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Post-fledging spatial use by a juvenile Wedge-tailed Eagle *Aquila audax* using satellite telemetry

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Despite considerable knowledge on aspects of the ecology of the Wedge-tailed Eagle *Aquila audax*, information on home range size has been limited to estimates based on visual observations and nesting densities. This study aims to provide a methodological and theoretical framework for the potential applications and recommendations for the use of satellite tracking to research eagles. In November 2012 a juvenile Wedge-tailed Eagle was captured soon after fledging and released with a GPS (Minitrack™) tracking unit fitted via a backpack style harness. The unit was scheduled to take location fixes at 90-minute intervals between 0530 and 2200 hr. Location data from the eagle's first six weeks post-fledging were analysed using the minimum convex polygon (MCP) and fixed kernel methods and showed that, over time, there was a significant increase in area used and distance travelled per day. This study, the first time a Wedge-tailed Eagle has been satellite tracked for research, serves as a pilot study.

INTRODUCTION

The Wedge-tailed Eagle *Aquila audax* is common throughout the Australian mainland, despite heavy persecution up until the late 1970s (cf. Leopold and Wolfe 1970) and plays an important ecological role as a top predator and scavenger. The Wedge-tailed Eagle may be Australia's most researched bird of prey (Fuentes *et al.* 2007). Courtship and territorial displays, hunting behaviour and diet of this eagle have been well documented mainly by direct observation (Leopold and Wolfe 1970; Brooker 1974; Olsen *et al.* 2006a; Olsen *et al.* 2006b; Debus *et al.* 2007; Fuentes *et al.* 2007; Olsen *et al.* 2010).

Knowledge of Wedge-tailed Eagle ranging behaviour has previously been limited to breeding birds, based on estimates from visual observations and nesting densities (cf. Leopold and Wolfe 1970; Ridpath and Brooker 1987; Robertson 1987; Sharp *et al.* 2001). However, using these techniques to interpret home range or density estimates can often be misleading due to observation bias, that is, the quality of the data depends on the amount and timing of research effort and the accuracy of the observation (Village 1982; Gargett 1990; Olsen and Fuentes 2005). Brooker (1974) was able to utilise radar to track Wedge-tailed Eagles from Carnarvon Tracking Station; however, this was limited to in-flight observations only. Radio tracking has been recommended (Olsen and Osgood 2006; Olsen *et al.* 2008) as a method that can be used to more accurately determine the home range size and habitat use of raptor species.

An alternative method for tracking Wedge-tailed Eagles involves using transmitters with embedded Global Positioning Systems (GPS), which have recently become small enough to attach to birds (Meyburg and Fuller 2007). These data are collected via satellite and can be used to provide information on the spatial patterns and habitat use which would otherwise be impossible to obtain with accuracy (Meyburg and Fuller 2007). Additional advantages of satellite tracking includes minimising disturbance to the individual (thereby minimising the risk of influencing the subject's movement and behaviour), and reducing time in the field by the researcher.

There are many examples of studies utilising satellite telemetry on *Aquila* species (cf. Meyburg *et al.* (2000) for the Lesser Spotted Eagle *Aquila pomarina*; Meyburg *et al.* (2005) for the Greater Spotted Eagle *A. clanga*; McIntyre and Collopy (2006) for the Golden Eagle *A. chrysaetos*, and Pérez-García *et al.* (2013) for Bonelli's Eagle *A. fasciata*); however, a notable omission is that of Australia's own *Aquila*, the Wedge-tailed Eagle (Debus *et al.* 2007). Utilising this technology has the potential to fill numerous gaps in knowledge on factors such as juvenile dispersal, survival and recruitment, social organisation, and home range size, habitat use and territorial interactions (Marchant and Higgins 1993), which is important for the conservation management of the species.

Ridpath and Brooker (1987) estimated home range size of Wedge-tailed Eagles in the arid zone of Western Australia by dividing the area searched by the number of known adult pairs. Their research estimated territory size at around 50 square kilometres in the dry west coast region, and 32–103 square kilometres in dry southern inland regions of Western Australia. An early estimate of Wedge-tailed Eagle home range size in the eastern highlands (near Canberra) was 28–32 square kilometres (derived from Leopold and Wolfe 1970), based on nesting density (Ridpath and Brooker 1987; Sharp *et al.* 2001). It is important to recognise, however, that there is likely to be a discrepancy between the size of an eagle's territory and home range, the latter of which encompasses the former.

Estimating home range size can vary depending on the method of calculation used (cf. Olsen *et al.* 2011). The two most commonly used methods to calculate home range size are the minimum convex polygon (MCP) (Mohr 1947) and the fixed kernel methods (Worton 1989), neither of which have been utilised in studies of the Wedge-tailed Eagle. The MCP is a method used to delineate the maximum area used by the individual (Mohr 1947). This method is sensitive to 'outliers', which may be encompassed in the 'occasional sallies' described by Burt (1943), potentially overestimating the home range size (Bosch *et al.* 2010). A second limitation is that the MCP assumes uniform habitat utilisation by lacking internal structure (Andersen *et al.* 1990; Kenward *et al.* 2001). The fixed kernel method is generally considered more accurate than the MCP at estimating home range size because it is less sensitive to outliers and allows different levels of spatial use within the home range to be identified (Elchuk and Wiebe 2003; Nilsen *et al.* 2008).

The post-fledging period is not well documented for several species of raptor (McIntyre and Collopy 2006). At the time of the summary of known information on the Wedge-tailed Eagle for The Handbook of Australian and New Zealand Birds (HANZAB) (Marchant and Higgins 1993), there was limited published information on Wedge-tailed Eagle behaviour in the post-fledging period (Allott *et al.* 2006). This was true at the time of publishing by Debus *et al.* (2007), and is still the case today. Studies in the Northern Hemisphere, however, have been advancing quickly through the use of satellite telemetry.

Soutullo *et al.* (2006a) used satellite tracking to report that juvenile Golden Eagles, once fledged, spent a brief period making restricted flights around the nest, gradually increasing the average distance of flights from the nest with time. O'Toole *et al.* (1999) also reported that juvenile Golden Eagles progressively increase distance from the nest once fledged, and Soutullo *et al.* (2006b) found that the area explored by juvenile Golden Eagles increased over time after fledging. Based on the findings of this literature, the following hypotheses were investigated in this study on a juvenile Wedge-tailed Eagle: (a) area explored (i.e. home range size) increases over time, and, (b) distance travelled per day increases over time.

This pilot study on the satellite tracking of Wedge-tailed Eagles aimed to provide a methodological and theoretical framework for use while contributing to the scientific knowledge on the post-fledging period of this species.

STUDY AREA

Satellite tracking was carried out in Mt Mugga Mugga Nature Reserve, Symonston, ACT, and from nearby roads (exact location withheld for security reasons). The nest used by the eagles in this study was located less than 200 metres from a road, less than 300 metres from an industrial quarry and 400 metres from the nearest residential house. A major road borders the northern edge of the site. The habitat at Mt Mugga Mugga and surrounds varies from dense eucalypt forest to open woodland with patches of rocky grassland. The dry forest community of the upper slopes consists of tall woodland with dominants of Scribbly Gum (*Eucalyptus rossii*), Brittle Gum (*E. mannifera*), Red Stringybark (*E. macrorhyncha*), some Red Box (*E. polyanthemos*) and Drooping She-oak (*Allocasuarina verticillata*); the lower slopes dominated by Yellow Box / Blakely's Red Gum (*E. melliodora* / *E. blakelyi*) woodland (National Capital Development Commission 1988). A ridgeline divides suburbia to the west and rural lease paddocks to the east. Elevation within the study area ranges between 600 and 813 metres above sea level.

METHODS

Harness and tracking unit

In November 2012 a juvenile Wedge-tailed Eagle was reported injured and was captured by hand by running it down and forcing it to repeatedly fly uphill. Just-fledged raptors are occasionally found on the ground (Olsen 2014). The eagle was assessed and found to be uninjured. It was released the following day fitted with a numbered and coloured metal leg band (Australian Bird and Bat Banding Scheme #150-40456, blue aluminium colour band with white numbers: 0 over 1) and a Minitrack™ GPS tracking unit (Sirtrack) weighing 70 grams fitted via a backpack-style harness. The unit had a built in VFH transmitter to allow the researcher to locate the young eagle using a hand-held Sirtrack three-element Yagi antenna and Titley's Australis 26k Scanning Receiver. A Handheld Command Unit was used to remotely download the data once within close proximity. The download process was slow and required the Handheld Command Unit to be within 500 metres of the tagged individual for more than a few minutes, thus limitations arose due to the challenge of staying in range of a wary eagle.

Harness design was based on that used by Steenhof *et al.* (2006) with modifications to the breast piece. The breast piece was constructed of a 10 millimetre wide ring cut from a sheet of five-ounce leather, of which four lengths of 14 millimetre wide Teflon ribbon were sewn through without being sewn onto the leather ring itself (Figure 1a). Each length of ribbon was secured from the breast piece to the Minitrack™ unit around the wings, as a backpack is worn (Figure 1b,c). The Minitrack™ transmitter was factory fitted with four attachment points for the Teflon ribbon (Figure 1d).

Our design made it possible for the entire transmitter and Teflon attachments to come away at once if the leather breast piece was broken in any place. The leather breast piece is designed to eventually break; either by natural forces or physical removal by the eagle, releasing the satellite unit (see Figure 1). The combined weight of the Minitrack™ unit and harness was 80 grams, representing 2.4 percent of the juvenile eagle's body weight, which was 3300 grams, a ratio of equipment to body weight within the range recommended by Sirtrack, and Kenward (2001) for birds.

Data set

The available GPS satellite units were accurate to less than 30 m (Thomas *et al.* 2011). Location fixes were programmed to be sent by the satellite unit at 90-minute intervals and not between 2200 and 0530 hrs, to extend transmitter battery life (expected to be approximately three months). Thus twelve location fixes per day were possible. In order to create even sample sizes for comparison, fixes recorded on the first and last day of data collection were excluded from analyses that have been subset into weeks, as these days did not have a full complement of fixes. Locations were plotted using the geographic information system ArcGIS v9.3.1. Home range estimates (area used) including minimum convex polygon and fixed kernel methods and distances traversed were calculated in ArcGIS using the Hawth's Tools application. All other analyses were carried out using the statistical package R v2.1 (R Core Team 2012). Differences were considered significant when $P < 0.05$. Analysis of variance (ANOVA) was used to compare the MCP and fixed kernel home range estimates.

To test the hypotheses, the MCP and fixed kernel methods were applied in a linear regression of home range size against time. It should be noted that the term 'home range' is loosely applied in the analyses presented in this study, as the juvenile tracked in this study was moving about in the home range of its parents, and would likely not be aware of any territory borders as such.

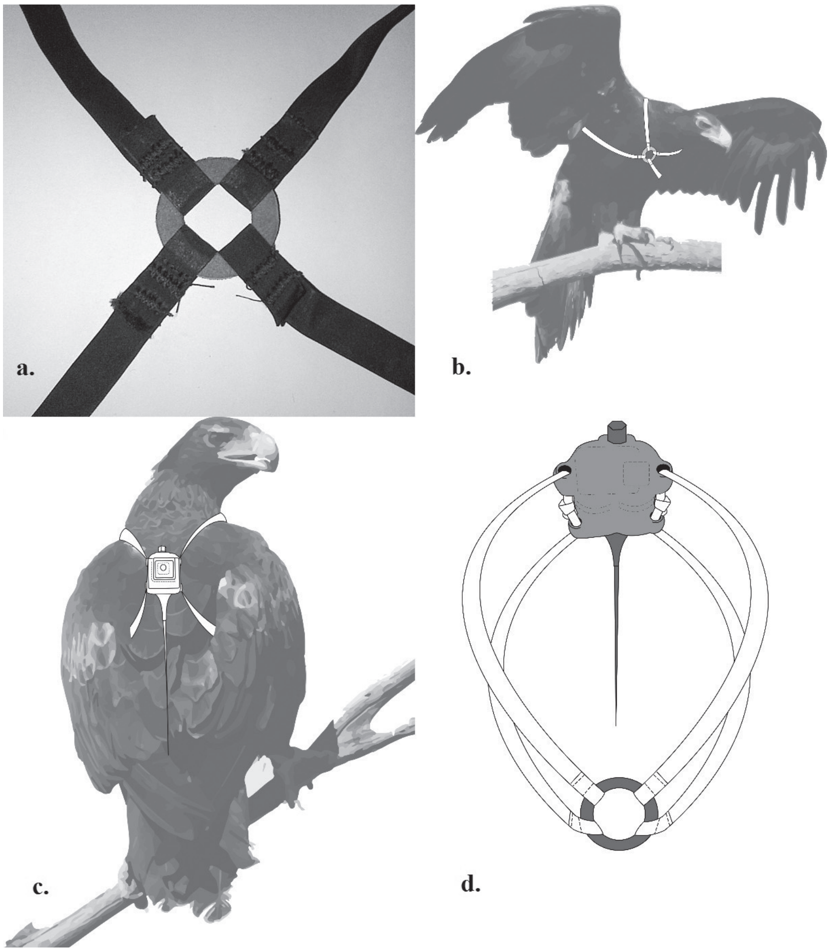

Figure 1. *(a) Harness breast piece constructed of a 10 mm wide ring cut from a sheet of five ounce leather; four lengths of Teflon ribbon (14 mm wide) are sewn through the loop without being sewn onto the leather ring itself; (b) front view; (c) rear view; (d) attachment of harness to Minitrack™ unit. Minitrack™ unit rests on the dorsal surface of the eagle between the bird's wings, antenna pointing rearward. Teflon ribbon is fed through the loops on the Minitrack™ unit and tied off. Superglue is added to the knot for extra strength. Images by D. Ginty 2013.*

Minimum convex polygon and fixed kernel methods

To test for any change in the area used over time, the data set was subset into six weekly samples, and analysed using the 95% MCP to reduce the effect of outliers. Kernel isopleths were examined in ArcGIS to determine the most suitable smoothing factor (h). Based on visual inspection, the best fit of locations was represented by h = 50. Core areas are usually represented by 50% isopleths (Elchuk and Wiebe 2003), widely used and hence generally assumed to be the best value. Core areas are best identified, however, by creating incremental plots of home range estimates at fixed-kernel contours between 20 and 90%; areas increase slowly and then escalate markedly to include outliers (Kenward *et al.* 2001; Elchuk and Wiebe 2003). This point of inflection best defines the core area (Elchuk and Wiebe 2003). An investigation of the fixed-kernel contours for the six weeks of data found the mean inflection point to be 50.83; hence the core area can be determined by analysing location estimates using the 50% isopleth.

The 100% MCP was used to represent a boundary of the juvenile eagle's traversed area in its first six weeks post-fledging. However, this is not ecologically very meaningful, as utilisation of a home range is not uniform (Newton 1979; Ridpath and Brooker 1987; McGrady *et al.* 2002; Elchuk and Wiebe 2003); the MCP simply calculates the area within the outermost locations (Nilsen *et al.* 2008; Doucette 2010). The kernel method is more ecologically meaningful because it can detect areas of frequent use (Worton 1989). For comparison the 95% MCP was calculated per week to identify a shift in area used over time. The fixed-kernel method was used to identify centre(s) of activity; the 90 and 95% level identifying the majority of locations and the 50% level used to identify core areas of intensive use. After comparison of residuals, the MCP and fixed-kernel outputs at the 95% level were transformed to be analysed via a linear model using a log transformation; transformation of area was compared to time. This was an attempt to understand and model underlying processes from which the data may have emerged, and improved the fit of the regression.

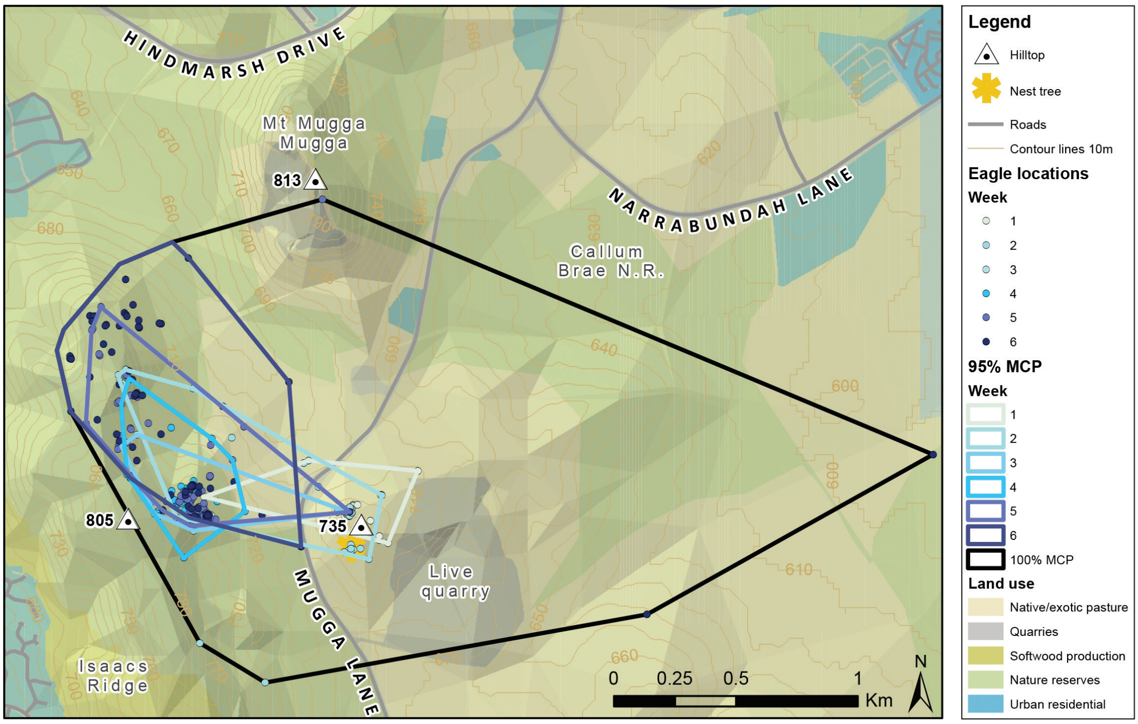

Figure 2. *Polygons of weekly locations (95% MCP, blue shades) of a juvenile Wedge-tailed Eagle for six weeks post-fledging. The 100% MCP is represented by the black line and includes locations from 44 days from release.*

An analysis was conducted to compare whether the 95% fixed-kernel home range size varied depending upon the time interval of location fixes. The data were first subset to only use location fixes at 3, 4.5 and 6 hourly intervals and then compared with the fixes at 90-minute intervals that were programmed into the Minitrack™ unit. This was conducted to assess whether potentially the battery life of the unit could have been extended without significantly impeding home range size calculations.

Distance per day

Several home range studies report average straight distances travelled per day as a basic measure of movement and dispersal (O'Toole *et al.* 1999; Kenward 2001; Soutullo *et al.* 2006a; Soutullo *et al.* 2006c). This study measured distance travelled per day as the total straight-line distances between all points per day.

RESULTS

MCP and kernel methods

From day of release with satellite transmitter until the final download six weeks later, the total area used by the eagle was 4.22 square kilometres, measured using the 100% MCP (Figure 2). By sub-setting the data set into weeks using the 95% MCP, a shift north, north-west along the ridgeline can be seen from the nest site in week one (Figure 2). The areas most frequently used, as measured by the 95% kernel, encompassed 0.65 square kilometres (Figure 3). Two core areas were identified by the kernel method in Figure 3 (50% isopleths), comprising a total core area of 0.04 square kilometres.

After examining both the MCP and fixed kernel techniques at the 95% level, they were compared to determine which best defined the home range; an ANOVA comparing the MCP and fixed kernel methods for home range size per day found the two methods to be significantly different from each other ($F = 80.06$; df = 1, 40; $P = 0.0001$). A linear regression applied after a log-transformation of home range size (area) per day was highly significant for both the fixed-kernel estimation method ($F = 27.3$; df = 1, 40; $P = 0.0001$, coefficient of determination of $R^2 = 0.39$), and MCP method ($F = 35.49$; df = 1, 40; $P = 0.0001$, coefficient of determination of $R^2 = 0.46$) (Figure 4). Area used could be predicted from the equations Log_e (Kernelarea) = 0.08 ×day – 4.21, and Log_e (MCParea) = 0.13 ×day – 7.41, where area is in square kilometres (Figure 4).

By running analyses of home range size (area) estimated using the fixed-kernel method at different time schedules, it was found that fixes could be taken at up to six-hour intervals without significantly affecting the home range size estimate (multiple comparisons based on the Tukey-Kramer procedure) (Figure 5).

Distance per day

Distances travelled per day significantly increased over time ($F = 9.10$; df = 5, 36; $P = 0.0001$) (Figure 6). Multiple comparisons based on the Tukey-Kramer procedure revealed that distances travelled per day in week one were significantly less than distances in weeks five and six; week six was also significantly different from weeks two, three and four, and distances travelled in week five were significantly larger than in week three (Figure 6). Distances up to 1.07 kilometres between 90-minute fixes were reached in the juvenile's second week post-fledging (Table 1). The longest distance moved between fixes was 3.28 killometres, in week 6 (Table 1).

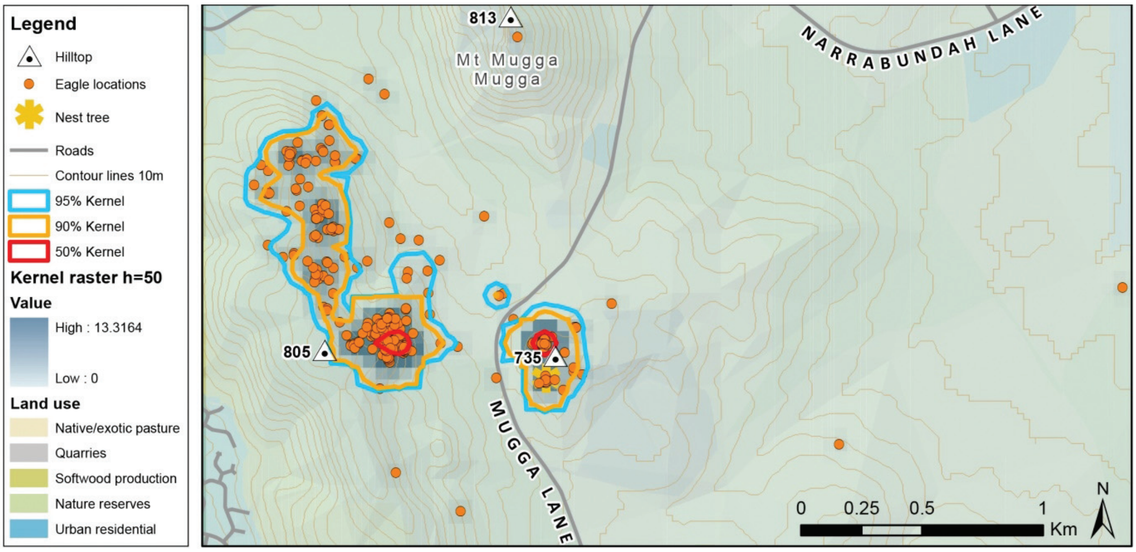

Figure 3. *Locations of a juvenile Wedge-tailed Eagle for 44 days from day of release with fixed kernel density contours; kernel estimates are given with h = 50.*

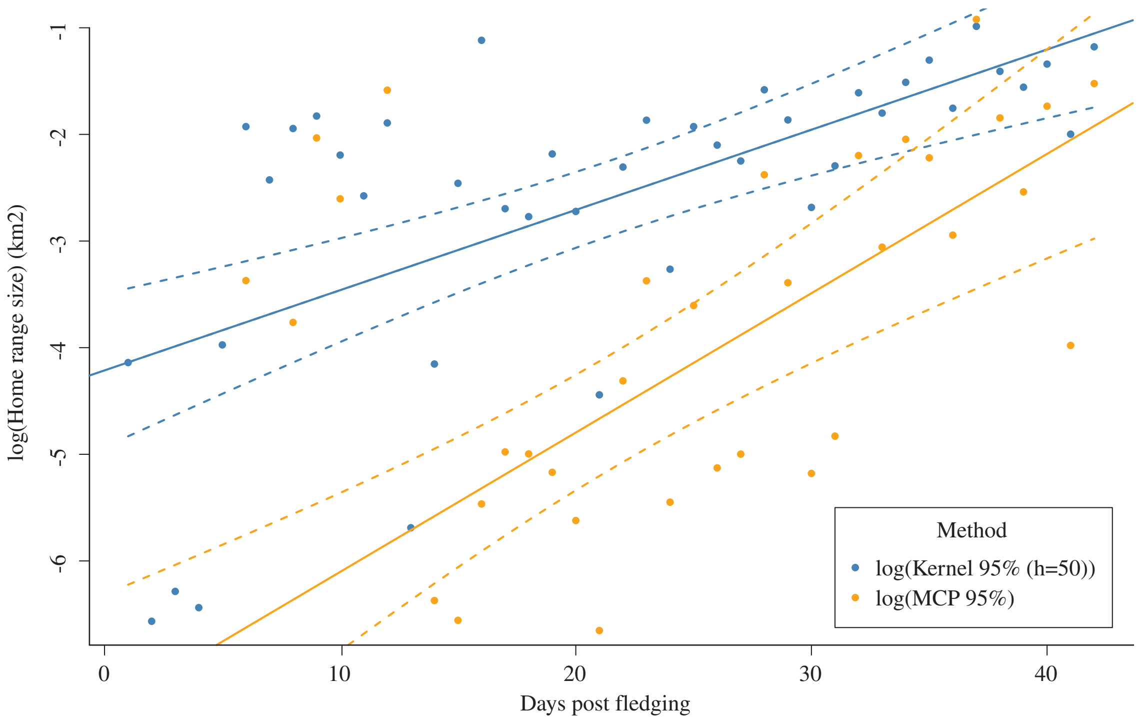

Figure 4. *Estimates of home range size (area) used by a juvenile Wedge-tailed Eagle for 42 days from day after release measured using 95% MCP and fixed kernel methods following log transformations; h = 50. Dashed lines represent 95% confidence limits for the prediction of the mean value of Y for a given X.*

DISCUSSION

Minimum convex polygon and fixed kernel methods

Six weeks of data were obtained due to the unexpectedly short lifespan of the satellite transmitter and the limitations associated with downloading the information from the Minitrack™ unit. Estimates of home range size varied considerably between the two methods of home range calculation. Whilst identifying a shift in area used per week, the MCP output of Figure 2 does not identify which areas were more intensively used, which are clearly defined by the kernel output shown in Figure 3. The fixed kernel method identified two core areas, centered on two dead perch trees situated 160 metres north and 1130 metres to the west of the nest tree (Figure 3).

With the MCP method sensitive to outliers, it therefore includes data points that may not be considered as the 'normal activities' of the animal as described by Burt (1943). However, when considering territorial eagles, outliers produced by long-

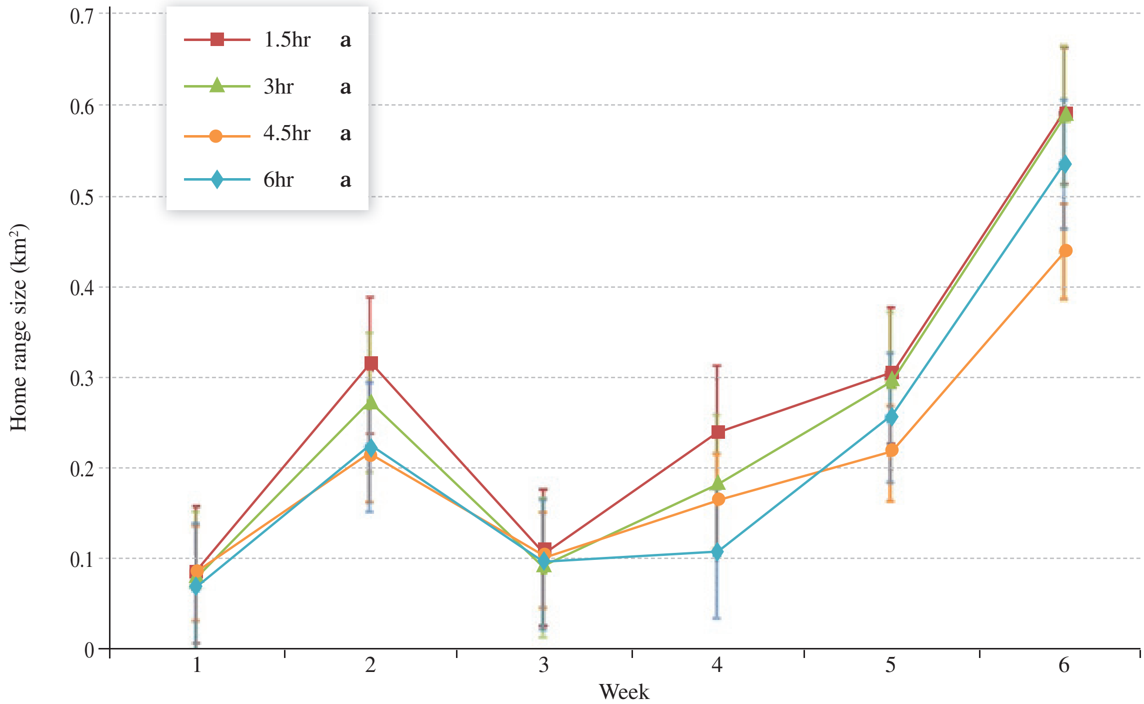

Figure 5. *Estimates of home range size (area) used by a juvenile Wedge-tailed Eagle for six weeks post-fledging measured using 95% fixed kernel method; h = 50. Estimates were created by taking location fixes at 1.5, 3, 4.5 and 6 hourly intervals. Weekly means are given with standard error bars. a = Tukey-Kramer comparison code; letters shared in common between groups indicate no significant difference.*

distance flights outside of the 'normal' home range can be attributed to surveillance of the home range, searching for new foraging areas, defending the home range against intruders, searching for potential partners, and reasons related to human disturbance (Pérez-García *et al.* 2013). If the 100% MCP is ignored, information provided by the outliers may be overlooked. Examples of such scenarios include the distribution of rare prey that might be found in an eagle's diet should eagles be taking such prey on those occasional excursions outside of the area given by the 95% MCP or kernel, or the identification of point sources of problems such as deliberate poisoning of carcasses. Additionally, knowledge of these long flights enables the observer to decide whether an individual sighted outside of known breeding areas indicates a new territory, or whether the individual belongs to the known breeding area and is simply travelling farther than previously realised (Pérez-García *et al.* 2013). Therefore, while usually excluded from home range analysis, these outliers are nonetheless important and should not be ignored.

Both home range estimation methods identified a significant increase in area used per day (Figure 4). This outcome was expected of a just-fledged bird; once it has left the nest the area it is able to explore is expected to increase. The same was found by O'Toole *et al.* (1999) and Soutullo *et al.* (2006b), who reported that the area explored by juvenile Golden Eagles increased over time, after first progressively increasing distance from the nest.

Our results suggest that location fixes could be taken at up to six-hourly intervals without significantly affecting home range size estimates (Figure 5). Therefore, the battery life of the Minitrack™ unit could be extended much further by reducing the number of daily fixes. When tracking with VHF, the Titley's Australis 26k Scanning Receiver or similar is recommended over Telonics TR models, the latter of which was found to be more sensitive to interference.

Distance per day

After fledging, the distance travelled per day increased overtime, the sixth week in particular being significantly different from the first four weeks (Figure 6), which concurs with the findings of Allott *et al.* (2006) and Debus *et al.* (2007), that juveniles range away from the nest approximately three weeks after fledging. A similar pattern has also been documented in juvenile Golden Eagles (O'Toole *et al.* 1999; Soutullo *et al.* 2006b). Soutullo *et al.* (2006a) described this as the exploratory phase, with a gradual shift away from the nest.

The results agree with the findings of Debus *et al.* (2007); in the first week the juvenile was travelling short distances from the nest to nearby trees and spending the majority of time in a tree not far from the nest tree (Figure 2, 3). Debus *et al.* (2007) reported one juvenile flying 500 – 800 metres from the nest in its fourth week post-fledging. The juvenile in our study was moving up to 770 metres between fixes in its fourth week post-fledging, however it had already reached distances up to 1.07 kilometres between fixes in its second week (Table 1). By its sixth week post-fledging, the eagle had reached a maximum of 3.28 kilometres between 90-minute fixes, and distances up to 5.97 kilometres per day which contrasts markedly with distances travelled in the first few weeks (Figure 6; Table 1). Straight line distances between fixes, however, are likely to be underestimates of the total distances travelled. The eagle was observed on several occasions travelling back and forth along a ridgeline within a 15-minute period, and so the distances

Table 1

Summary statistics of distance travelled between fixes (km, every 90 minutes) by a juvenile Wedge-tailed Eagle for six weeks post fledging. Mean (± standard deviation) and maximum distances travelled between fixes are presented per week. Minimum distances are given in metres because all values were < 0.00 km. Nb. GPS fixes are generally accurate to less than 30 m.

Week	Mean ± SD (km)	Max (km)	Min (m)
1	0.04 ± 0.11	0.59	0.49
2	0.10 ± 0.20	1.07	0.22
3	0.07 ± 0.12	0.64	1.06
4	0.10 ± 0.13	0.77	1.88
5	0.20 ± 0.25	1.29	0.98
6	0.37 ± 0.59	3.28	2.23

presented between fixes are minimums. Further, each fix is not necessarily at the end of a movement – several fixes were taken mid-flight.

The last observation of the juvenile in the natal area was on 28 Mar 2013, 121 days after fledging. At dispersal the eagle was still wearing the harness, which was still transmitting via VHF. Once dispersed and out of range it was not possible to determine the eagles whereabouts, its fate, or at what point the harness became detached. The harness was designed with this outcome in mind; therefore untreated leather was used to make the breast piece which would break under natural wear and tear from the environment and from the bird tugging at it, allowing the entire transmitter and Teflon attachments to come away at once.

CONCLUSIONS

This study has served as a successful pilot for future research on Wedge-tailed Eagles by providing an overview of home range analysis methods and functional satellite unit attachment. This study has used satellite telemetry to identify core areas, determine distance travelled per day, and measure changes in area used over time.

The area explored and the distance travelled per day by the eagle in this study progressively increased post-fledging, a finding in common with studies on similar species. The 95% MCP was used per week to identify a shift in the area explored over time as the eagle moved farther from its natal nest. The kernel method was more suitable than the MCP in determining areas of frequent use, and identified two core areas. Both methods identified a significant increase in area used per day.

Satellite tracking will enable a much deeper understanding of the spatial ecology of Australia's raptors, though limitations in the technology due to a considerable demand on resources are still hindering its application at its full potential. This study, the first time a Wedge-tailed Eagle has been satellite tracked for research, is a first step towards answering some long-held questions about ranging behaviour and dispersal patterns of the Wedge-tailed Eagle, and highlights the potential application of this technology in the conservation biology of threatened species.

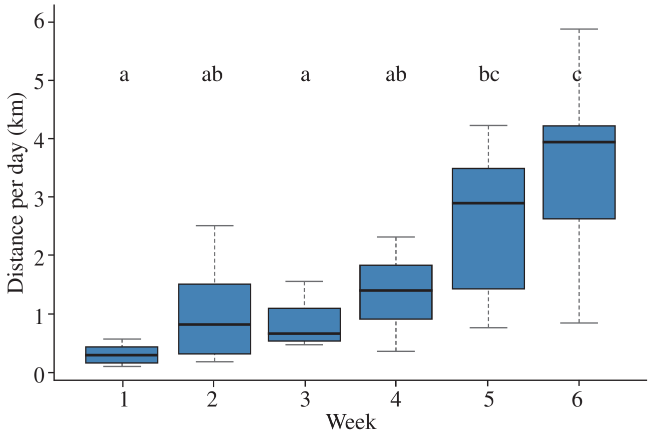

Figure 6. *Distance travelled per day (km) by a juvenile Wedge-tailed Eagle for six weeks post fledging. Boxes indicate the quartiles, thick vertical line the median, whiskers give 1.5 times the interquartile range, and dots the extreme cases outside this range. Letters represent Tukey-Kramer comparisons – letters shared in common between or among the groups indicate no significant difference.*

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Eagle capture, handling and satellite tagging procedures were in compliance with the Committee for Ethics in Animal Experimentation (CEAE) protocols at The University of Canberra (CEAE reference number 12-03) and ACT Government Licensing and Compliance: License to take and release (license number LT2012563).

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