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Study of seed dispersal by Emu (*Dromaius novaehollandiae*) in the Jarrah (*Eucalyptus marginata*) forests of south-western Australia through satellite telemetry

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Abstract

Global positioning system (GPS) technology for tracking wildlife continues to evolve at a remarkable pace. As animal movement is increasingly recognised as being critical for several ecological processes, advanced telemetry technology permits collection of a high volume of data across short time intervals that was previously unobtainable. Here we describe the use of GPS telemetry to track the movements of five tagged Emus (*Dromaius novaehollandiae* Latham) released within the Jarrah (*Eucalyptus marginata* Sm.) forests of south-western Australia. The Emu plays a significant role as a seed disperser for many species. Describing the movement patterns of this species is a key requirement in refining the extent and significance of its contribution to seed dispersal, both locally and over long distances. We found that Emus followed a typical correlated random walk pattern and that each bird demonstrated a variable response to the landscape in terms of behaviour, extent of movement and habitat selection. From a methodological perspective, 50% of our devices detached before 30 days of GPS locations could be collected, reflecting a need for device refinement for future studies on large ratites. Nevertheless, our preliminary data provide useful insights into the movements of the Emu and potential impacts on seed dispersal within the Jarrah forests.

Introduction

The Emu (*Dromaius novaehollandiae* Latham) possesses unique traits that make it a key seed dispersal agent, particularly within the Jarrah (*Eucalyptus marginata* Sm.) forests of south-western Australia, where up to 22% of the flora has developed vertebrate dispersal mutualisms (Willson *et al.* 1990). The Emu is also an important non-standard dispersal agent for plants that have not evolved traits for dispersal by frugivores, as it ingests seeds of many species with various dispersal morphologies (Calviño-Cancela *et al.* 2006, 2008). Seed dispersal is fundamentally important for plant demography and some key ecological processes driving the dynamics of communities and ecosystems (Howe and Smallwood 1982). Dispersal of seeds is the primary process of movement during the life-cycle of plants, leading to establishment of next-generation individuals both near and far from parents (Nathan 2006).

Seed dispersal is typically characterised by dispersal kernels, which are one-dimensional probabilistic curves that describe the likelihood of a quantity (or proportion) of seed material being dispersed a given distance (Morales and Carlo 2006). To generate such kernels for frugivore dispersal, a general model of dispersal needs to be constructed, which requires either empirical or mechanistic understanding of seed load, gut retention times and displacement velocity (movement) (Nathan *et al.* 2008; Tsoar *et al.* 2011). These important elements, as they relate to the Emu, have been dealt with in some complexity and detail in the literature: the diet of the Emu has been extensively studied, and the ability of the Emu to consume large amounts and variety of seed material is well known (Noble 1975; Davies 1978; Quin 1996; Davies 2002; Dunstan *et al.* 2013). The Emu can deposit large quantities of seed in a single scat (~1220 medium-sized seeds, primarily from the Ericaceae, per 100 g of scat material: A. Nield, unpubl. data), a common observation for large frugivores (Howe 1989; Bradford and Westcott 2010). The retention of material within the gut of the Emu has also been

examined. Davies (1978) reports some seed material passing through the gut in as little as 3 h, with retention times ranging between 4 and 48 h for material consumed at the same event. Davies (1978) also reports some seed material being held for >100 days. Herd and Dawson (1984) report a mean gut retention time (GRT) of 5.5 h for the solid phase of fibrous material digested, and Willson (1989) reports GRTs for the consumption of pseudoseeds of 1–2 days. Allometric estimations of GRT from body size (Robbins 1993) suggest a mean GRT of ~5 h. Although mean estimates of gut retention time may appear relatively short, it is the rarer events, held within the gut for sustained periods, that contribute to long-distance dispersal, which is a key driver of plant population dynamics (Nathan 2006).

The final component of a general model to describe seed dispersal, animal velocity/movement, has not been previously investigated in detail as it applies to the Emu. Although allometric means are available to describe animal velocity (Calder 1996), system-specific empirical data are preferred where available. Davies *et al.* (1971) recounts the visual recapture of banded Emus moving through the arid and semiarid zones in Western Australia, suggesting that some birds are capable of moving many hundreds of kilometres over the course of a few months. However, this method lacks sufficient spatio-temporal detail, with many weeks passing between observations. While general descriptions of Emu behaviour also exist (Curry 1981; Patodkar *et al.* 2009), no study to date has used modern and emerging technologies to elucidate the patterns of Emu movement and behaviour. The use of new animal-tracking technologies, particularly for other ratites, has already been invaluable in understanding individual behaviours, habitat preferences and facilitating conservation management (Campbell *et al.* 2012).

The use of GPS telemetry to describe the behaviours of ratites is an emerging field of investigation in animal ecology (see Campbell *et al.* 2012). GPS telemetry, when combined with advanced animal movement analysis software (Calenge 2006; Calenge *et al.* 2009) permits detailed investigation of fine and landscape-scale movements and the feedbacks between habitat selection and general behaviours.

The aim of this paper is to present the preliminary findings of a broader study of the movement ecology of Emu and seed dispersal in south-western Australia. We present a methodology for the satellite tagging and monitoring of captive Emus released into Jarrah forests. The initial displacement of released birds is discussed, along with implications for the understanding of the role of the Emu as an important seed-dispersal agent.

Materials and methods

Study site

Emus were released into the Avon Valley National Park (31.63°S, 116.19°E) and contiguous Moondyne Nature Reserve, ~50 km north-east of Perth, Western Australia. Numerous Emus occur in the area, as evidenced by scat (A. Nield, unpubl. data) and visual observations. The Avon Valley lies at the northern end of the Darling Scarp on the transition between the northern extent of the Jarrah forest and the drier Wandoo forest (*E. wandoo*), the former associated with lateritic hill tops and ridges, and the latter with the clay/loam soils of lower slopes and valleys (Department of Environment and Conservation: DEC 2012). The understorey vegetation is sparse, and consists of common shrub and subshrub species including *Xanthorrhoea preissii*, *Banksia sessilis*, *Grevillea bipinnatifida*, *Leucopogon nutans* and *Macrozamia riedlei*. The Avon Valley has a Mediterranean type climate, receiving a mean annual rainfall of 816 mm, largely confined to the winter months (June–August; Lower Chittering meteorological station, 31.61°S, 116.11°E, Bureau of Meteorology: BOM 2014).

Satellite tracking

We sought to characterise Emu activity by following the movements of individual birds using global positioning system (GPS). The design and implementation of the study was carried out in accordance with guidelines by the National Health and Medical Research Council (2013). It was not feasible to capture wild birds in Jarrah forest for GPS-tracking owing to their elusive behaviours, speed and

resistance to anaesthetics (T. Oldfield, pers. comm.). A pilot trial was conducted at the Clackline Free Range Emu Farm near Toodyay, Western Australia, on two captive birds from December 2012 to February 2013 to ensure the efficacy of the attachment cuff, that Emu movement and behaviours were not impeded, and that the cuffs did not cause injury or irritation. Birds at the farm were free to roam around large fenced paddocks and forage for food from native vegetation as well as supplementary stock feed. GPS tracking devices were custom-made by Telemetry Solutions, USA following a design used on another large ratite, the Southern Cassowary (*Casuarius casuarius*) (Campbell *et al.* 2012). The total weight of the GPS-tracking unit and attachment cuff was 310 g, <1% of the weight of the adult birds used in the study. Tracking cuffs were secured above the ankle joint using non-UV-resistant tie-wraps, designed by the manufacturers to degrade and detach within 1 year. Males weigh, on average, 31.5 kg and females 36.9 kg (Davies 1967). During March 2013, six birds were selected from the adult cohort at the Clackline Free Range Emu Farm for the study. The birds were transported in a custom-designed Emu trailer and released into the Avon Valley National Park area in south-western Australia, an area of typical Jarrah forest. The entire tagging, transport and release process was overseen by a consultant avian veterinarian. The six birds used in the study were not sexed at the time of GPS attachment due to the difficulty of sex determination and to minimise the time taken to physically restrain the birds. Attempts to sex the birds via their calls (following Curry 1981) were unsuccessful.

The GPS download schedule varied from short intervals (data collected every 15 min) to long intervals (data collected every hour) as a trade-off between resolution of movement information and battery conservation. Expected battery life is ~18 months. The GPS tracking unit contained both a VHF transmitter for locating the birds and a UHF transmitter for data transfer. Each device contains a unique VHF frequency so that individual birds could be tracked via the use of an antenna (we used a simple 3-element Yagi mounted on a vehicle).

Data analysis

We used the 'adehabitatLT' package (Calenge 2006) within R (R Core Team 2012) to examine the trajectories for each of the tagged birds. For each of the birds, individual trajectories were split into

'bursts' for analysis (Calenge 2006). Bursts represent diurnal movement during which regular relocations (GPS positions) of individual birds were recorded. Each burst approximately correlates with one day. Only regular bursts of trajectories were analysed, i.e. where the same period (generally 1 h) passed between GPS fixes. For each burst within a bird's overall trajectory, we used a 'runs' test with 500 replications to detect potential autocorrelation of missing relocations (Calenge *et al*. 2009). We present the mean-squared displacement between consecutive moves (R_n^2) to describe the distance travelled between successive relocations (Kareiva and Shigesada 1983).

The number of relocations within each habitat type were calculated to provide a proportional indication of the time spent within each area. Habitat was classified as either forest, agricultural land, edge (within 50 m of forest/farm edges) or road (on or within 25 m of unsealed roads). The approximate area of each habitat type within the convex hull of all GPS locations was also determined.

Using the movement data pooled across each bird, the straight-line distance between the last evening GPS point (1830 hours) and the first morning GPS point (0630 hours) point was calculated. The first and last GPS points taken during the day reflect the approximate sunrise and sunset times for the Avon Valley National Park during the period for which GPS data were collected.

Results

Six emus were tagged, transported to Avon Valley National Park and released. One of the six GPS tracking devices detached from the attachment cuff during transportation. Two GPS units detached ~2 weeks after field deployment (Emu 4 and Emu 5, see Table 1). These two GPS devices were retrieved from the field and movement data downloaded. Damage to the cuff and location of the find indicated that the units detached after becoming caught on farm fences. The attachment of the devices above the ankle joint provided reasonably accurate GPS fixes, with 6 (± 1; 95% CI) satellites used, on average, per location. The horizontal dilution of precision (HDOP) for most GPS fixes was <2 (Table 1).

Table 1. Number of relocations (GPS positions) following the initial release of five Emus into Avon Valley, Western Australia

'NA dist' refers to the distribution of missing values during *n* bursts for each trajectory. The horizontal dilution of precision (HDOP) for each bird is also shown. Numbers in parentheses are the 95% CI

	n relocations	Start	Finish	NA dist	*n* bursts	HDOP
Emu 1	374	27.iii.2013	25.iv.2013	Random	33	1.7 (±0.1)
Emu 2	663	27.iii.2013	13.v.2013	Random	60	1.9 (±0.1)
Emu 3	611	27.iii.2013	13.v.2013	Random	53	1.9 (±0.1)
Emu 4	283	27.iii.2013	13.iv.2013	Random	20	1.8 (±0.2)
Emu 5	199	27.iii.2013	13.iv.2013	Random	17	1.7 (±0.1)

During the first few weeks, each of the birds moved different distances from the release site (Fig. 1). After the first week, Emu 4 had moved ~8 km from the release site and Emu 5 ~6 km, while the other birds remained within 2 km of the release point. Over the first two weeks, each bird was observed on several occasions to ensure that the GPS cuff did not impede movement or visibly affect behaviour. As in the pilot trial, the birds showed no obvious signs of discomfort and all were observed standing, walking, running and foraging. Each bird was also observed foraging close to wild Emus in the area.

The movement trajectory of each bird was distinct (Fig. 2). The trajectories also show that the birds readily moved between different habitat types. The convex hull of the GPS points encompassing the movement of all birds was ~75 km^2. Within this area, 75% of the landscape was forest (primarily Jarrah forest, with small pockets of *Eucalyptus wandoo*), 22% agricultural, 2% forest edge and 1% roads (Table 2). There was clear evidence that the birds followed fence lines that divide the Avon Valley forest remnants and the surrounding mosaic of agricultural land. In all, 23% of the GPS locations were recorded either on roads/along fence lines or in Jarrah forest within 500 m of farm land. Birds remained mostly within the forest (41% of GPS points were recorded in the forest habitat),

but also visited permanent water sources on neighbouring farms. Four of the five tagged Emus showed a general trajectory bias in their movements, favouring a north-east path. Steep slopes and deep valleys were avoided and no bird entered the valley through which the Avon River flows.

Fig. 1. Mean squared displacement (MSD) derived from five birds tagged and released into the Avon Valley National Park, Western Australia.
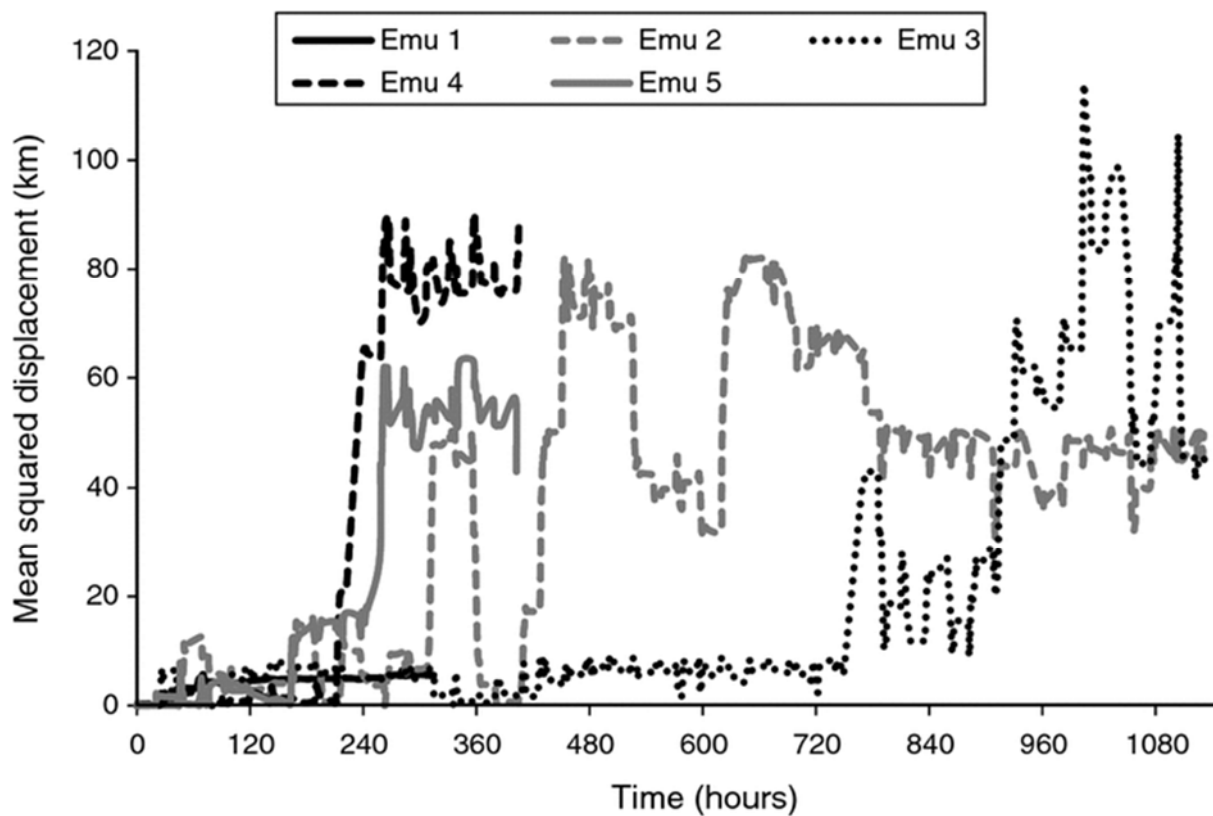
Nocturnal movement was minimal, with the median step-length during the nocturnal period (1830 hours to 0630 hours) 13 m^{h-1} (±6). Comparatively, the median step-length during the diurnal period was 150 m^{h-1}(±20).

Fig. 2. Movement trajectories of five emu released into the Avon Valley National Park, Western Australia, during the first month of the study. (*a*) Emu 1, (*b*) Emu 2, (*c*) Emu 3, (*d*) Emu 4, and (*e*) Emu 5. The triangles and squares indicate the start and end of the trajectories respectively.
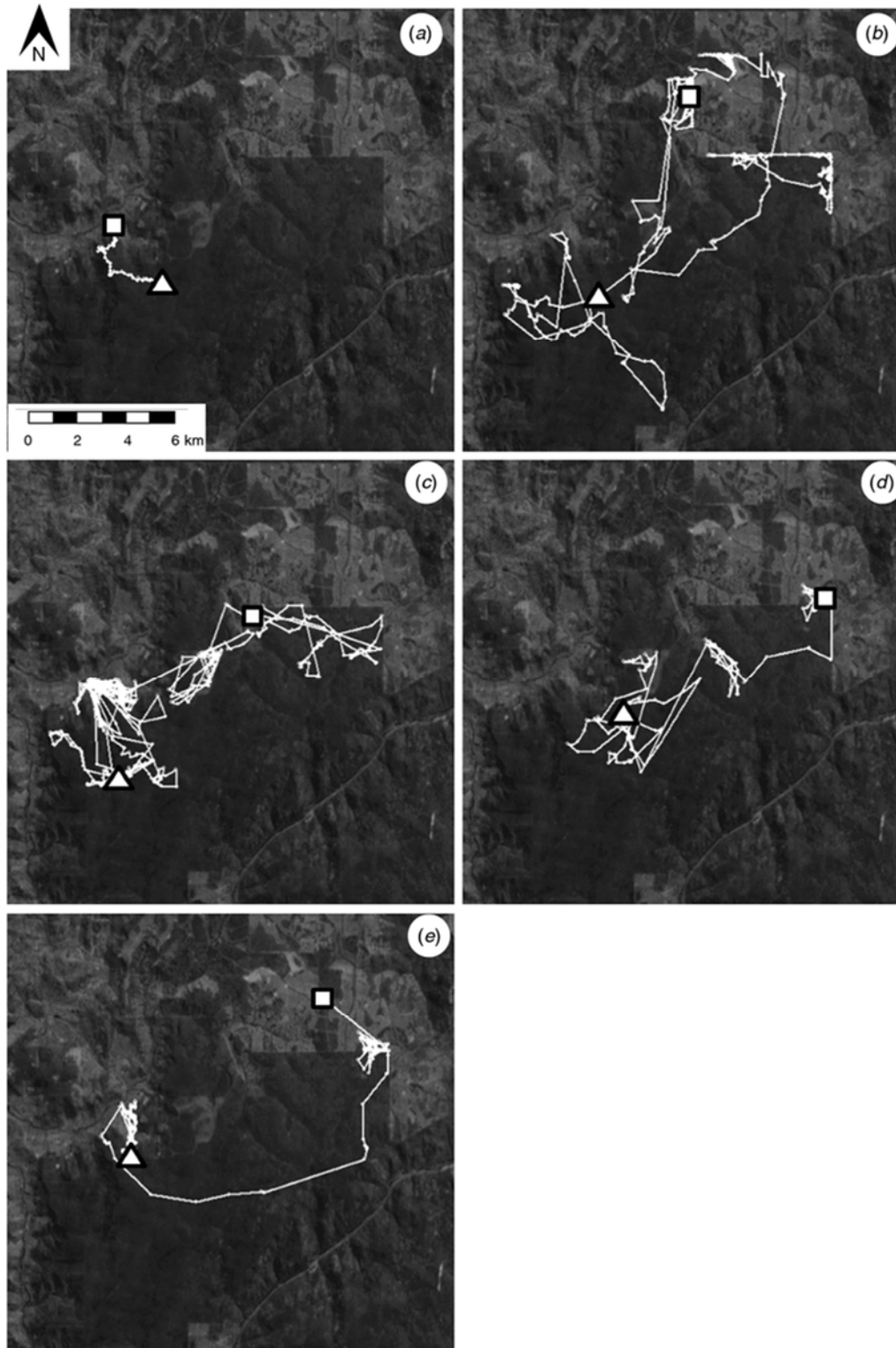
Table 2. Percentage of GPS fixes recorded for Emus in different habitat types classified in Avon Valley, Western Australia

Also presented is the percentage habitat type cover estimate calculated from the convex hull of all GPS points. Numbers in parentheses indicate 95% CI. Total area is ~75 km^2

Habitat	% habitat cover	Emu 1 (%)	Emu 2 (%)	Emu 3 (%)	Emu 4 (%)	Emu 5 (%)	Overall
Forest	75	13	45	54	59	32	41%±(16)
Agricultural	22	67	2	24	26	10	26%±(12)
Edge	2	19	25	9	8	52	23%±(16)
Road	1	1	28	13	7	6	10%±(9)

For each bird, there were periods during which the mean squared displacement (MSD) distance did not substantially increase over time (Fig. 1). This indicates periods of local foraging, where birds travel short distances over an extended period (many hours) and is notably different from those periods where MSD increased sharply over short time scales, when the birds were generally migrating between foraging locations. This general behavioural split between local foraging and broader-scale migration is seen in the individual bird trajectories.

Discussion

We describe here the preliminary findings of the application of GPS telemetry to captive (semihabituated) Emus released into natural bush to better understand their movement ecology as it relates to seed dispersal of large-seeded species of Jarrah forests.

Our preliminary data highlight the utility of GPS telemetry to elucidate the movement ecology of a large ratite, whose movement potential had only previously been described from traditional bird-banding methods, with weeks or months passing between observations (Davies *et al*. 1971).

While Davies *et al*. (1971) provides interesting insights into general Emu ecology, they do not provide

enough quantitative detail to be readily used in models of seed dispersal. Seed dispersal is a critical process in the lifecycle of plants and has the potential to shape the distribution and structure of populations (Levine and Murrell 2003). Moreover, the spatial patterns of seed dispersal and recruitment are increasingly recognised as paramount to plant population dynamics (Nathan and Muller-Landau 2000). Without fine-scale data on the movement of the Emu, or indeed any significant dispersal agent within a system in which strong seed dispersal mutualisms exist, it is difficult to quantify the impact of the agent on dispersal.

The Emu is already known to be a potentially important dispersal agent for species that have endozoochorous dispersal morphologies, as well as for those that do not have adaptations for dispersal by frugivores (Calviño-Cancela et al. 2006). The Emu's generalist diet (Dunstan et al. 2013) makes it an ideal general seed disperser, and likely contributes to the demography of many species. Although the outcome of seed passage is equivocal for fruits consumed by many ratites, with some species benefiting from ingestion while others suffer reduced seed viability, the sheer volume of material consumed makes these large birds very important for seed dispersal (Noble 1975; Bradford and Westcott 2010).

We observed unique trajectories for each of the released birds and the GPS tracking data shows that movements, at some scale, are generally consistent with correlated random walks (Bovet and Benhamou 1988). It is important to note that while some interest has developed in the application of Lévy walks (Viswanathan and Afanasyevt 1996) to animal movement data to describe the pattern of movement (Benhamou 2007; Reynolds 2008), it is not our aim here to assess the utility of the various movement models. Seed rain pattern, the spatial fingerprint of the seed-dispersal process by frugivores, is impacted by seed-dispersal distances (movement following ingestion), disperser activity and the habitat structure within the landscape (Rodríguez-Pérez et al. 2012). Our data highlight the fine-scale responses to the landscape that individual frugivores demonstrate, and that may have an important impact on seed rain and subsequent plant population dynamics. Habitat preference by frugivores has been shown to vary with scale, with local preference given to resource-rich areas that promote foraging behaviours, though these local preferences become diluted at a landscape scale

when environmental conditions (e.g. steep slopes/impassable areas) preclude or limit access (Rodríguez-Pérez *et al*. 2012).

Overall, we found that tagging Emus with GPS telemetry devices similar to those used by Campbell *et al*. (2012) for the Cassowary was, at least in the short term, an effective telemetry method for collecting movement data. However, we caution the use of the method of attachment for long-term investigations on animal movement. Within the first month we lost 50% of our devices, with one detaching during transport and two others being removed, presumably after being caught on a fence. As our devices were designed to detach after 12 months of use through UV deterioration and wear and tear, our conservative method of attachment to ensure no harm per our ethics requirements may have contributed to the early loss of these devices. Nevertheless, we have captured preliminary data on the movement of Emus within the Jarrah forests of south-western Australia to a level of detail that has not been described before. The movement of these birds over short periods has been shown to be substantial and, considering their potentially large gut retention times, underscores the important role they play as a seed-dispersal agent for many plant species.

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