930 ha, respectively. Further, while the calculated home-range size of Female 1 was influenced by the foray, before this dispersal the animal still displayed a sizable 100% MCP of ~8127 ha (Table 1). The large home-range estimates may be related to the technology used, because ARGOS fixes are not as accurate as GPS fixes. However, the ARGOS system does provide a radius of error associated with each fix, and we excluded fixes where no radius of error was provided and for fixes with a radius of error greater than 1.5 km we visually inspected each of these and excluded outliers. At the end of this process each red fox had less than eight fixes with a radius of error greater than 1.5 km, and in each case these fixes were located right next to other fixes. Thus, excluding these fixes would have had little bearing on the results. As such, we are confident that our data reflect the movements of the red foxes collared. Indeed, our sample sizes for all red foxes tracked were greater than the minimum recommended by Seaman *et al*. (1999) for calculating kernel density estimates (>50 fixes).

Red foxes have been implicated in the demise of a suite of small to medium-sized native species in Australia (Dickman 1996; Woinarski *et al*. 2015). As such, considerable research effort is dedicated towards developing effective control strategies (e.g. Thomson *et al*. 2000). It is generally accepted that red fox control needs to be undertaken using a coordinated approach at large spatial scales (McLeod *et al*. 2010), and home-range size data can help to determine the appropriate scales (Carter *et al*. 2012). Our data suggest that this scale needs to be very large in arid Australia. Indeed, to cover the area over which the three red foxes roamed in the Simpson Desert the control program would need to cover at least 70 000 ha. However, targeted control may be possible around focal areas of activity such as roads and bores. Unfortunately, the sampling rate and accuracy of our data limited our ability to define focal areas of activity, but the data have nonetheless provided insights into the large ranges of red foxes in the Simpson Desert.

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