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Home Range of an Adult Female Peregrine Falcon (*Falco peregrinus*) during the Breeding and Non-breeding Seasons in Kentucky, USA

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ABSTRACT

The peregrine falcon (*Falco peregrinus*) is a *Species of Greatest Conservation Need* in Kentucky's State Wildlife Action Plan. The Kentucky Department of Fish and Wildlife Resources has monitored Kentucky's peregrine falcon population since 1997. However, research on the movements, habitat use, and breeding and non-breeding home range of Kentucky's nesting peregrine falcons is lacking. In this study, we used a solar-powered platform transmitter terminal (PTT) with global positioning system (GPS) and Argos capabilities to monitor the movements of a single adult, breeding female, peregrine falcon from 7 June 2015 to 4 May 2018. We found that the female falcon spent the majority of her time in close proximity to the nest site throughout the breeding and non-breeding season. Seasonal home range varied significantly with the largest home range size estimated during the post-fledging period, followed by the non-breeding season, and the smallest home range occurring during the pre-fledge period of the breeding season. We suspect that the increase in home range size observed during the post-fledging period can be attributed to parental care and post-fledge dependency of young.

KEYWORDS: raptor tracking, Argos, home range, peregrine falcon, satellite telemetry, solar-powered GPS transmitter

INTRODUCTION

The American peregrine falcon (*Falco peregrinus*) was removed from the United States Fish and Wildlife Service endangered species list in 1999 (USFWS 1999). Nonetheless, due to local conservation concern, the Kentucky Department of Fish and Wildlife Resources (KDFWR) listed the peregrine falcon as a *Species of Greatest Conservation Need* in Kentucky's State Wildlife Action Plan (KDFWR 2013), authorizing statewide restoration, management, and monitoring initiatives for the species to continue. The first nest in decades was established and documented in Kentucky on a bridge in downtown Louisville during 1997 (Burford 2001). The KDFWR has since monitored the nesting population annually and initiated a nestling banding program in 2001 (Burford 2001). Kentucky's nesting population has steadily increased, totaling 16 nesting pairs documented in 2019, with 14 nests on man-made structures, 8 of which were located at industrial sites (Raley and Taylor 2019). With 50% of Kentucky's nesting peregrine falcon population occurring at industrial sites, it is important to understand how falcons utilize these unique urban landscapes year-round.

Our anecdotal observations and long-term monitoring efforts suggested Kentucky's nesting peregrine falcon population was non-migratory, residing at territories year-round. Year-round occupancy at peregrine falcon nest sites can occur when food demands are met and local conditions are suitable (Morata 2018). Remaining at territories year-round circumvents migration, which is energetically expensive and can lead to greater mortality (Newton 2007; Franke et al. 2011). Literature on the spatial ecology of non-migratory peregrine falcons during the breeding and non-breeding season is sparse. Burt (1943) described home range as the "area traversed by the individual in its normal activities of food gathering, mating, and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered part of the home range." Identifying home ranges can provide insight into an animal's behavior, habitat components, and limiting factors that are critical for effective conservation management (Burt 1943; Powell 2000; Morata 2018).

While much was learned through the aforementioned population-monitoring and banding efforts, research on the movements, habitat use, and breeding vs non-breeding home ranges of Kentucky's nesting peregrine falcons is lacking. Solar-powered satellite transmitters

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provide researchers with data on free-ranging animal movements and behavior within their environment (Rutz and Hays 2009; Bograd et al. 2010). Significant advancements in the size and battery life of solar-powered satellite transmitters have expanded the array of species in which this technology can be applied (Holland and McCutcheon 2007). In this study, we used a solar-powered, Argos platform transmitter terminal (PTT) with global positioning system (GPS) capabilities to track the movements of a single, breeding, female peregrine falcon at a power-generating station in Kentucky.

Peregrine falcon behaviors and movements are variable seasonally and are largely dependent on sex (Cade and Enderson 1996; Palmer et al. 2001). During courtship, egg laying, and incubation stages of the breeding season, female falcons spend more time at nest sites than male falcons (Cade and Enderson 1996). However, once nestlings hatch, female falcons progressively spend less time at the nest (Palmer et al. 2001; Lapointe et al. 2013; Sokolov et al. 2014; Morata 2018). In our study, we investigate the variation of home range size during the non-breeding season and the pre-fledge and post-fledge stages of the breeding season.

MATERIALS AND METHODS

Study site

Since 1997, 61% of peregrine falcon nesting attempts in Kentucky have been located in nest boxes supplied by KDFWR (Raley and Taylor 2019). The East Kentucky Power Cooperative (EKPC), Spurlock Generating Station has hosted a pair of peregrine falcons since 2006, with the first nesting attempt occurring in a nest box installed on a smokestack by KDFWR during the 2007 nesting season (Veverka et al. 2007). Since occupancy, the EKPC Spurlock Generating Station nest site has hosted 11 successful nests with 33 young fledged (Raley and Taylor 2019). The generating station is located in the northeastern region of Kentucky along the Ohio River, 8 km from Maysville, Kentucky and 92 km from Cincinnati, Ohio (Figure 1). During this study a neighboring peregrine falcon nest was discovered in 2018, on a bridge in Maysville, Kentucky, approximately 7.5 km from the study site (Raley and Taylor 2018). Land cover within a 4.8 km radius of the nest site consisted of forested (55.9%), open (27%; pasture, grassland, scrubland, cultivated crops), open water (8.6%), and developed (8.4%) (MRLC 2018).

Capture techniques and transmitter attachment

Trapping efforts took place at the EKPC Spurlock Generating Station near the nest site. We targeted trapping attempts at the end of the nesting period in late May – June when the young falcons had recently fledged from the nest and food demands were high. We used a harnessed pigeon trap, as described in Bloom et al. (2007), and a rock pigeon (*Columba livia*) lure. Once captured, we took morphological measurements and attached a U.S. Geological Survey aluminum leg band and an alphanumeric colored leg band to a single female falcon (Bird Banding Lab Permit #23400). We then attached a 17-g (1.8% body weight), solar-powered Argos/GPS satellite transmitter (PTT-100) (Microwave Telemetry, Inc., Columbia, Maryland, U.S.A.) via a harness with teflon straps, and secured with copper tube closures as described in Buehler and Fraser (1995) to the falcon (falcon weight = 960 g).

PTT programming and statistical analyses

Solar Argos/GPS PTTs provide high-accuracy GPS fixes compared to location estimates provided by Argos based Doppler shifts of the PTT's signal frequency alone (Microwave Telemetry, Inc . 2019). The model of Argos/GPS PTT we used was relatively new at the time of our study allowing for GPS tracking of peregrine falcons, whereas most previous studies relied on doppler shift data. The GPS data were accurate to ±18 m and transmitted via the Argos system. We programmed the PTT, according to manufacturer recommendations, to take one location per hour for daylight hours and one location after dark daily. This resulted in the PTT taking 13 fixes each day in spring, 15 in summer, 13 in fall, and 12 in winter. Data were downloaded and analyzed every three days. We received location fixes from the PTT between 7 Jun 2015 – 4 May 2018 for a total of 4,800 fixes during the study period. All low-quality fixes (no fix, 2D fix, low voltage, battery drain, and date error) were excluded from this analysis (total excluded

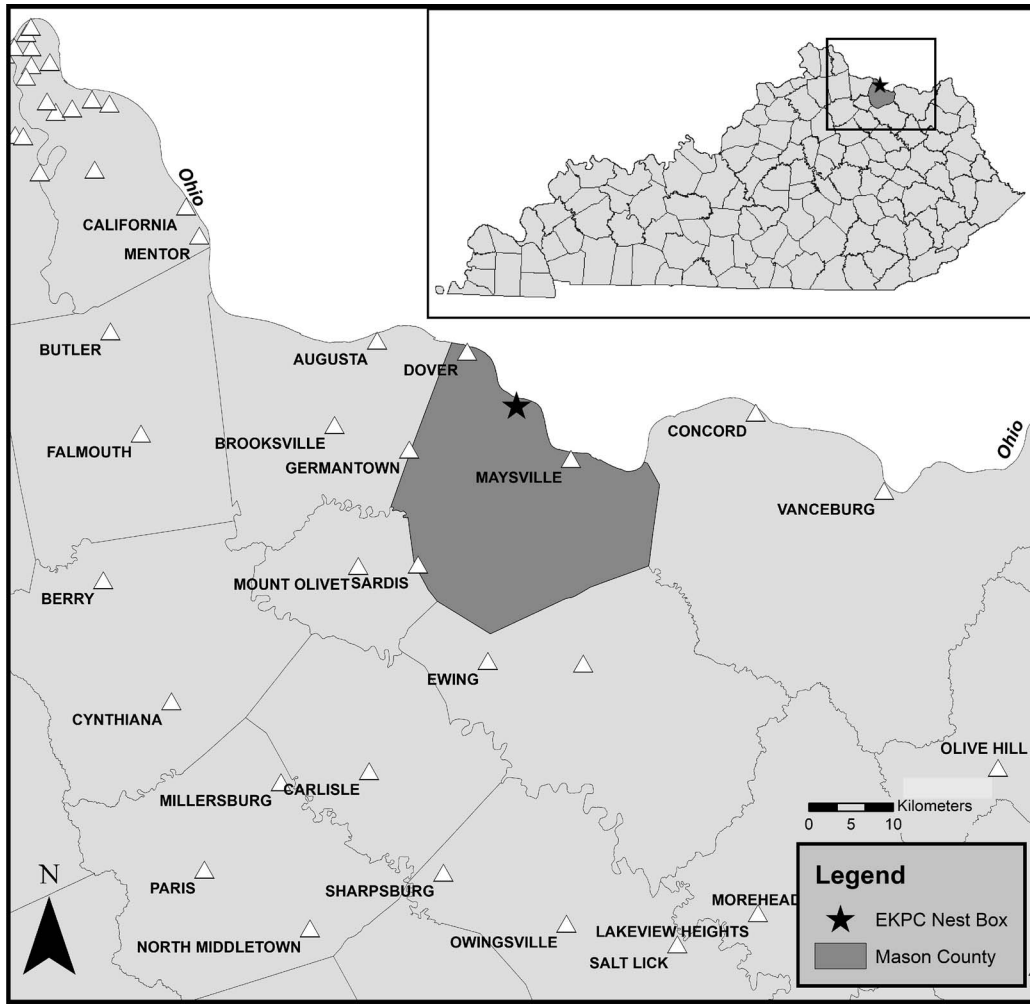

Figure 1. Approximate location of East Kentucky Power Cooperative Spurlock Generating Station peregrine falcon nest box, in Mason County, Kentucky, USA.

data, 1,354). Telemetry fixes were categorized into non-breeding (16 Aug – 31 Jan) and breeding season (1 Feb – 15 Aug). Breeding season was then subcategorized into pre-fledge and post-fledge periods, and date ranges were determined based on our long-term population monitoring data. The pre-fledge subcategory encompassed courtship, egg laying, incubation, and nestling stages (1 Feb – 31 May), while the post-fledge subcategory included the post-fledging dependency stage (1 Jun – 15 Aug). Post-fledging dependency is the period after young leave the nest and remain reliant on their parents for food (Bustamante 1994).

To estimate home range size we used 95% fixed Kernel Density Estimators (KDE) with a scaled reference, rule-based *ad hoc* bandwidth analysis (Worton 1989; Kie 2013) within the Reproducible Home Ranges package (Signer and Balkenhol 2015) in program R, version 3.6.1 (R Core Team 2019). The KDE method calculates home ranges by identifying areas of importance using the density in which an animal utilizes its space (Tétreault and Franke 2017) Scaled reference bandwidth was used to minimize over-smoothing and fragmentation of estimated home ranges with high sampling rates (Kie 2013). We used the 2011 National

Table 1. ARGOS/GPS PTT Fix Data Received 7 Jun 2015 – 4 May 2018. GPS fixes received, omitted and utilized for home range estimate analysis.

Category	Total fixes	Removed fixes	Good fixes	Good fixes (%)
Pre-fledge	1772	312	1460	82.4
Post-fledge	1308	169	1139	87.1
Non-breeding	1717	870	847	49.3
Total	4797	1351	3446	71.8

Landcover Database (NLCD; MRLC 2018) to determine the percentage of available landcover types within each season's home range. Land cover types were categorized into developed, forested, open water, and open landcover which pooled landcover identified as pasture, grassland, scrubland, and cultivated crops in the NLCD (MRLC 2018).

RESULTS

PTT functionality

Upon review of the data, we utilized 71.8% of the GPS fixes received during this study. We omitted 28.2% of the locations received due to low quality fixes (date error = 3, no fix = 71, low voltage = 1005, 2D fix = 155, battery drain = 120). The highest percentage of low quality fixes occurred during the non-breeding season when 870 fixes were omitted, ranging from 49% - 53% annually (Table 1). Meanwhile, 84.3% of the GPS fixes received were utilized during the breeding season. The highest number of low quality fixes (148, 37%) occurred during the last season (breeding) the PTT was operational.

Breeding season

During the study period, the female falcon had the smallest average home range during the pre-fledge period of the breeding season (3.43 km^2), with 93% of the location fixes falling within 0.8 km of the nest site (Figure 2 a-d). The land cover within the average pre-fledge home range consisted of forested (19.7%), open (12.4%), developed (37.7%), and open water (30.2%). Alternatively, the largest average home range was observed during the post-fledge period of the breeding season (20.36 km^2) (Figure 2 e-h). The post-fledge home range size varied the most annually with the 2015 season 11.2 times the area of the 2017 season (334.4 km^2, 29.8 km^2). Still during the post-fledge period, 76% of the location fixes occurred within 0.8 km of the nest site. Land cover within this home range was comprised of open (51.7%), forested (37.93%), developed (6.6%), and open water (37.9%).

Non-breeding season

During the non-breeding season, the female falcon occupied an average home range of 9.63 km^2, or an area about 2.8 times greater than the pre-fledge period home range (Figure 2 i-l). There was no indication of migration or relocation to wintering grounds. In fact, 86.9% of the location fixes occurred within 0.8 km of the nest site during the non-breeding season. The non-breeding season average home range land cover consisted of forested (40.5%), open water (25.0%), developed (21.2%), and open (13.2%).

DISCUSSION

PTT functionality

The use of solar-powered PTT's for bird monitoring is rapidly increasing; however reporting on the performance and fix loss rate is lacking (Silva et al. 2017). The majority of low quality fixes during this study were consistently observed during the non-breeding period, averaging 50% of the total fixes during this season being excluded from analysis. We assume this was due to less daylight hours and perhaps lower light levels in the winter preventing full recharge of the battery. In addition to low quality fixes, we also received 12 false mortality signals throughout the study, which seemed to be related to low battery voltage. The omission of low quality fixes is standard practice and expected when analyzing PTT data, however the amount of omissions is highly variable depending on the study (Douglas et al. 2012). For instance, fix loss rates ranged between 26% - 66% in a single study of eight solar Argos/GPS PTT tracked bearded vultures (*Gypaetus barbatus*) (Silva et al. 2017). Silva et al. (2017), suggests researchers consider power consumption, data transfer speed, and remote reprogrammable duty cycling capabilities in addition to cost and weight when selecting tracking devices. We suspect the programmed duty cycle (1 fix per hour during daylight hours) was too burdensome for the performance abilities

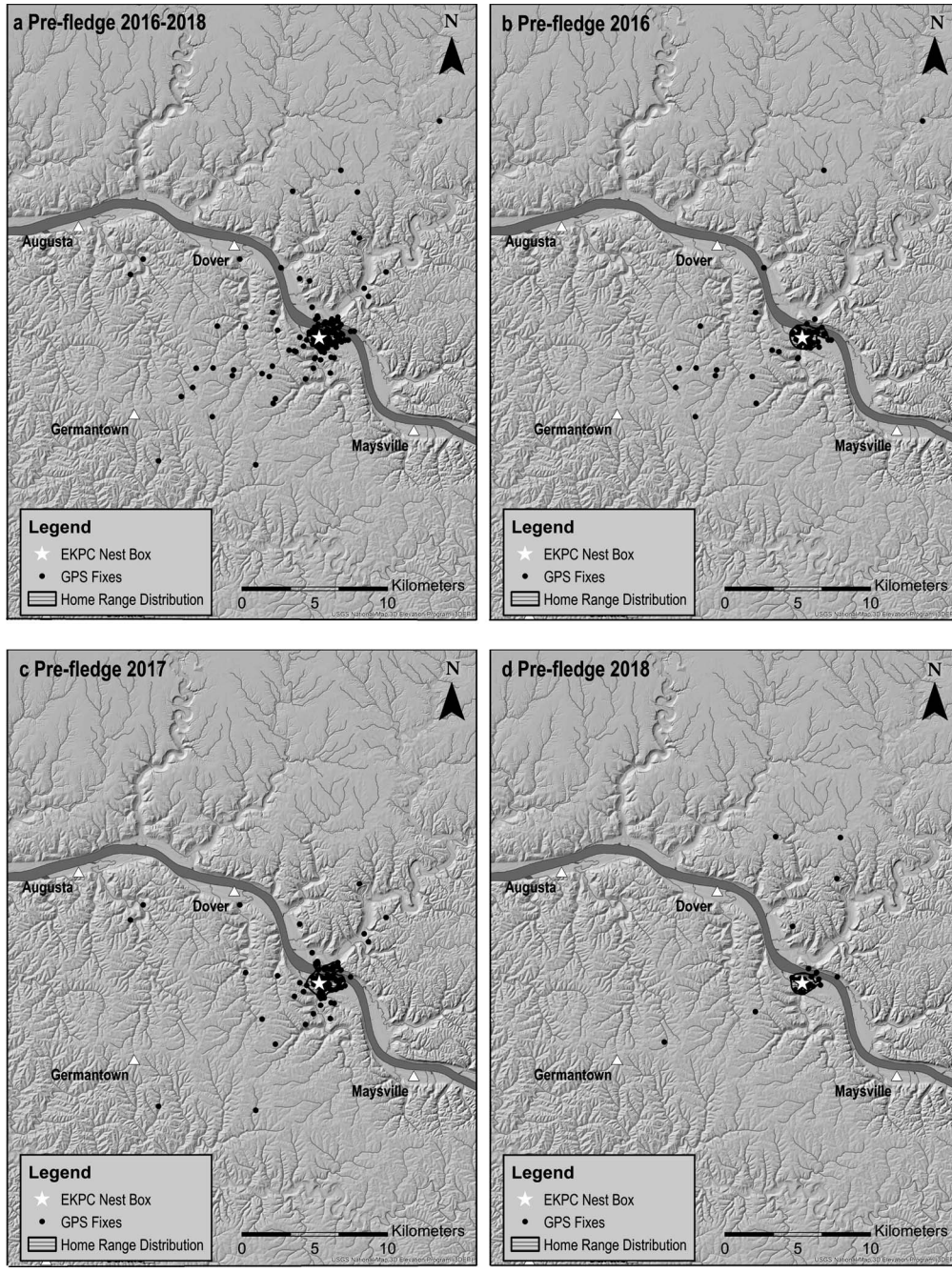

Figure 2. GPS fixes and home range distributions of an adult breeding female peregrine falcon (7 Jun 2015 – 4 May 2018) during the pre-fledge (a-d), post-fledge (e-h), and non-breeding (i-l) seasons. Home range determined by 95% Kernel Density Estimators using scaled reference bandwidth.

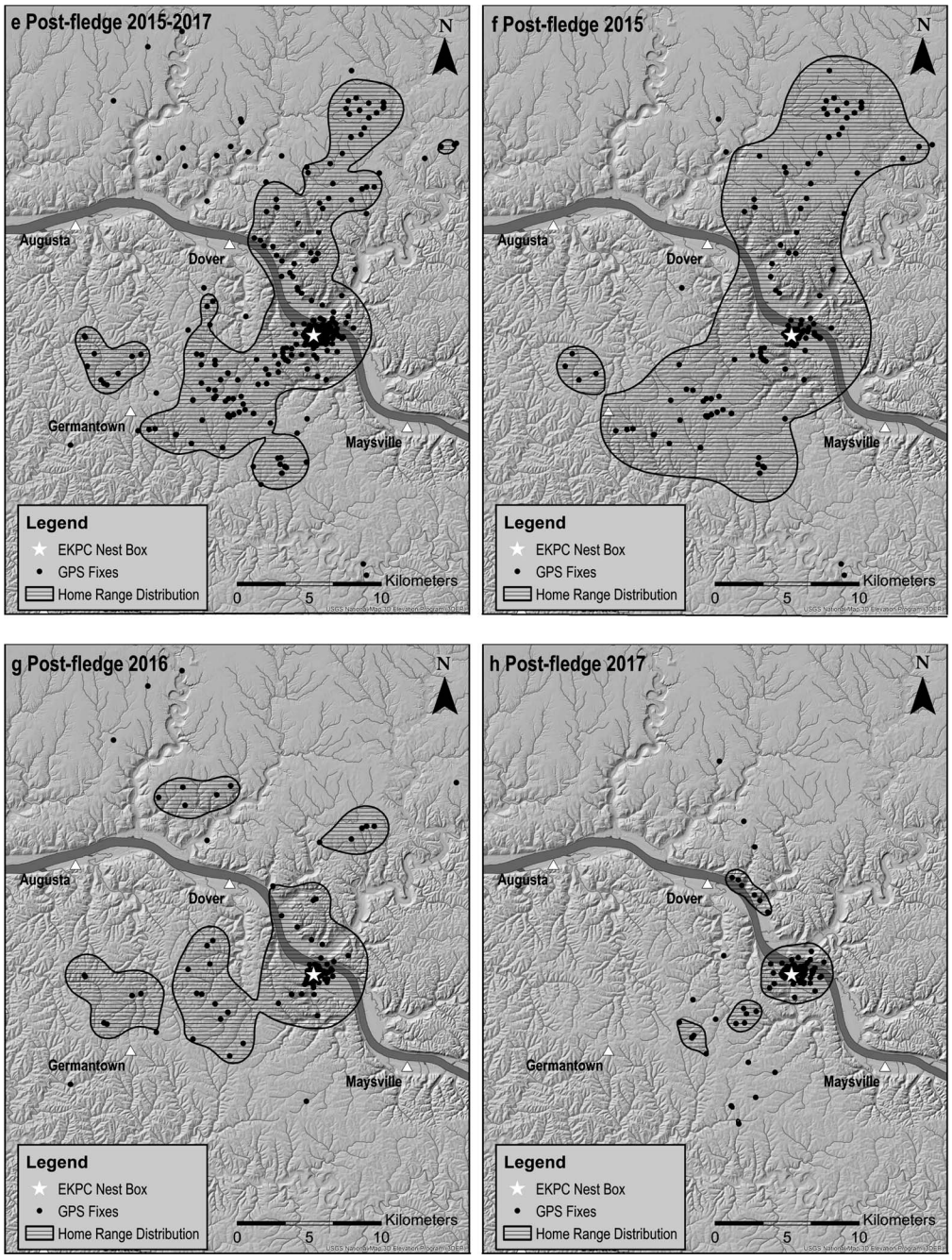

Figure 2. Continued.

of this PTT model and associated battery during the winter months. The manufacturer has since adjusted their recommendations for this model. Since most GPS PTTs cannot be reprogrammed remotely, we recommend being conservative when programming the frequency of fixes taken daily, especially during winter and when using new technology.

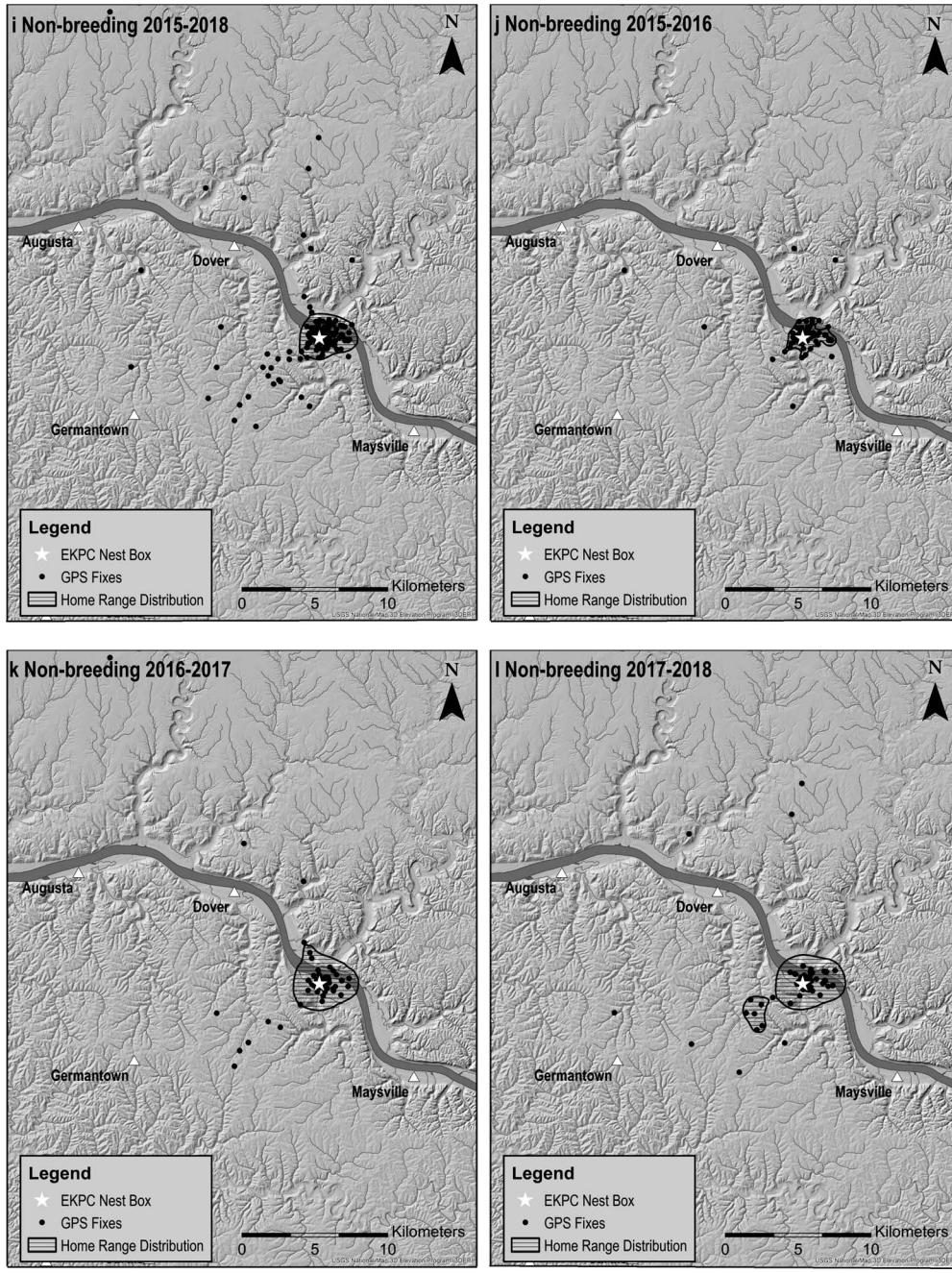

Figure 2. Continued.

Variation in home range size

Observations collected during long-term monitoring and banding efforts, previously suggested Kentucky's nesting falcon population was non-migratory. Data collected over the course of this study support this hypothesis. Home range, territory size, and habitat use for

adult peregrine falcons in Kentucky was virtually unknown prior to this research, based only on anecdotal observations. The female falcon remained close to her nest site year-round with 86% of the location fixes occurring within 0.8 km of the nest site. This was similar to the findings of Morata et al. (2018) and Holland and McCutcheon's (2007) study of the New Zealand falcon (*Falco novaeseelandiae*), both studies gave reports for both breeding and non-breeding seasons.

The home range size during the pre-fledging period was the smallest observed during the study (3.43 km^2) followed by the non-breeding season (9.63 km^2), and the post-fledging period (20.36 km^2). Lapointe et al. (2013), Sokolov et al. (2014), and Morata et al. (2018) also reported similar changes in the home range size of breeding female falcons in relation to stages of the breeding season using satellite tracking. Morata et al. (2018) found an average home range estimate of 38.6 km^2 for resident female peregrine falcons breeding in Humboldt County, California, USA. Lapointe et al. (2013) and Sokolov et al. (2014) identified differences in home range size within the breeding season for female falcons. Lapointe et al. (2013) reported an average home range of 83.9 km^2 during the pre-fledge period, and 201.9 km^2 during the post-fledging period, while Sokolov et al. (2014) estimated an average home range size of 9.8 km^2 during early-nesting, 35.1 km^2 during late-nesting, and 106.8 km^2 post-fledge. In our study, the pre-fledging period included the courtship, egg laying, incubation, and nestling stages of the breeding season. Home range size during this time can be variable depending on the sex of the falcon (Cade and Enderson 1996; Palmer et al. 2001). During courtship, egg laying, and incubation, the female falcon progressively spends more time at the nest (Cade and Enderson 1996). Once the chicks hatch, and as brooding demands decrease, the female gradually spends less time at the nest and more time foraging (Palmer et al. 2001; Lapointe et al. 2013; Sokolov et al. 2014). In our study, once the young fledged, the home range size of the female falcon increased substantially. This can probably be attributed to parental care and post-fledging dependency of young (Lapointe et al. 2013; Sokolov et al. 2014). Adults continue provisioning behaviors until young become self-reliant and disperse from their natal territories (Bustamante 1994; Sokolov et al. 2014). We observed highly variable home range sizes during the post-fledging periods of our study annually, and this could be the result of many factors including the number and sex of young, fledgling survival and dispersal, prey availability, and weather conditions. Additional research with a larger sample size is needed to investigate seasonal variation in post-fledging home range size.

Landcover use

The majority of Kentucky's peregrine falcon nests are located in developed areas with 50% occurring at industrial facilities (Raley and Taylor 2019). Understanding how peregrine falcons utilize these areas and surrounding habitat can influence future monitoring and management. The landcover included in the home range estimates of this falcon consisted mainly of forested (40.5%, 37.2%), developed (21.2%, 9.0%), and open (13.2%, 48.1%) land cover types during the non-breeding and breeding season, respectively. However, despite high percentage of available forested (40.5) landcover within the home range, the GPS fixes located within the home range were largely located within or bordering open or developed landcover types. Similarly, the landcover where fixes occurred outside of the home range were almost entirely located in or bordering open landscapes during both the breeding and non-breeding seasons, suggesting these landcover types were preferred over forested. The developed land cover type observed in this study comprised mostly of the power-generating station and the surrounding infrastructure. While the percentages of land cover types varied within the seasonal home ranges, the majority of GPS fixes occurred at the EKPC generating station. For instance, in the post-fledging period the developed land cover only encompassed 6.6% of home range, however 75.9% of the GPS fixes occurred within this cover type.

Studies have indicated that the reduction of predators, food availability, and safe nesting locations are key factors contributing to the establishment of urban nesting peregrine falcon populations (Cade et al. 1996; Rejt 2001; Caballero et al. 2016; Johnson 2018).

Feral pigeons, most commonly rock pigeons, have become one of the most prevalent avian species and widespread aerial nuisance wildlife found in urban settings (Fitzwater 1988; Rose et al. 2006). Rock pigeons and European starlings (*Sturnus vulgaris*) congregate in large numbers in urban environments, including power-generating stations, and make up a large percentage of prey consumption in urban peregrine falcons (Drewitt and Dixon 2008, Rejt 2001). In addition to abundance, rock pigeons are non-migratory, culminating in a vital food source for urban peregrine falcons year-round. Serra et al. 2001 found that pigeons were the highest-ranking food source by both capture rate and biomass (30.4%; 54.0%) during the non-breeding season for a pair of urban peregrine falcons. Large industrial sites such as power-generating stations provide an abundance of nesting locations for pigeons and starlings, resulting in extensive nuisance populations at such sites (M. Beumel, LG&E-KU, pers. comm., 24 Nov 2015). While the diet of the female falcon observed during this effort was not studied, we presume the abundance of food supply at this study site is integral to the localized movements and home range size observed and may account for the smaller home range sizes overall in comparison to the other studies previously mentioned. We also infer that developed and open landcovers provide ample foraging opportunities for peregrine falcons and can account for the abundance of GPS fixes observed in these land cover types throughout the study.

CONCLUSION

During the course of this study we observed 85.3% of GPS fixes fell within 0.8 km of the nest box. This indicates that the power-generating station and surrounding landscape satisfied the habitat requirements of this female falcon, allowing for year-round occupancy at this site. While we did observe larger home range sizes and annual size variation during the post-fledging period, we believe this is due to parental care during the post-fledge dependency stage of the breeding season. Our research estimated smaller home ranges sizes overall, in comparison to similar studies on peregrine falcons. This could be attributed to regional differences in habitat and prey availability. Further research with a larger sample size, including both sexes and various age classes is necessary to gain a better understanding of peregrine falcon home range and land cover use in Kentucky.

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