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Source: *Acta Ornithologica*, 55(1) : 77-87

Published By: Museum and Institute of Zoology, Polish Academy of Sciences

URL: <https://doi.org/10.3161/00016454AO2020.55.1.008>

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GPS telemetry and home range of the White-backed Woodpecker *Dendrocopos leucotos*: results of the first experience

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Campion D., Pardo I., Elósegui M., Villanua D. 2020. GPS telemetry and home range of the White-backed Woodpecker *Dendrocopos leucotos*: results of the first experience. *Acta Ornithol.* 55: 77–87. DOI 10.3161/00016454AO2020.55.1.008

Abstract. The White-backed Woodpecker *Dendrocopos leucotos* is one the rarest and the most vulnerable woodpeckers in Europe. Intensive forest practices have caused a widespread decline of the species. In the Spanish Pyrenees, on the south-west limit of the species range, a population of the *lilfordi* subspecies (Lilford Woodpecker) is estimated at less than 200 individuals which are confined to a few relatively well-conserved beech forests. Despite being an endangered taxon, our knowledge about the size and shape of its home range is still incomplete. Conventional radio-tracking studies of the taxon have been limited due to the complex topography of forests, whereas miniaturized GPS devices have not been available for such a small bird (~100 g bodyweight) until recently. Here, we evaluate for the first time the utility of modern lightweight GPS tags to characterize the home range of the White-backed Woodpecker. Using 3.4 g GPS-tags we tracked movements of 14 adult individuals during the breeding and post-breeding periods between years 2017–2019. On average, the failure rate (the percentage of failed fix attempts) was 30%, and 76% of successful fixes were accurate (error < 20 m). According to 95% kernel density estimator, the mean home range (~300 ha) was several times larger than previously reported for the species, and it did not change over the post-breeding period. This finding challenges the utility of previous management recommendations for protecting small buffer areas around the nest or single forest stands. By modeling the home range size as a function of the number of fixes and errors, we found that males had significantly larger home ranges than females. Our results demonstrate that GPS telemetry is feasible in White-backed Woodpecker adults, and it can provide novel and accurate information about the home range of the species if potential sources of error are adequately addressed.

Key words: White-backed Woodpecker, GPS, home range, radiotracking, forest management

Received — Nov. 2019, accepted — Jun. 2020

INTRODUCTION

The advent of global positioning system (GPS) technology has opened new avenues in the study of the spatial ecology of animals (Cagnacci et al. 2010). This technology allows collection of animal locations (or fixes) at higher rates and shorter intervals (Frair et al. 2004), without tracking the animals actively. Thus, it is possible to overcome some of the most frequent biases in direct human observations or VHF (very-high frequency) technology towards more accessible areas, more suitable working hours and favorable weather conditions for sampling (Hebblewhite & Haydon 2010). In addition, spatial precision of GPS locations greatly exceed that obtained via triangulation of radio-signals (± 22 m *vs.* ± 50 –600 m, respectively; Bradshaw et al. 2007), which makes GPS

telemetry data highly valuable for the study of the use of space by animals (Kie et al. 2010). However, there are technical challenges that can blur the potential of GPS telemetry for wildlife tracking.

One main limitation of GPS telemetry is that acquisition of fixes relies on the performance of satellites. Several studies have shown that topography and vegetation (canopy cover, tree density and height) can reduce precision of fixes and, in some cases, even prevent data acquisition (Frair et al. 2004, Janeau et al. 2004). If fix losses or/and location errors are not random across time and/or space, then certain areas used by animals are likely to be underrepresented in GPS data, and such bias need to be addressed to avoid incorrect inferences about the use of space by animals (D'Eon 2002, Frair et al. 2004).

Another limitation are trade-offs between weight and size of GPS devices and battery life and archival memory (Hebblewhite & Haydon 2010). GPS tracking has traditionally been restricted to animals large enough to carry relatively heavy devices (Meade et al. 2005). Recently, light-weight GPS-tags became available, allowing extension of this technology to small animals, including bats and birds lighter than 20 g (Recio et al. 2011, Cvikel et al. 2015). Here, we present the results of the first GPS-tracking experience of the White-backed Woodpecker *Dendrocopos leucotos* (onwards WBW), a bird with a body mass around 100 g.

The WBW is one of the rarest and biggest spotted woodpeckers in Europe. This species inhabits broad-leaved forests across Eurasia (from the Iberian Peninsula to eastern Siberia) and several Japanese and Chinese islands (Grangé & Vuilleumier 2009). Since the WBW specializes on wood-boring beetles and other bark-living insects, its presence is restricted to old-growth forests with plenty of standing and laying dead wood (Aulén & Lundberg 1991, Garmendia et al. 2006, Gerdzhikov et al. 2018). The food specialization makes the species particularly sensitive to intensive forestry management practices that reduce dead wood and old-growth trees, and introduce conifers (Cramp 1985, Carlson 2000).

Past forestry intensification triggered population depletion in north Europe (Virkkala et al. 1993, Carlson 2000) and it is the most likely cause of the decline in abundance observed over most of the species' range in past decades (Winkler & Christie 2019). Although the number of WBW in Europe is thought to be stable since the 2000s (Birdlife International 2016), many populations of the WBW are small and/or suffer from isolation (Winkler & Christie 2019), which makes this species the most vulnerable woodpecker in Europe (Gorman 2004). This situation has motivated the implementation of specific conservation plans and programs for captive breeding and reintroduction in north Europe (Birdlife International 2016).

Reproductive isolation between populations has promoted morphological and ecological variation in the WBW. One of 11 or 12 recognized subspecies (Winkler & Christie 2019), the Lilford Woodpecker (*D. leucotos lilfordi*), occurs in the mountains of southern Europe and in the center and west of the Caucasus. This subspecies shows a greater sedentariness and lower population dynamics and productivity than the nominate

D. leucotos leucotos (Grangé 2015). Unlike the nominate subspecies, the Lilford Woodpecker inhabits almost exclusively mountain beech forests rich in large-diameter snags and mature, dead and decaying trees (Garmendia et al. 2006, Gerdzhikov et al. 2018). These trees are essential for nesting and foraging (Melletti & Penteriani 2003). Given that hybridization between the Lilford Woodpecker and the *D. leucotos leucotos* is extremely rare in their contact areas (Matveyev & Vasic 1973, Haffer 1989), many authors have suggested that they are actually different species (Matveyev & Vasic 1973, Haffer 1989, Grangé & Vuilleumier 2009).

The population of the Lilford Woodpecker in the Spanish Pyrenees, on the south-west limit of the species range, is estimated at less than 200 individuals (Camió & Senosiain 2004). For that reason, the taxon is listed in the highest threat category on the national red list. The conservation of the Lilford Woodpecker relies to a great extent upon availability of favorable habitat, which is limited in the Pyrenees. Traditional logging has resulted in a simplification of the beech forest structure through reduction of woody debris, old-growth trees and decaying wood. As a result, Lilford Woodpecker individuals are confined to a few relatively well conserved beech forests (Fernandez et al. 1994). Therefore, it is urgent to harmonize forest management practices with the ecology, behavior and habitat requirements of this endangered bird.

Existing individuals need to be protected from detrimental management practices across their home ranges (*sensu* Burt 1943), so that they can perform normal activities such as feeding, finding shelter, mating and breeding successfully. Buffer areas of 500 m radius from the nest have been suggested to protect minimum habitat characteristic for the Lilford Woodpecker (Camió et al. 2014, Cárcamo et al. 2014). In other cases, conservation actions are limited to the forest stand where the nest is located. However, it is unclear whether any of these approaches would be enough, because quantitative information about the size and shape of the home range is lacking for this bird. The only existing estimates (50–100ha) are based on data from the nominate *D. l. leucotos* (Aulén 1988, Scherzinger 1990, Virkkala et al. 1993, Ettwein et al. 2018, 2019), which given the ecological differences between taxa may not apply to the Lilford Woodpecker.

In this study, we tracked with GPS-tags 17 of individuals of the Lilford Woodpecker during

breeding and post-breeding periods. Our aims were (i) to assess the suitability of lightweight GPS tags (3.4 g) for tracking movements of this forest specialist bird, and (ii) to estimate home range sizes of males and females after accounting for potential sources of error (failure rate and location accuracy).

METHODS

Study area

We conducted the study in seven beech forests located in the south face of the Western Pyrenees (Navarre, Spain), included within the Natura 2000 network (Special Conservation Areas ES0000126, ES2200019 and ES2200018). These forests occur in mountain steep slopes (20–40%), within an elevational range of 900–1200 m and under humid conditions (mean annual precipitation 1500–2000 mm).

Pyrenean beech forests were intensively managed through coppicing for charcoal production from at least medieval period to mid-twentieth century, when the recovery of the forest began in terms of area, and size and age of individual trees. Past decades have witnessed a reduction in the intensity of exploitation of these forests induced by the lowering of wood value. In parallel, several planning instruments for designation of protection zones and implementation of good practices have been developed. Nowadays, the shelter wood uniform system is the most common regeneration method, with a successive felling every 30 years and a final cutting age of target trees of ~120 years. However, these new practices have not reversed the legacy of past centuries: beech forests are structurally poor and many of the potential plant and animal species are still absent.

Field procedure and GPS data

Birds were captured near the nest during the breeding periods of 2017, 2018 and 2019 by using mist nets erected at 9.25–12.95 m on a pole system originally designed for catching bats. Each bird was tagged with three official metal rings (model C) following Aranzadi's Ringing Scheme for estimating annual survival rates. GPS tags (PinPoint GPS-VHF-75, Biotrack Ltd.) of 3.4 g were attached to captured birds using leg-loop harnesses (Naef-Daenzer 2007). The battery guarantees at least 150 fix attempts.

Birds were tracked from 10:00 to 18:00 over 3 non-consecutive days per week over the breeding

(May–June) and post-breeding (July–October) periods. Data were collected at rates of 5 independent fixes per day, with two time-lapse hours between fixes. To avoid possible loss of information due to the disappearance of the bird or premature failure of the emitter, we download data remotely once a month using a Yagi antenna.

Data analyses

The raw data obtained from GPS-tags were processed and analyzed in R (version 3.6.3; R Core Team 2020). We first quantified analyzed the failure rate, measured as the percentage of failed fix attempts, over tracking days and day time. Next, we estimated the location error of fixes on the basis of HDOP (horizontal dilution of precision) recorded by the GPS. HDOP is a measure of the satellite geometry constellation that is widely used in wildlife tracking studies for filtering implausible fixes (Recio et al. 2011, Silva et al. 2017, Liu et al. 2018). The greater the value of HDOP, the lower the constellation geometry, and hence the lower possible accuracy of a given location (Liu et al. 2018). We filtered out fixes with a HDOP value > 5, which according to the manufacturer's information and field tests carried out by ourselves with three emitters prior to deployment is equivalent to a location error lower than 20 m.

Individual home ranges were estimated by 50% (core area), 80% and 95% kernel density estimator (KDE), with a rule-based *ad hoc* bandwidth (Kie 2013). KDE estimates were calculated using the *rhrHrefScaled* function in the package 'rhr' (Signer 2016). Home range areas of breeding and post-breeding periods were compared by means of a paired t-test, because the sampling size was insufficient to fit a mixed model that accounts for repeated measures on the same individuals.

The accuracy of KDE estimators is related to the tracking duration (or the number of fixes; Fleming & Calabrese 2017). Thus, comparison between individual home ranges should account for sampling differences (Signer 2016). We visually explored the effect of the tracking duration (number of days with fixes between the first and the last tracking-day) on estimates of home range size through accumulation curves. In addition, we analyzed differences in home range sizes between males and females using multiple linear regressions, with sex, the number of fixes and the failure rate as explanatory variables. Since the number of tracking days was highly correlated to the number of fixes ($R = 0.96$), it was not included in the model to avoid possible multicollinearity issues.

The response variable (KDE home range) was square-root transformed to reduce heteroscedasticity. The 'female' category was set as the reference level for comparison between sexes. We repeated the same procedure for each KDE level with data from the full tracking season, and the breeding period. The sampling size of the post-breeding period ($n = 6$) was insufficient for fitting the model.

RESULTS

We captured and tagged a total of 17 individuals (3 juveniles, 7 adult females and 7 adult males) during the breeding periods of 2017, 2018 and 2019. Three other adult individuals were also captured and tagged but not considered in this study because, in one case, the GPS-tag detached the day after the capture, and in the others, the birds disappeared before we could retrieve data from their transmitters.

On average, captured juveniles weighed 79.63 g (range: 77.40–82.00 g) and adults 109.43 g (range: 100.20–119.40 g), so the GPS-tags were equivalent to 4% or less of their bodyweight, respectively.

Two of three GPS-tagged juveniles apparently died several days after being released. The only survivor juvenile was tracked over only 7 days

(just 15 accurate fixes). Regarding adults, all individuals continued feeding their chicks and completed successfully the breeding period (May–June), except two individuals whose nests were depredated by a Pine Marten *Martes martes* several days after being tagged. 75% ($n = 12$) of adults tracked throughout 2017 or 2018 were visually confirmed in the same territory one year after. One of the birds tagged in 2017 was recaptured in 2018 and showed no signals of physical damage resulting from the GPS-tagging. This individual was tagged again and completed a second breeding period successfully.

On average, adults were tracked over 61 ± 40 days (\pm SD) (Table 1). In six of these individuals (3 females and 3 males) the tracking was extended to the post-breeding period, which allowed us detect a family group of two tagged adults and two juveniles 22 weeks after leaving the nest. Other family groups were also detected in the monitoring of the birds several weeks after leaving the nest.

The mean failure rate of GPS-tags was 30%, being similar between sexes (Table 1), and ranging between 7–60% across individuals. Out of the 1799 collected fixes, 76% were accurate (HDOP < 5) (Table 1). After removing fixes with an HDOP > 5, we retained, on average, 98 ± 65 fixes per individual (Table 1). The rate of success of accurate fixes

Table 1. Summary of GPS-tag performance and size of home ranges of the Lilford Woodpecker based on kernel distribution estimators (KDE). Decimal numbers are omitted for clarity. ¹ — Estimates based on data from six individuals.

	All individuals (N = 14)		Females (N = 8)		Males (N = 6)	
	Mean \pm SD	Range	Mean \pm SD	Range	Mean \pm SD	Range
GPS data						
Tracking season (days)	61 \pm 40	7–124	57 \pm 42	7–124	66 \pm 40	11–107
Failures (%)	30 \pm 15	7–60	31 \pm 18	13–60	29 \pm 13	7–41
Number of location errors	30 \pm 21	6–62	27 \pm 24	6–62	33 \pm 19	8–54
Number of fixes	98 \pm 65	15–206	95 \pm 73	15–206	102 \pm 58	32–174
Tracking season KDE (ha)						
95%	303 \pm 145	86–586	227 \pm 104	86–390	405 \pm 134	274–586
80%	191 \pm 101	51–404	166 \pm 107	51–404	224 \pm 92	126–362
50%	80 \pm 48	22–201	71 \pm 55	22–202	93 \pm 39	51–157
Breeding KDE (ha)						
95%	308 \pm 174	86–665	226 \pm 106	86–380	418 \pm 195	222–665
80%	193 \pm 116	51–415	164 \pm 108	51–404	232 \pm 125	126–415
50%	84 \pm 59	22–204	71 \pm 56	22–202	102 \pm 63	51–204
Post-breeding KDE (ha) ¹						
95%	283 \pm 121	177–496	269 \pm 79	209–359	298 \pm 173	177–496
80%	176 \pm 67	102–285	152 \pm 32	123–186	200 \pm 92	102–285
50%	73 \pm 30	38–126	63 \pm 3.78	59–67	84 \pm 44	38–126
Distance of fixes to nest (m)						
Tracking season	795 \pm 236	432–1298	705 \pm 187	432–1020	915 \pm 255	588–1298
Breeding	786 \pm 236	421–1252	702 \pm 185	421–956	897 \pm 265	572–1252
Post-breeding	850 \pm 294	556–1327	641 \pm 79	556–713	1058 \pm 281	766–1327

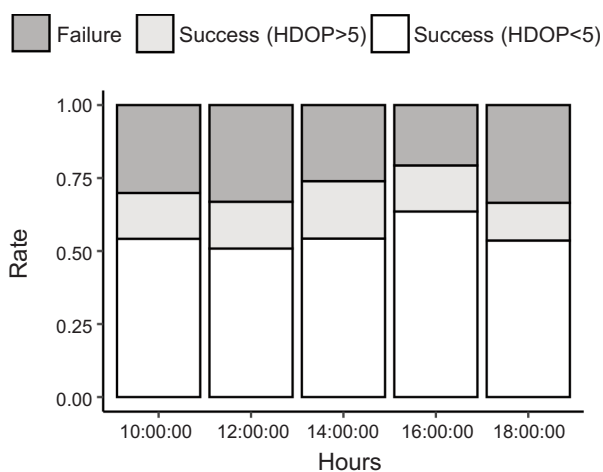


Fig 1. Rate of failure and success of GPS fixes attempted across scheduled hours of day in the tracking of 14 Lilford Woodpecker adults. Accurate fixes were filtered according to HDOP (horizontal dilution of precision) values lower than 5, which is roughly equivalent to a location error lower than 20 m.

was slightly higher at 14:00 and 16:00 hours than in other scheduled hours of day (Fig. 1).

Overall, the greater number of fixes were collected at intermediate distances from the nest regardless of the studied period (Fig. 2). However, there were differences between sexes: the distribution of fixes was left-skewed towards closer locations from the nest in females, except in the post-breeding period ($n = 6$) (Fig. 2).

The mean size of home range (\pm SD) according to 95% KDE estimator was 303.14 ± 145 ha, with

individual home ranges ranging from 86 to 585 ha (Table 1). Mean (\pm SD) 80% KDE estimate was 191.28 ± 101.4 ha, and the mean core-area was 80.39 ± 48.68 ha (\pm SD) (Table 1). 95%, 80% and 50% KDE estimates were between 5–10 ha larger when only individuals with stabilized accumulation curves ($N = 11$) were considered.

On the basis of the 6 birds tracked over both breeding and post-breeding periods, we found that KDE 95% home ranges were not statistically different between periods ($t = -1.18$, $p = 0.29$). KDE 80% and KDE 50 were not significantly different either ($t = -1.03$ and -1.04 , $p = 0.35$ and 0.34 ; respectively). In most of these birds, accumulation curves of home range stabilized after 20–30 tracking days (a minimum of 37 accurate fixes) over the breeding period, and they did no substantially change over the post-breeding period (Fig. 3).

At all KDE levels and tracking periods, mean values of home range were larger for males than females (Table 1). The same pattern was found when home ranges of concurring males and females (two pairs) individuals were visually examined. Furthermore, in both cases, male's home range encompassed female's one (Figs. 4A and 5B). One of these individuals was tracked over 2017 and 2018, displaying a highly congruent home range across years but distant nest locations (Fig. 4C).

In most cases, the shape of the home ranges was irregular and the nest was located far away from the center of the 95% KDE (Fig. 5). A buffer area of 500 m radius around the nest overlapped

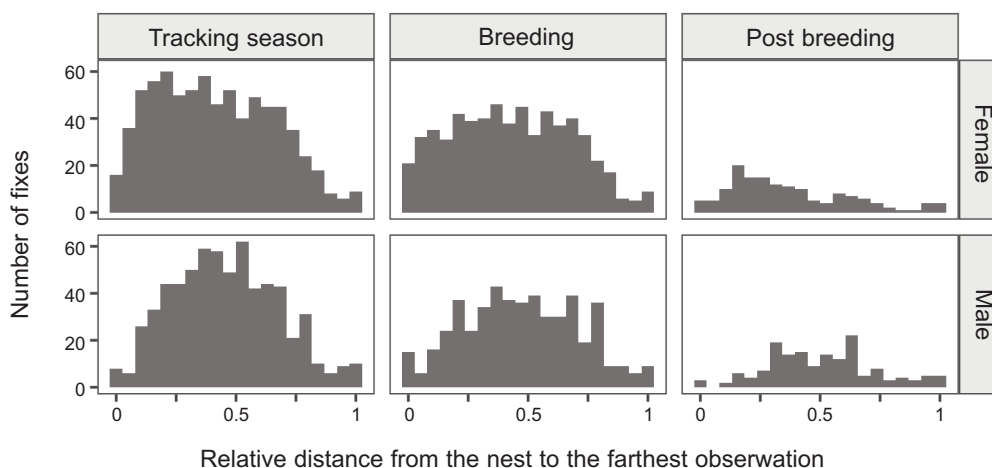


Fig 2. Distance of fixes from the nest obtained from GPS-tracking Lilford Woodpecker throughout the tracking season and breeding and post-breeding periods. For the sake of comparison between individuals, fix distances are normalized according to the largest observed value for each individual.

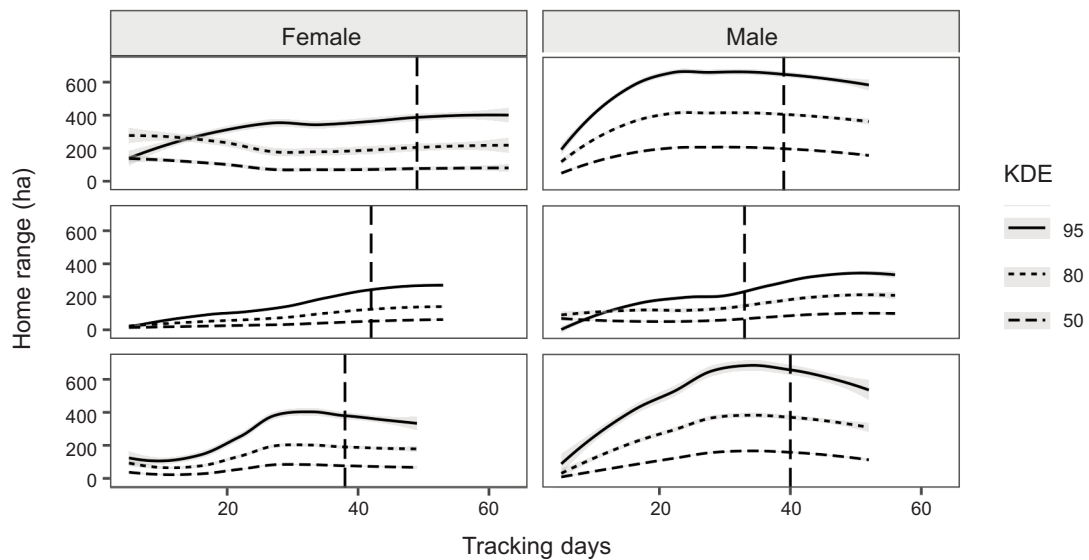


Fig 3. Accumulation of the home range area based on kernel density estimators (KDE) over tracking days in six Lilford Woodpecker individuals monitored over both breeding and post-breeding periods. Shaded areas stand for confidence intervals. Vertical dashed lines indicate approximately the beginning of the post-breeding period (1st of August).

only the core areas partially, whereas the shape of forest stands were highly inconsistent with the shape of home ranges (Fig. 5).

Results of the multiple linear model showed that the size of the home range (including both breeding and post-breeding periods) was significantly explained by the sex of individuals, the number of fixes and the failure rate ($F_{3,10} = 11.46$, $p = 0.001$, $R^2 = 0.71$). The same results was obtained when breeding home ranges were analyzed ($F_{3,10} = 5.65$, $p = 0.01$, $R^2 = 0.52$). The number of fixes and the failure rate were both significantly related (or marginally significant in the case of the breeding home range), though their effect was weak (Table 2). Once accounted for these variables, models gave statistical support for the observed difference between sexes in 95%

KDE home ranges (Table 2). In contrast, none of the explanatory variables were significantly ($\alpha = 0.05$) related to 80% and 50% KDEs ($F = 1.39$, $p = 0.30$; $F = 0.85$, $p = 0.50$, respectively), even though mean differences were apparent between sexes (Table 1). Models based on the breeding home range were not significant either (80% KDE: $F_{3,10} = 1.32$, $p = 0.32$; 50% KDE: $F_{3,10} = 1.09$, $p = 0.40$).

DISCUSSION

Recent technological advances have made possible the development of lightweight GPS-tagging devices for small-size birds (see review in Liu et al. 2018). Our results demonstrate that miniaturized GPS-tags of 3.4 g are suitable for tracking adults of the forest specialist Lilford Woodpecker. As expected for devices lighter than 5% of the body-weight of the carrying bird (Snijders et al. 2017), we found neither physical damage on birds nor any other negative effect on the performance of adult individuals. In fact, survival of tagged adults (75%) and nest success (81%) were close to mean values previously reported for the WBW (see Pasinelli 2006, and reference herein). In contrast, we were unable to assess the use of GPS-tags for tracking juveniles, because the sampling size ($n = 3$) was insufficient given the high mortality observed. Juveniles of the WBW have one of

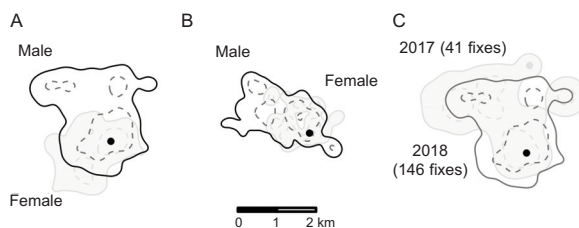


Fig 4. Home ranges based on 95% kernel density estimator (KDE, solid line) and 50% KDE (dashed line) of two concurring pairs of the Lilford Woodpecker (A and B) and of the same male individual in two successive years (C). Black dots indicate nest locations. 80% KDE is omitted for clarity.

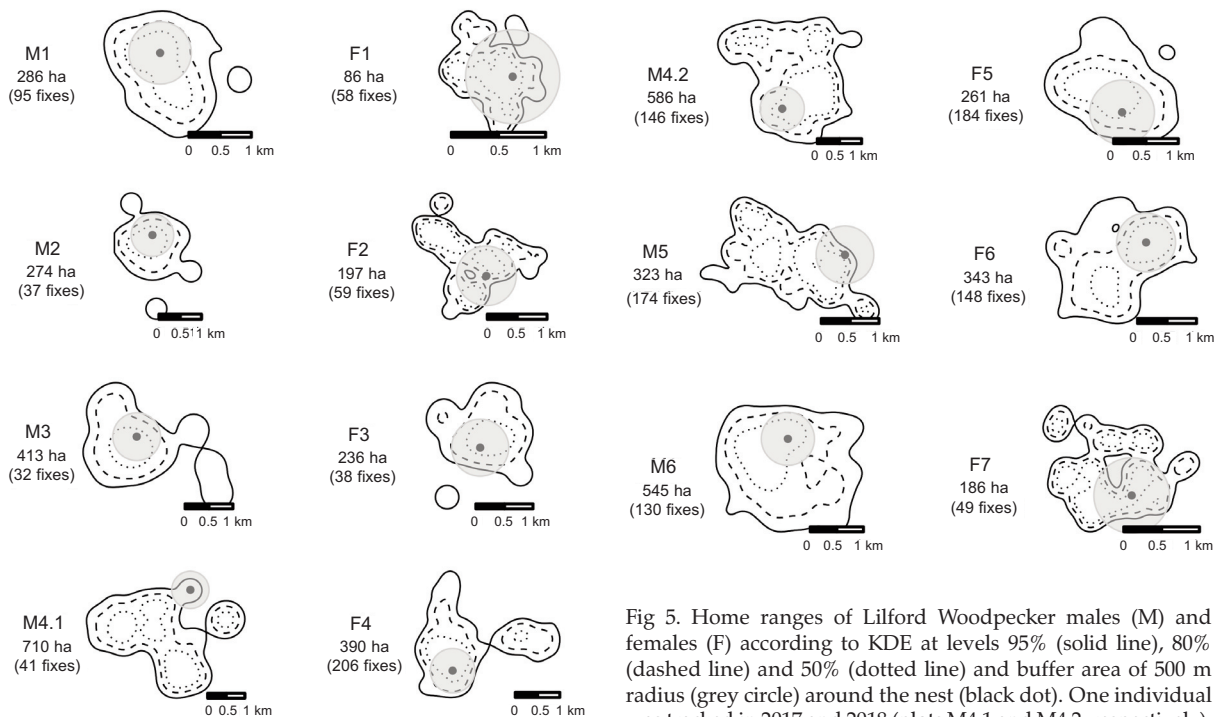


Fig 5. Home ranges of Lilford Woodpecker males (M) and females (F) according to KDE at levels 95% (solid line), 80% (dashed line) and 50% (dotted line) and buffer area of 500 m radius (grey circle) around the nest (black dot). One individual was tracked in 2017 and 2018 (plots M4.1 and M4.2, respectively).

the lowest survival rate among European woodpecker species (Pasinelli 2006), because their low development from nestling at the moment of first flight and their constant food calls during first days out of the nest make them particularly vulnerable to predation (Grangé 2015 and D.C. per. obs.). Some studies have shown that carrying of GPS-tags can increase predation risk for birds by making them more visible and reducing their ability to escape predators (Severson et al. 2019). However, it is unclear whether this happened to juveniles of the WBW.

Monitoring of adults lasted up to 124 days, which is lower than the average tracking duration of conventional VHF units. Still, the life of the battery was long enough for the aim of this study (characterizing accurately Lilford Woodpecker's

breeding and post-breeding home range size). In fact, we found that the home ranges of two third of tagged adults stabilized within the 20–30 days. In the few other individuals, GPS-devices stop collecting fixes two weeks after deployment probably due to technical issues or an unexpected battery drain. Whatever the reason, our accumulation curves suggest that home range areas of these particular individuals were underestimated, and so was the mean size of the Lilford Woodpecker's home range reported in this study.

The mean failure rate reported in this study (30%) is within the range observed in other wildlife studies conducted in forest habitats. For instance, Cain et al. (2005) based on a review of 35 studies of wildlife tracking found a mean failure rate for GPS transmitters of 30.7%. The

Table 2. Effect of sex, number of successful GPS fixes and failure rate (percentage of failed fix attempts) on home range estimates of the Lilford Woodpecker based on 95% kernel density estimator. The multiple linear model was fitted with data from the whole tracking season and the breeding period, separately.

Dataset	Predictor variable	Estimate	SE	t	p
Tracking season	Sex: male	5.16	1.25	4.14	0.002
	n of fixes	0.04	1.25	4.04	0.002
	Failure rate	0.11	0.05	2.41	0.03
Breeding period	Sex: male	5.35	1.80	2.97	0.014
	n of fixes	0.04	0.02	2.735	0.021
	Failure rate	0.13	0.07	1.92	0.083

filtering criterion adopted ($\text{HDOP} < 5$) further reduced the effective number of fixes used for home range estimation, but not as much as expected under a dense canopy forest (Recio et al. 2011). The proportion of accurate fixes (76%) was indeed as high as observed by Liu et al (2018) under experimental conditions, which suggests that the filtering criterion adopted was not too restrictive.

Aside from a slight increase in accuracy of fixes in the afternoon (probably due to positioning of the satellites), we found no other clear temporal pattern in the loss of fixes or location errors. Given that canopy cover, the most influential variable on fix failure (see D'Eon et al. 2002, Recio et al. 2011), was similarly high and homogeneous across studied forest, it is likely that differences in the proportion of losses and errors found between individuals were mainly driven by topographic differences (see Janeau et al. 2004). Importantly, the effect of these error on estimates of home range size, though significant, was minor, as evidenced by model coefficients, thus corroborating that home-range estimates are relatively robust to those bias (Frair et al. 2004).

Despite being conservative, our estimates of individual home ranges were much larger than previously reported elsewhere. In fact, estimated breeding and post-breeding home ranges (86–665 ha and 177–496 ha, respectively) were more than 3–15 times larger than that reported in radio-tracking studies from the Alps (20 ha in breeding season and about 100ha in post-breeding period, Ettwein et al. 2019), and also 3 times larger than those estimates inferred from observations of breeding pairs in multiple locations, including the Pyrenees (Aulén 1988, Scherzinger 1990, Wesolowski 1995, Carlson 2000, Melletti & Penteriani 2003, Grangé 2015). Also, our home range estimates fairly exceed the size of the territories (20–30 ha) previously suggested by Garmendia et al. (2006) in the Pyrenees. Such discrepancy may arise from other aspects than methodological ones (mapping-VHF-GPS technique or home range estimation method). Since the WBW is highly dependent on dead wood for nesting and foraging (Melletti & Penteriani 2003), we suggest that the scarcity of this resource in Pyrenean managed beech forests might have led individuals to use larger areas than in the Alps, where the dead wood is more abundant (Christensen et al. 2005). The low availability of dead wood could also explain the high mobility of individuals observed in this study (up to 2 km from their nest). Unlike

in the nominate species (Ettwein et al. 2019), the breeding and post-breeding ranges are similar in the Lilford Woodpecker. This finding is consistent with the unexpected long post-fledgling period observed in this study (up to 22 weeks after leaving the nest), which may indicate that juveniles are following the parents in their movements across a relatively stable home range over several months.

Another striking finding of this study was the larger home ranges of males than of females, even within the same territory. Although no sexual differences have been documented so far in the WBW (Ettwein et al. 2019), such differences are not rare in other woodpecker species. For instance, Kajzer et al. (2019) found that males' home ranges of the Three-toed Woodpecker *Picoides tridactylus* were two times larger than that of females. There are at least two plausible explanations for the inter-sex difference in the home range size. Some authors suggest that it may be related to the bill size dimorphism (Aulén & Lundberg 1991, Stenberg & Hogstad 2004, Hogstad & Stenberg 2005, Myczko et al. 2020), because the longer and heavier bill of males would allow them feeding a wider range of resources (Aulén & Lundberg 1991, Stenberg & Hogstad 2004), and thus, finding food in larger areas than females. However, this explanation assumes that food resources are irregularly distributed across the landscape, a fact that remains to be tested in the study area.

Another possible explanation is related to inter-sexual differences in territory defense: males could invest more effort marking the territory not only near the cavity, but in distant locations from the nest (Catchpole & Slater 1995). This hypothesis could also explain why female fixes clustered at closer distance from the nest than those of males throughout the entire tracking season. However, such behavior is not universal among woodpeckers. Furthermore, in some cases females can be as aggressive as males (Fedy & Stutchbury 2005). Further studies are therefore needed to support (or reject) this hypothesis in the Lilford Woodpecker.

As in other woodpecker species home ranges of both females and males were irregularly shaped and not centered on nests, which may reflect territorial conflicts between individuals (Bocca et al 2007, Camprodón et al. 2015). Taken together, these findings, while preliminary, do not support the use of a forest stand of 20–30 ha (Garmendia et al. 2006) or radial buffer areas around the nest (Campion et al. 2014, Cárcamo et

al. 2014) as conservation spatial units. These units may not only be insufficient to meet the habitat requirements of the Lilford Woodpecker, but can also be ineffective if irrelevant areas for the species (some of those around the nest; see Fig. 5) are included. Given the large territories used by the Lilford Woodpecker, forest management measures and forestry planning must be designed on a large scale too (see also Carlson 2000 and Camprodón et al. 2007), and without neglecting the particular interests of the local forest owners. The existence of large unprofitable areas in the Pyrenees that could only be exploited with the support of public funding, would provide an opportunity to minimize potential local conflicts.

In conclusion, our study showed for the first time that GPS-telemetry is not only technically feasible for monitoring WBW adults, but very valuable for achieving a deeper understanding of the species' home range. Nevertheless, the forest canopy condition and mountain topography of the species' habitat, among other factors, can substantially reduce the number of accurate fixes collected by GPS-tags. For such reason, GPS data need to be analyzed with caution. After filtering implausible fixes according to HDOP values, we found that home ranges were unexpectedly large, irregularly shaped and relatively constant between the breeding and post-breeding period. We also found that males' home ranges were larger than those of females. Despite this novel evidence, questions about the fine-scale association between movements of the WBW and habitat features remain. The high quality of GPS telemetry data provides a solid basis for future work in this regard.

ACKNOWLEDGEMENTS

This study was supported by the POCTEFA HABIOS project, funded by FEDER. The Government of Navarre provided the necessary permits for the capture and marking of birds. IP was supported by the University of the Basque Country (ref. ESPDOC18/43). Our greatest gratitude to Gorka Gorospe, Gonzalo Dean, Alfonso Senosiain and Susana Cárcamo for their invaluable help in locating nests. We also thank the Environmental Guards of the Demarcations of Aezkoa and Ultzama, and in particular, Xabier Azpiroz and Javier Zuazu, for their assistance in the fieldwork. Ola Olsson and an anonymous reviewer provided very helpful comments on an earlier draft.

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STRESZCZENIE

[Wielkość arealów osobniczych dzięciołów białogrzbietych w Hiszpanii: wyniki pierwszych badań z zastosowaniem technologii GPS]

Dzięcioł białogrzbiety jest jednym z najrzadszych i najbardziej zagrożonych dzięciołów w Europie. Intensywna gospodarka leśna spowodowała powszechny spadek jego liczebności. Jednym z ponad 10 rozpoznawanych podgatunków dzięcioła białogrzbietego, występującym w górach południowej Europy oraz na zachodzie i w środkowej części Kaukazu, jest *Dendrocopos leucotos lilfordi*, który czasami podnoszony jest do rangi osobnego gatunku (dzięcioł łuskogrzbiety). W porównaniu z podgatunkiem nominatywnym (*D. l. leucotos*) podgatunek *lilfordi* jest bardziej osiadły oraz odznacza się niższą produktywnością populacji. Populacja podgatunku *lilfordi* zasiedlająca hiszpańskie Pireneje jest szacowana na mniej niż 200 osobników. Przy podejmowaniu działań ochronnych, w celu zapewnienia minimalnych wymagań środowiskowych, sugerowane jest zachowanie stref ochronnych o promieniu 500 m od gniazda. Jednak dane dotyczące wielkości i kształtu arealów osobniczych zostały dotychczas zebrane tylko dla podgatunku nominatywnego. Biorąc pod uwagę różnice między podgatunkami oraz specyfikę siedlisk zajmowanych przez podgatunek *lilfordi*, konieczne są podobne badania, których wyniki mogą zostać zastosowane w praktyce ochrony tego podgatunku. Konwencjonalne badania dzięciołów białogrzbietych z zastosowaniem telemetrii są ograniczone ze względu na złożoną topografię lasów górskich, natomiast dla tak małego ptaka (masa ciała ~100 g) jeszcze do niedawna nie było dostępnych urządzeń GPS, które cechują się znacznie większą precyzją uzyskiwanych lokalizacji. W pracy wykorzystano oraz oceniono użyteczność nowoczesnych, zminiaturyzowanych (3,4 g) urządzeń GPS do scharakteryzowania arealów osobniczych dzięciołów białogrzbietych z podgatunku *lilfordi*. W latach 2017–2019 schwytano w okresie lęgowym i założono lokalizatory GPS 14 osobnikom. Urządzenia GPS były zaprogramowane do zapisywania pięciu lokalizacji dziennie w ciągu trzech niekolejnych dni w tygodniu w okresie lęgowym (maj–czerwiec) oraz połęgowym (lipiec–październik). Lokalizacja zapisywana była co dwie godziny między godz. 10:00 a 18:00. Taki sposób zbierania danych umożliwił nie tylko ocenę wielkości arealów zajmowanych przez dzięcioły, ale także pozwolił na oszacowanie dokładności pomiarów

lokalizacji oraz częstości, z jaką próby zapisania lokalizacji kończyły się niepowodzeniem. Brak zapisanej lokalizacji może być związany z charakterystyką terenu — jego topografią lub roślinnością (wysokość koron, zagęszczenie drzew) wpływającą na połączenie z satelitami GPS.

W analizie wyników oprócz liczby brakujących lokalizacji określono liczbę lokalizacji o dokładności większej i mniejszej niż 20 m. W dalszych analizach uwzględniono tylko te ostatnie. Oszacowano 3 kategorie wielkości arealów, biorąc pod uwagę liczbę lokalizacji: centrum aktywności (core area) obejmujące 50% stwierdzeń, oraz areal osobniczy wyznaczony na podstawie 80 i 95% lokalizacji.

Średnio wskaźnik niepowodzeń w zapisie lokalizacji wyniósł 30%, zaś wśród zapisanych lokalizacji 76% miało dokładność poniżej 20 m, najwięcej użytecznych do analiz lokalizacji uzyskano w godzinach popołudniowych (o 14:00 i 16:00) (Fig. 1). Średnio urządzenia GPS zapisywały lokalizację dzięciołów przez ponad 60 dni (Tab. 1). Średnia wielkość areалу (~300 ha, Tab. 1) była kilkakrotnie większa niż podawana dotychczas dla dzięciołów białogrzbietych i nie różniła się dla okresu lęgowego i połęgowego, choć samice w okresie lęgowym stwierdzane były częściej bliżej gniazd (Fig. 2). Stwierdzono, że po 20–30 dniach namierzania ptaków (minimum 37 dobrej jakości zapisów lokalizacji) szacowana wielkość areалу jest już ustabilizowana (Fig. 3). Arealy samców były większe niż samic (Tab. 1, Fig. 4, 5). W przypadku osobnika, u którego lokalizator GPS został założony w dwóch sezonach lęgowych stwierdzono, że wielkość jego arealów w poszczególnych sezonach była zbliżona, pomimo, że gniazda położone były dość daleko od siebie (Fig. 4C). W większości przypadków kształt arealów był nieregularny, a gniazda położone były dość daleko od centrów aktywności (Fig. 5). Strefa wokół gniazda o promieniu 500 m proponowana jako sposób ochrony najbardziej wykorzystywanych przez dzięcioły białogrzbięte siedlisk pokrywała się z centrami aktywności podgatunku *lilfordi* tylko w pewnym stopniu (Fig. 5).

Uzyskane wyniki podważają użyteczność wcześniejszych zaleceń dotyczących ochrony małych obszarów wokół gniazda lub pojedynczych drzewostanów. Lokalizatory GPS mogą dostarczyć nowych i dokładnych informacji o wielkości arealów tego gatunku, zwłaszcza, jeśli zostaną wzięte pod uwagę potencjalne źródła błędów w zapisie lokalizacji.