1-1-2008

The effect of exposure on landscape scale soil surface temperatures and species distribution models

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Recommended Citation
Ashcroft, Michael B.; Chisholm, Laurie; and French, Kris: The effect of exposure on landscape scale soil surface temperatures and species distribution models 2008, 211-225.
https://ro.uow.edu.au/scipapers/3151

Abstract

Species distribution models (SDMs) often use elevation as a surrogate for temperature or utilise elevation sensitive interpolations from weather stations. These methods may be unsuitable at the landscape scale, especially where there are sparse weather stations, dramatic variations in exposure or low elevational ranges. The goal of this study was to determine whether radiation, moisture or a novel estimate of exposure could improve temperature estimates and SDMs for vegetation on the Illawarra Escarpment, near Sydney, Australia. Forty temperature sensors were placed on the soil surface of an approximately 12,000 ha study site between November 2004 and August 2006. Linear regression was used to determine the relationship with environmental factors. Elevation was correlated more with moderate temperatures (winter maximums, summer minimums, spring and autumn averages) than extreme temperatures (summer maximums, winter minimums). The correlation (r 2) between temperature and environmental factors was improved by up to 0.38 by incorporating exposure, moisture and radiation in the regressions. Summer maximums and winter minimums were predominately determined by exposure to the NW and coastal influences respectively, while exposure to the NE and SW was important during other seasons. These directions correspond with the winds that are most influential in the study area. The improved temperature estimates were used in Generalised Additive Models for 37 plant species. The deviance explained by most models was increased relative to elevation, especially for moist rainforest species. It was concluded that improving the accuracy of seasonal temperature estimates could improve our ability to explain the patchy distribution of many species.

Translocation of the Eastern Bristlebird 1: radio-tracking of post-release movements

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Summary

Translocating birds to a new area of habitat to restore or supplement depleted populations may pose a significant threat to the translocated individuals. While for many species, translocated individuals appear to move larger distances than resident animals, species with poor dispersal capacity may be restricted in movements and translocation methods may need to accommodate differences in movements to ensure success. In this study, designed to provide insights to inform our broader program of translocations in New South Wales, Australia, we investigated post-release movements in the endangered, semi-flightless Eastern Bristlebird (*Dasyornis brachypterus*). We predicted that movements would be minimal, with few differences between males and females, similar to published information for a resident un-manipulated population. Following the release of 45 birds at a host location at Jervis Bay, NSW, over a three-year programme, we followed individuals for up to two weeks using radio-tracking. The translocated birds had larger maximum movements and moved through much larger home ranges than non-translocated individuals from the resident population. Translocated birds moved 300 m further after release when conspecifics were present. Males moved further than females and tended to have larger home ranges, although average daily displacement did not differ. We concluded that the semi-flightlessness of the species does not result in minimal movements. Release at a small number of locations in the new habitat was considered appropriate for the species, as animals seem to move enough to find new unoccupied areas in a relatively short period. This work provided us with increasing confidence to continue with further translocations.

Key words: Dasyornis, movements, home range, re-introduction, recovery action, threatened species

Introduction

Translocation is a common conservation strategy for threatened species management (Griffith *et al.* 1989; Armstrong & McLean 1995; Fischer & Lindenmayer 2000). Translocations aim to increase the number of individuals (Baxter *et al*. 2008) or the number of populations (e.g. Evans *et al.* 2009) thereby reducing the likelihood of extinction of the species. However, moving animals to unfamiliar surroundings may pose significant threats to translocated individuals, influencing the potential success of these conservation programmes. Faced with a novel environment, animals often exhibit significant increases in movements (Parker *et al.* 2008), apparently associated with unfamiliarity of the environment or searching for a suitable area to inhabit. These increased movements may lead to reduced population survival as a result of low population density and birds travelling beyond the host site and therefore beyond control measures aimed at managing threats to the species.

Movements may differ depending on the presence of conspecifics (Roe *et al.* 2010), although not in every situation. For example, movements of translocated Bobwhites (*Collinus virginianus)* did not differ from resident birds (Terhune *et al.* 2010). Post-release movements can also differ with gender (Ryckman *et al*. 2010) and release protocol (Parker *et al*. 2008; Rantanen *et al*. 2010; Ryckman *et al*. 2010). Movements are likely to be closely tied to the life history of species. Species which flock might not move more than resident individuals but for species that are territorial, movements may be in response to aggression from established territory holders or the need to seek unoccupied areas. Also, differences in movements between males and females are likely where each sex takes different roles in territory establishment or breeding. Understanding the movements of animals in their new environment in the early period following release will help to determine how the translocated individuals are establishing in the new environment and facilitate predictions for future translocations of the species.

The Eastern Bristlebird (*Dasyornis brachypterus*) is an endangered bird in Australia. It is cryptic, ground-dwelling and semi-flightless (Bain *et al.* 2008) and, therefore, not expected to be able to recolonise new areas readily (Baker 1997). Birds occupy overlapping home ranges of 2-10 ha (Baker 2001) and occur in densities of up to 0.5 birds per ha (Baker 2001). Translocation, with the aim of establishing additional colonies, was identified as a key recovery action in the New South Wales state recovery plan for the species (NPWS 2000) to reduce the impact of potential threats to the species, particularly fire, which has the potential to cause local population extinctions.

The present study was part of a broader translocation program for the Eastern Bristlebird. Here, we examine the movements of 45 birds during the first few weeks of their release in their new host location at Jervis Bay, NSW, staged over three years. This study provided increasing confidence to continue with the translocation program. The longer-term monitoring for this translocation and a subsequent translocation at a second location, (Illawarra, NSW) is provided in Baker *et al.* 2012.

In this paper, we describe the short-term movements of radio-tracked Eastern Bristlebirds immediately after their translocation to vacant habitat and compare these results with resident birds radio-tracked within their natural habitat from a previous study by Baker and Clarke (1999). We investigate differences in movements of translocated birds when the habitat was unoccupied and when conspecifics were present. As the species is a poor flier, we did not expect movements to be much greater than the movements of resident birds, however, we expected movements to be greater in the presence of conspecifics where birds need to spread further to find unoccupied habitat. As there is no indication that males and females have different home ranges, we predicted no differences in movements between males and females.

Methods

This study was conducted in the Jervis Bay area of south-eastern New South Wales. Following a favourable feasibility analysis in the translocation proposal (Whelan & MacKay 2002), which concluded that the proposed host site provided suitable habitat and sympathetic management, 51 wild-trapped Eastern Bristlebirds were moved over three years. Birds were caught following the methods of Baker and Clarke (1999) at an average of one or two per day and transported individually in foam-padded cages (30 cm x 30 cm x 60 cm) lined with soft vegetation from the source environment. The birds are sensitive to disturbance during breeding (August to February) and difficult to catch (Baker & Clarke 1999) so the translocations were planned to occur over several months after the breeding season. All birds caught were translocated. The birds were sourced from Bherwerre Peninsula (150°45', 35°04'): 16 in 2003, 20 in 2004 and 15 in 2005. Birds were released individually and directly into the host environment at the nearby Beecroft Peninsula (150°48', 35°03').

The host site was approximately 12 km north of the source site and a 45 minute drive, with all birds released 1-4 hours after capture. There was one fatality in 2003 during processing and there were 5 fatalities in 2004 following release, thus the effective translocated population was based on 15 birds released each year. Post-hoc DNA analysis revealed that these 45 birds were: 24 males, 19 females and 2 undetermined. Two release points 1 km apart were used. Releases were made in *Phase 1* at site R_1 (150°48'30", 35°03'57") in the first year and site R_2 (150°47'3", 35°04'21") in the second year, and then in *Phase 2*, in the third year, 8 birds were released at R_1 and 7 birds at R_2.

The translocated birds were fitted with radio-tags (*sensu* Baker & Clarke 1999), where tags were glued to the interscapular area using quick-setting cyanoacrylate glue, once a small area of feathers was removed. In the second year, nine individuals had a transmitter attached using a small backpack harness in addition to the glue (*sensu* Bramley & Veltman 1998). A shoulder harness was used instead of a leg harness because this is suited to ground-dwelling and semi-flightless birds (Rappole & Tipton 1991). The harness was made from readily degradable rubber bands that wrapped around the shoulders and included a weak link of cotton across the back. Both techniques were designed to have the transmitters fall off the birds within the battery life (approximately 6 weeks) so that transmitters could be recovered.

After release, birds were radio-tracked every hour between sunrise and sunset for the first five days. Thereafter, they were radio-tracked once in the early morning, once around mid-day and once in the late afternoon. Radio-tracking involved triangulation for location fixes from numbered positions along trails through the release sites using a combination of hand-held and tower-mounted antennae. Two to five bearings were taken when locating a bird, depending on its position in relation to the trail. Location fixes were calculated using LOCATE II (Nams 1990) and mapped using ArcView GIS 3.3 (ESRI Inc.).

Five aspects of the translocated birds' movements were investigated: (i) maximum displacement away from the release point each day, (ii) maximum displacement moved in a day from the last position the day before, (iii) home range size, (iv) displacement between consecutive morning positions and (v) average daily displacement per hour. We have used "home range" to describe the area traversed by the birds newly arrived in the host environment but acknowledge that initially, the birds were totally unfamiliar with the area. Where possible, comparisons were made between sexes and between birds in the first and second phases. Analysis of variance was used for comparisons and a Huynh-Feldt epsilon degrees of freedom correction for violating the sphericity assumption of a repeated measures analysis of variance was used as needed. Measures of the movements of translocated birds were tabulated and compared with resident birds from an earlier study (Baker & Clarke 1999; Baker 2001). For all comparisons among years and sites, we did not take account of differences in habitat resources because we assumed negligible differences during the study.

Home ranges were calculated using the Animal Movement extension for ArcView GIS 3.3 (Hooge & Eichenlaub 2000). Both the minimum convex polygon (MCP) (Anderson 1982) and kernel utilisation distribution (UD) (Worton 1987) were calculated for direct comparison to previous research. The MCPs were calculated over four-day periods using only three location fixes per day, morning, mid-day and afternoon, to maximise sample sizes with an equal survey effort. The calculations for the UDs used all location fixes available for birds over the first four days only.

Repeated measures analysis of variance was used, which requires data sets with no missing values. To overcome this constraint, subsets of tracking data were used and hence, the sample sizes vary in the analyses. Analyses have been carried out with a compromise between retaining sample sizes and maximising numbers of days in the analysis. The data were not normally distributed and were transformed before analysis using the square root transformation (Bartlett 1936) as group variances were proportional to the means (Zar 1984). Graphs and tables report non-transformed data.

To investigate differences between the movement of translocated and resident birds, we compared the movements of 47 birds translocated from Bherwerre Peninsula to Beecroft Peninsula (2003-5) with 19 resident birds radio-tracked in the source population at Bherwerre Peninsula in 1997 (Baker & Clarke 1999; Baker 2001).

Results

Comparison of transmitter attachment techniques

The period of attachment of glued radio-tags (period = 7.4 days, range 1-34 days, n = 39) was similar to the period of attachment for the glued and harnessed radio-tags (period = 6.8 days, range 2-14 days, n = 4). These results exclude four birds that died in a storm following release and one bird presumed to have been taken by a raptor due to the location and condition of its remains.

Maximum displacement from the release point

On their first day, birds (n = 20) moved an average of 409 ± 271 (sd) m from the release point and by their tenth day, the average distance of these birds (n = 7) was 898 ± 446 m from the release point in a straight line (Fig. 1). The maximum displacement of birds from the release point increased significantly over time when analysed over 5 days (n = 20; $F_{4, 72}$ = 5.536, P = 0.001), 8 days (n = 12; $F_{7, 70}$ = 2.506, P = 0.023) and 10 days (n = 7; $F_{9, 45}$ = 3.324, P = 0.03). There was a significant difference between sexes ($F_{1, 5}$ = 10.673, P = 0.022) with males consistently further away from the release point than females, ranging from 26 m away on the first day to 659 m away on the ninth day (Fig. 1). As sample sizes were small (m = 5, f = 2) another two analyses were performed with larger sample sizes, for the first eight days (m = 8, f = 4) and across the first five days (m = 11, f = 9). Males were significantly further away from the release point compared to females over eight days ($F_{1, 10}$ = 6.12, P = 0.033) but not over five days ($F_{1, 18}$ = 1.249, P = 0.278) (Fig. 1).

Over the first eight days, birds in the second release phase (n = 6) were significantly further (approximately 300 m) from the release point than birds released in the first release phase (n = 6) where conspecifics were absent ($F_{1, 10}$ = 5.248, P = 0.045) (Fig. 2).

Maximum displacement in a day

For all birds during the first nine days after release, the maximum displacement from its last position the day before increased from 177 ± 107 (sd) m to 529 ± 299 m, although this change was not statistically significant ($F_{2.5, 9.9}$ = 3.416, P = 0.067, *df* calculated with Huynh-Feldt correction). For the first five days, males increased their maximum displacement in a day from 125 ± 52 m to 317 ± 182 m and females' distances remained similar between 228 ± 92 m and 210 ± 161 m, although, the differences between sexes was not statistically significant ($F_{2.9, 31.5}$ = 2.409, P = 0.088).

For the first five days, second phase birds increased the maximum displacement per day from 194 ± 104 m to 346 ± 167 m and this was significantly different to first phase birds, which decreased the maximum displacement from 159 ± 69 m to 120 ± 34 m over this time ($F_{1, 11}$ = 6.237, P = 0.03).

Home range over 4-day periods

Overall, the average of the birds' home range MCP areas tended to increase over the first three, 4-day periods from 16 ± 15 (sd) ha to 37 ± 39 ha, although the difference was just non-significant ($F_{1.4, 7.2}$ = 4.460, P = 0.06). Males tended to have larger MCP home ranges than females, with males attaining 19 ± 23 ha in the first four days to 61 ± 39 ha in days nine to twelve compared with females from 7 ± 7 ha to 19 ± 32 ha during the same period. The difference between males and females was not statistically significant for the 12 day period ($F_{1, 5}$ = 3.865, P = 0.106), but was significant across the initial eight day period ($F_{1, 16}$ = 6.144, P = 0.025).

The effect of release phase (Phase 1 vs Phase 2) on the home range of birds varied with the time period (interaction term, $F_{1, 16}$ = 5.811, P = 0.028) (Fig. 3). During the first 4-day period, birds from both release phases used similar areas, but over the next four day period second phase birds had home ranges much larger than the first phase releases.

The 50% UD area was calculated for the first four day period. There was no difference between males and females over this period (t_{29} = 0.54, P = 0.6); males had a 50% UD of 4 ± 3 ha and females of 5 ± 6 ha. There was also no difference between first and second phase releases with 50% UD (t_{29} = 0.77, P = 0.45).

Displacement between positions on consecutive mornings

From the morning of the second day to the morning of the ninth day, there was a significant increase in the average distance between birds' positions on consecutive mornings ($F_{6, 24}$ = 2.583, P = 0.045) from 199 ± 133 (sd) to 676 ± 496 m. However, analysing the data from the morning of the second day to the morning of the fifth day revealed no significant changes over time. There was no difference in the distance between positions on consecutive mornings of males compared to females over the first three morning periods ($F_{1, 10}$ = 0.464, P = 0.511). Males ranged from 190 ± 120 to 405 ± 384 m and females from 264 ± 238 to 146 ± 130 m.

First phase birds decreased the distance between positions on consecutive mornings from 264 ± 226 to 229 ± 191 m over the first three morning periods while second phase birds increased from 182 ± 139 to 331 ± 337 m. However, there was no significant difference between first and second phase birds ($F_{2, 20}$ = 2.854, P = 0.081).

Average daily displacement per hour

During the first five days there was no significant change over time of the hourly distances moved by the released birds ($F_{4, 40}$ = 0.613, P = 0.656). Birds moved an average of 136 ± 78 (sd) m/h and ranged between 12 and 471 m/h. There was a significant interaction between time since release and sex ($F_{4, 40}$ = 5.195, P = 0.002) caused mainly by a significant divergence in the male and female trajectories between day 3 and day 4 ($F_{1, 10}$ = 51.193, P = 0.19). There was no overall significant difference between the sexes ($F_{1, 10}$ = 0.206, P = 0.66).

There were no differences in the hourly movements of first phase birds compared to second phase birds. First phase birds averaged 136 ± 85 m/hr over the first 5 days and second phase birds averaged 137 ± 63 m/hr.

Comparison of movements of translocated birds with resident birds

The periods of tracking were similar for translocated birds (mean = 7.1 days, range 1-34 days) and resident birds (8.0 days, range 3-28 days) and data for both translocated and resident birds were collected during March-June. However, the translocated birds had larger maximum movements and moved through much larger home ranges than the resident birds. Translocated birds ranged through MCP areas over five times the size of home ranges of resident individuals (Table 1).

Discussion

This translocation was staged over three years to enable the progressive evaluation of methods and ongoing success of the project without risking a large number of Eastern Bristlebirds at any one time. The translocation reported in the present study resulted in birds being detected annually in the vicinity of the release points up to 7.5 years post-release as well as others which dispersed to 4.6 and 6.3 km after 1.5 and 6.5 years respectively, and ultimately, the successful establishment of a new breeding population (Baker *et al.* 2012). A subsequent release of 50 birds in one stage in the Illawarra region of New South Wales resulted in birds detected in the vicinity of the release point after 1 year but not thereafter, although birds were detected 2-5 and 2-7 km from the release point 1.5 and 3 years post-release respectively (Baker *et al.* 2012). Comer *et al.* (2010) also used a staged translocation approach with Noisy Scrub-birds *(Atrichornis clamosus)*. In some translocations, males were released a year before females to test the habitat. Males were used as they are highly territorial, easier to catch and monitor, and considered more disposable than females. Presumably these males would also help to stimulate females to settle. Caution should be used with this technique unless there is an understanding of the breeding system of the species. Evaluating long-term trends in habitat occupation and dispersal may help to determine the efficacy of staged versus single release strategies.

Four birds died following a storm event and were all wearing backpack harnesses to attach their radio-tags. We considered that the harnesses had allowed the birds to become wetter than usual because of water travelling around the harness. Following this, the use of harnesses was discontinued. As no benefit was identified in radio-tag retention by using harnesses, the reversion back to just gluing was considered not to limit the collection of radio-tracking data. The fitting of the harnesses also increased handling time of the birds and for these reasons it is considered that the use of harnesses is not desirable for radio-tracking small ground-dwelling birds.

We predicted that the translocated Eastern Bristlebirds released into vacant habitat would not disperse far, given that they are poor fliers and occupy home ranges of up to 10 ha. In contrast, translocated birds moved further per hour and per day and had larger home ranges than resident birds. Furthermore, displacement continued to increase over the 2-week period of tracking, suggesting that birds continued to move away from the release site. As the habitat quality at the source and release sites was similar (Gibson 1999; Whelan & MacKay 2002; Bain 2006), the changes in movements are considered to reflect the species response to settling into the new host environment. Increased movements following translocation are not often recorded in birds. Translocated Northern Bobwhite (*Colinus virginianus*) (Terhune *et al*. 2006) and Sage-grouse (*Centrocercus urophasianus*) (Baxter *et al.* 2008) showed no difference in movements compared to residents despite being tracked over a much longer period. However, for mammals, translocated Dormice (*Muscardinus avellanarius*) (Bright & Morris 1994), European Hares (*Lepus europaeus)* (Ferretti *et al*. 2009) and Florida Key Deer (*Odocoileus virginianus clavium*) (Parker *et al*. 2008) dispersed further than residents. The cursorial and semi-flightless nature of Eastern Bristlebirds perhaps make them similar to flightless mammals in their dispersal behaviour.

A combination of conspecific attraction and the presence of vacant habitat seem to have driven dispersal in translocated the Eastern Bristlebirds. Second phase birds moved further from the release point, moved greater distances each day and had bigger areas of occupation after the first four days than the first phase birds, consistent with previous studies (Bright & Morris 1994; Castro *et al*. 1994) that suggested filled habitat can stimulate dispersal. We found little evidence that resident conspecifics stimulated settlement in this species as postulated with some other species (Smith & Peacock 1990; Stamps 1991; Stamps 2001), as we could not follow birds for a long time due to the limited life of the transmitters. Second phase birds were approximately 300 m further away from where the first phase birds were last recorded but may have still been dispersing and not settled. This distance approximates the diameter of an Eastern Bristlebird home range (Baker 2001).

Male Eastern Bristlebirds dispersed more than females, being consistently further from the release point than females, in contrast to our expectations. Males had larger home ranges in 8 days, with females seeming to stop moving away from the release point before males. This is similar to many results from mammal translocations (Davis 1983; Short & Turner 2000), whereas translocated birds species seem to be variable in responses where reported (Castro *et al.* 1994; Armstrong & Craig 1995). Discussions on male and female dispersal have generally postulated male-biased dispersal in mammals, and female-biased dispersal in birds (Greenwood 1980; Wolff & Plissner 1998; Clarke *et al.* 1997; Dale 2001) further highlighting similarities between the semi-flightless bristlebirds and small mammals. Interestingly, the rates at which the translocated Eastern Bristlebirds were moving per hour showed no differences between males and females. At the same time it seems that males were exploring a larger area whereas females explored smaller areas closer to the release point. These results suggest that females were undertaking a more intensive exploration of areas whereas males were undertaking a more extensive exploration of the area.

This study has implications for understanding the extent of dispersal in the management of current populations of Eastern Bristlebirds. Translocation to supplement or re-establish populations in Victoria and northern New South Wales is a recommended recovery action in the national recovery plan for the species (OEH 2011). There is currently a number of small, disjunct populations of the species (Bain & McPhee 2005; OEH 2011) throughout its range. This study has shown that translocation of birds to new appropriate areas is useful for establishing new populations. Birds are capable of moving through occupied areas, expanding population ranges (and sizes), provided quality habitat is available and not fragmented.

Acknowledgements

Funding for this work was provided by an ARC Australian Post-graduate Award – Industry scholarship with NSW DEC as the industry partner. The project received strong support from the NSW Eastern Bristlebird Recovery Team. Thanks to the many volunteers for assistance in the field; Rob Whelan for logistic support; Damon Oliver, David Priddel and two anonymous referees for their critical reviews of this paper.

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Table 1: Radio-tracking movement metrics [mean (range)] for Eastern Bristlebirds comparing birds translocated from Bherwerre Peninsula to Beecroft Peninsula during 2003-5 with resident birds at Bherwerre Peninsula in 1997.
MCP, minimum convex polygon; UD, utilisation distribution.

	Translocated – (this study)	Resident - (Baker & Clarke 1999; Baker 2001)
Greatest mean distance (range) between two points in one day	1st day: 323 (51-919) m, n = 46	1st day: 145 (75-230) m 2nd & 3rd days: 170 (100-325) m
Maximum hourly displacement of any bird	957 m	330 m
Average hourly movements	136 (12-471) m (47 birds, 5 days, 7-12 fixes/day)	115 m (one bird, 5 days, 9-18 fixes/day)
Home range size (MCP)	Days 1-4: 23 (1.5-71) ha, n = 31 Days 5-8: 27 (0.6-96) ha, n = 18 Days 9-12: 37 (1.1-98) ha, n = 7	7 days: 4 (1.5-6.6) ha, n = 7 10 days: 5.2 (2.8-8.7) ha, n=5 21 and 28 days: 9.6 &11.6 ha, n=2
Home range size (50% UD)	Days 1-4: 4.4 (0.2-22.9) ha, n=31	3 days: 0.5 (0.2-0.8) ha, n=3 5 days: 0.8 (0.3-1.6) ha, n=6

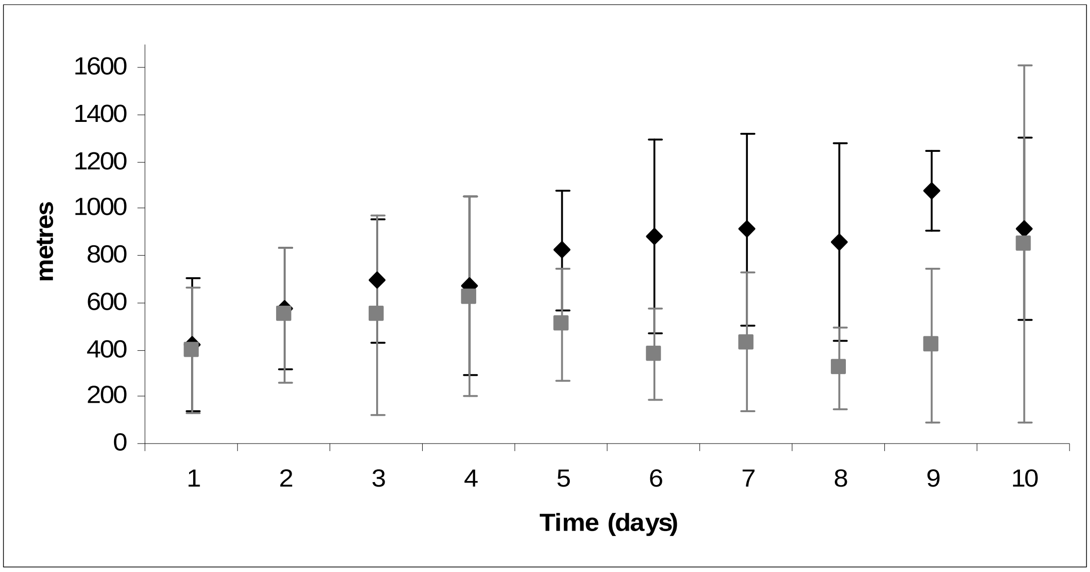

Figure 1: Maximum displacement from the release point each day (± sd). ◆ males, ■ females. Sample sizes vary: Days 1-5: n_m = 11, n_f = 9. Days 6-8: n_m = 8, n_f = 4. Days 9 & 10: n_m = 5, n_f = 2.

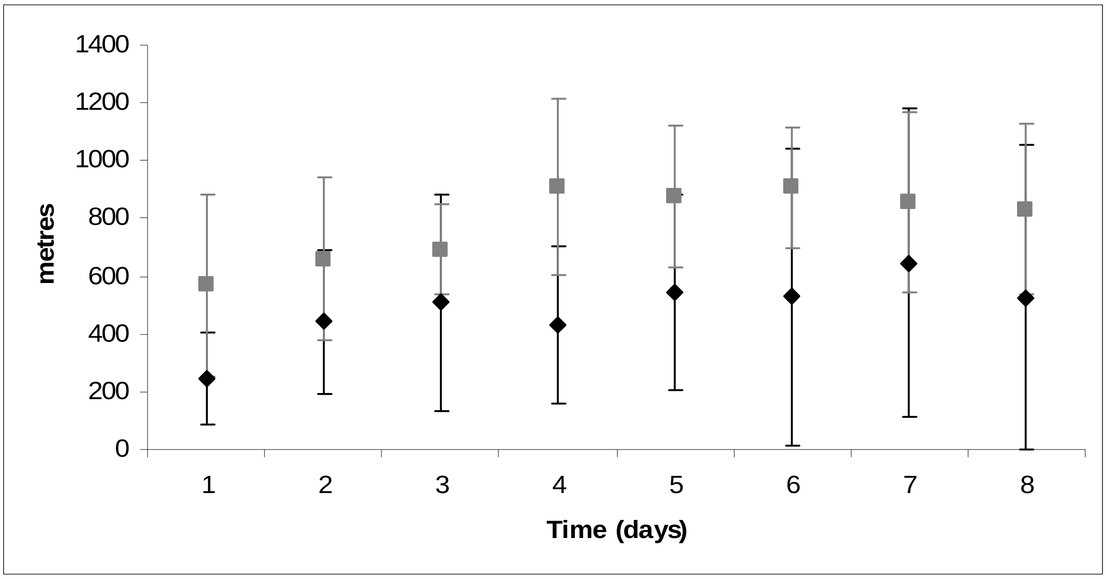

Figure 2: Maximum displacement from the release point each day (± sd). ◆ 1st phase birds (n = 6) and ■ 2nd phase birds (n = 6).

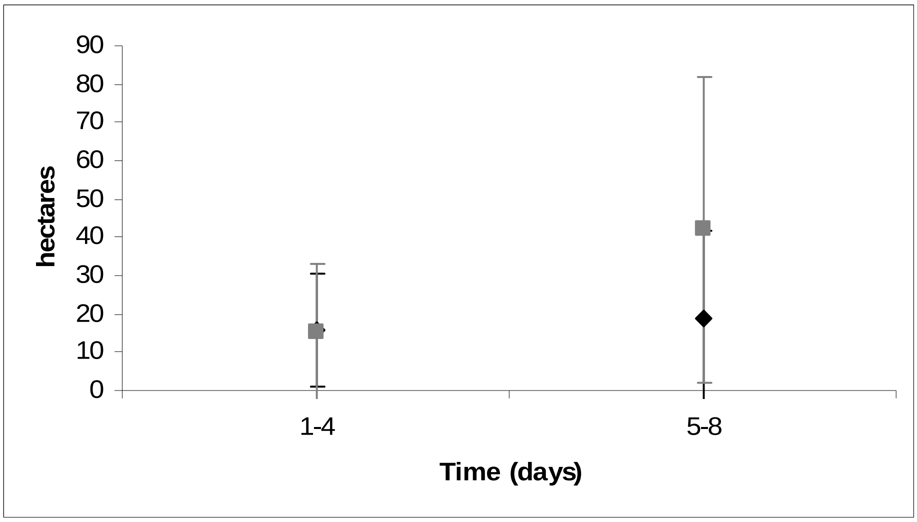

Figure 3: Home range (MCP) over four day periods (± sd). ◆ 1st phase birds (n = 12) and ■ 2nd phase birds (n = 6).