UNIVERSIDAD DE CHILE -FACULTAD DE CIENCIAS -ESCUELA DE PREGRADO

"Importance of habitat quality and composition in the movement of Magellanic woodpeckers (*Campephilus magellanicus*) in a heterogeneous forest landscape."

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BIOGRAFÍA

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A mi mamá Nancy y mi papá José, por enseñarme que con pequeños pasos podemos lograr grandes cosas.

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Lista de abreviaciones

AIC	Akaike Information Criteria
ARS	Area of Restricted Search
FPT	First-Passage Time
LME	Linear Mixed Effects model
PSRI	Plant Senescence Reflectance Index
VIF	Variance Inflation Factor

RESUMEN

La calidad del hábitat influencia el movimiento y las decisiones de forrajeo de los animales salvajes en escalas jerárquicas de tiempo y espacio, pero la heterogeneidad puede imponer restricciones en el movimiento, lo que impide que los animales sean forrajeadores eficientes. En esta investigación, analizamos los efectos de la calidad, estructura y composición del hábitat sobre los movimientos del carpintero magallánico (*Campephilus magellanicus)*. Se utilizó el tiempo del primer cruce para determinar las áreas de búsqueda intensiva como una función de las variables del hábitat, incluyendo estimadores de la calidad del hábitat en escalas de sitio y de ámbito de hogar. El análisis estadístico se llevó a cabo por modelos Lineares con Efectos Mixtos, teniendo como variable dependiente al tiempo del primer cruce y variables independientes a los atributos del hábitat. El promedio de los coeficientes del modelo indicó que el tiempo del primer cruce correspondía a una función de la calidad y composición del hábitat. Los carpinteros permanecieron más tiempo en sitios de calidad de hábitat mayor y también en sitios dentro ámbitos de hogar con mejor calidad de hábitat. En contraste, los individuos permanecieron menos tiempo en sitios con hábitats abiertos incluyendo, matorrales, praderas y turberas. La composición de las especies arbóreas también tuvo un efecto sobre el tiempo del primer cruce, donde los carpinteros permanecieron menos tiempo en sitios que presentaban Ñirre (*Nothofagus antárctica*). Los resultados son consistentes con estudios anteriores, en donde se demuestra que la calidad y composición del hábitat son variables de importancia para el movimiento de las especies a través de paisajes heterogéneos. A pesar de que los carpinteros adoptaron búsquedas intensivas en sitios de mejor calidad, el movimiento pudo verse influenciado por factores ecológicos diferentes a la calidad del hábitat, como el riesgo de depredación o la habilidad de detectar presas en hábitats alternativos.

Palabras clave: área de búsqueda intensiva, calidad del hábitat, escalas espaciales

ABSTRACT

Habitat quality influences the movement and foraging decisions of wild animals over a hierarchy of scales including space and time, but habitat heterogeneity may also impose restrictions on movement that prevent individuals from being efficient foragers. Here, we address the independent effects of habitat quality, spatial structure and composition on the movement of Magellanic woodpeckers (*Campephilus magellanicus*). We used a measure of time spent by individuals in a given area, the First-Passage Time (FPT), to determine the adoption of area restricted search (ARS) as a function of habitat variables, including remote sensing estimates of foraging habitat quality at the site and home range scales. The statistical analysis was performed using Linear Mixed Effects models, were the dependent variable correspond to the FPT and the independent variables were the habitat attributes. Averaged model coefficients showed that FPT was a function of foraging habitat quality and composition. Woodpeckers spend more time in sites of higher quality habitat and in sites within home ranges that include forest of better quality. In contrast, woodpeckers spend less time in sites with open habitats including shrub, grassland, meadows and peatlands. The composition of tree species also affected FPT, with woodpeckers staying less time in sites dominated by the Antarctic beech (*Nothofagus antarctica*). Results support the relative contribution of habitat quality and composition as drivers of movement across heterogeneous habitat. Although woodpeckers were more prone to adopt an ARS at forest sites of better quality, movement would also be influenced by ecological factors different from foraging habitat quality, such as predation risk or their ability to detect prey in alternative habitats.

Keywords: area restricted search, foraging habitat quality, spatial scales

INTRODUCTION

Heterogeneity in habitat quality influences habitat selection, movement and foraging of wild animals over a hierarchy of space-time scales (Holling, 1992). A behavioral decision, such as habitat selection, movement and foraging, is performed each time an animal searches for prey in a microhabitat within a habitat patch, with such a decision being made after choosing a habitat patch within its home range (Hutto, 1985; Kristan, 2006). Optimal foraging theory provides a basis for understanding spatio-temporal hierarchical decisions of animals emerging from their “perfect” knowledge on habitat quality (Stephens & Krebs, 1986). Animals whose movements are based on acquired knowledge of habitat quality should find the most profitable resource patches within their home ranges, minimizing the searching time for resources while optimizing residence times (Schultz & Crone, 2001; Ovaskainen & Cornell, 2003; Cobbold & Lutscher, 2014). However, ecological factors, such as territoriality and structural and compositional heterogeneity of the habitat, might influence animal biomechanical, cognitive and perceptual processes preventing it from being efficient or optimal foragers (Folse et al. 1989; Fagan et al. 2013; Avgar et al. 2015; Doherty and Driscoll 2018; Nathan et al. 2008). In particular, the ability of animals to return to high quality patches could decrease in heterogeneous habitat where resources are difficult to be found or have unpredictable spatio-temporal dynamics, and also by the presence of habitat features acting as barriers to movement (Nandintsetseg et al. 2016; Marchand et al. 2017; Spiegel et al. 2017). Therefore, understanding the mechanistic bases of movement in heterogeneous habitat, and their ecological consequences, is central for managing and restoring degraded landscapes (Nathan et al., 2008), in order to emulate habitat structural or compositional heterogeneity that enhances habitat use and survival.

Natural and human-driven changes in the quantity and quality of habitats may be particularly important in shaping the movement patterns of animals with stable territories, specialized diets and narrow habitat choices. This type of species are expected to be more vulnerable to habitat loss, having to modify their home range or their diets to survive. That is the case of Magellanic woodpeckers (*Campephilus magellanicus*), for which main prey (wood-boring beetle larvae) exhibit a hierarchical spatial distribution, which is mostly restricted to decayed trees present in old-growth forest stands (Vergara et al. 2015), the predominant in the Magellanic woodpecker's habitat. Here, we address the independent effects of foraging habitat quality, structure and composition on the movement of Magellanic woodpeckers, a woodpecker endemic to subpolar and temperate Patagonian forest and considered as keystone species by providing cavities to other forest species (Beaudoin & Ojeda, 2011).

The space use of Magellanic woodpeckers is directly related to foraging habitat quality, with home range size being inversely proportional to the amount of coarse woody debris and availability of decayed trees (Ojeda & Chazarreta, 2014; Soto et al. 2012; 2017). At finer spatial scales, Magellanic woodpeckers select and adjust residency times based on the decay of trees, spending more time at trees with higher decay, a habitat cue informing woodpeckers about the presence of their main prey inside trees, such as larvae of the long-horned beetle (*Microplophorus magellanicus*) (Vergara & Schlatter 2004; Vergara et al. 2016; Vergara et al. 2017a; Soto et al. 2017). Thus, Magellanic woodpeckers use information about the habitat quality at different spatio-temporal scales and adjust movement decisions accordingly (Vergara et al. 2015; 2016). Woodpeckers further respond to changes in habitat quality through individual decisions that scale up to local population levels, leading to more abundant woodpecker populations at forest sites where trees exhibit more advanced decay levels (Vergara et al. 2017b). Although these facts suggest Magellanic woodpeckers guide their movements based on perceptual and memorized information on habitat quality, structure and composition, heterogeneity may also influence their movement decisions.

Magellanic woodpeckers usually establish their territories in landscapes varying in habitat structure (e.g., old-growth vs. second-growth) and composition, including forest dominated by different tree species as well as open habitat like prairies, bushlands, exotic beaver ponds and bogs (Ojeda & Chazarreta, 2014; Soto et al. 2012; 2017). Magellanic woodpeckers may respond to such a habitat heterogeneity by modifying their movement geometry when finding an open habitat, which might be perceived as a movement barrier, but also by modifying their ability to find prey as forest structure or composition change. In order to assess the role of habitat heterogeneity in quantity and quality, we address the movement of woodpeckers by using first-passage time (FPT) analysis, a methodological framework intended to distinguish habitats used for foraging based on the time spent in the vicinity of successive path locations (Fauchald & Tveraa 2003). We expect that woodpeckers should respond to heterogeneity in habitat quality, structure and composition by adjusting first-passage time while moving across the landscape. Within this framework, woodpeckers should remain longer (i.e., larger first-passage times) as habitat quality increases at different spatial scales, but also in forest sites covered by old-growth forest and without open habitats. A description of this pattern is relevant to the conservation of woodpeckers, due to the knowledge on their responses to gradient of the studied habitat features that might be critical to conserve this species. This could give an insight of the areas that should be subject to protection and serve as a baseline for the assessment of the landscapes that might provide suitable habitat if restored.

METHODS

Study Area

We studied Magellanic woodpekers at a forest landscape located on Navarino Island, in the southernmost region of Chile (Fig. 1).The study landscape is covered by southern beech forest of *Nothofagus betuloides, N. pumilio* and *N. antartica*, Open habitats also are present in this landscape and include patches of shrublands, wetlands, peatbogs, meadows and ponds, with the latter two being produced by the introduced beaver (*Castor canadensis*) (Soto et al. 2012). The cover percentage (Table 1) of the *Nothofagus* species and the open upland (shrublands and meadows) and lowland habitats (peatbogs and ponds) were measured dividing the area, in which the vegetation is present, by the total area of study (350900 (ha) approximately), multiplied by 100.

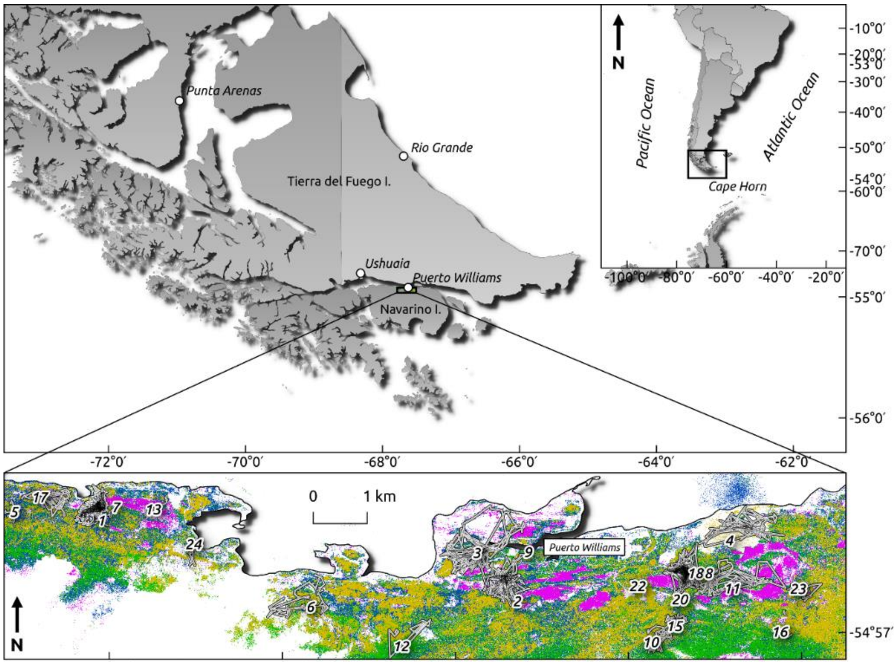

Fig. 1. Map of the study site showing the vegetation composition, the tree species and the 24 trajectories. (Green: *Nothofagus pumilio*; Yellow *Nothofagus betuloides*; Blue: *Nothofagus antarctica*; Purple: peatlands)

Movement data

A database of GPS relocation coordinates from 24 tagged male Magellanic woodpecker individuals was used (e.g., see Soto et al. 2017; P.M. Vergara *unpublished*). GPS coordinates were acquired using ATS G10 UltraLITE GPS Logger (Advanced Telemetry Systems, Inc.) devices, each being attached to a very high-frequency transmitter (ATS model A2440 2.3 g) for later recovery. GPS devices were placed on the back of male adult woodpeckers using a small amount of epoxy to six feathers. Magellanic woodpeckers are territorial, with individuals organized into family groups conformed by a pair of adults and one or two juveniles (Ojeda, 2004). Males guide the family group by eliciting a dominant social behavior while moving across forest habitat (Duron et al. 2018), hence GPS-tracking was limited to adult males. The positions of woodpeckers were recorded every 5 minutes, between 08:00 to 16:00 hrs and during 2014-2015 post-reproductive season (austral late spring and summer). The accuracy (measurement error) of GPS relocations was estimated to be 12.9 m (SE= 2.8, n= 12), as estimated from the Euclidean distances (m) between the GPS positions and the actual position of a reference point identified on an imagery-based map layer (P.M. Vergara *unpublished*).

For every woodpecker we calculated the maximum and overall speed (Table S1). Maximum speed was estimated using the Euclidean distance divided by the time lag between the GPS relocations. Overall speed was estimated by dividing the total travelled distance (i.e. the sum of the distance between GPS relocations) by the total time of a given burst of continuous relocations.

Data analysis

The code programmed for the analysis is available at GitHub (https://github.com/fmaron/woodpeckers).

First-passage time

We measured the first-passage time using the magellanic woodpeckers GPS relocations. The first-passage time (FPT) is defined as the time spent by an individual in circles of radius *r* centered on subsequent GPS positions along each trajectory. Hence as *r* increases, longer trajectory sections will be included within the circle (Fauchald & Tveera, 2003). The first-passage time for a circle with radius *r* located at position *i*, $t(r_i)$, considers the time that an individual takes to move along its trajectory from the edge to the center of the circle and the subsequent time up to the edge of that circle (Frair et al., 2005).

In order to estimate the FPT, we used the R package adehabitatLT (Calenge, 2006). Since the package is designed to deal with regular trajectories, this means constant time lag between successive relocations, we added missing values to define regular trajectories to our data (see Fauchald & Tveera, 2006). The last 6 woodpeckers data were excluded from further analysis, since it was not possible to define a regular trajectory, due to the different time lag between relocations (Fig. S1). On the other hand, the first-passage time method is designed for trajectories with 3 or more relocations so the data with less than 3 observations were eliminated (Table S1). As 6 observations were excluded, we estimated the first-passage time (FPT) from the trajectories (movement paths of length *n*) of GPS positions (i.e., *i*=1, 2, …, n) of 18 woodpecker individuals.

The relative variance of the first-passage time defined as $S(r) = Var[log(t(r))]$, increases with the circle radius because larger circles comprise trajectories that are longer and more variable in length. We established the proper spatial scale of FPT analysis by searching the value of *r* that maximize $S(r)$, because the ability of the FPT to detect area restricted search (ARS) increases as $S(r)$ takes maximum values (Fauchald & Tveera, 2003). The ARS is a behavioral mode characterized by slow and tortuous movements that are typically displayed by woodpeckers when selecting trees for foraging (Vergara et al.

2015; 2016). We maximized $S(r)$ for each trajectory and individual by estimating FPT over 50 different radii (*r*), in a range from 12 to 250 m, corresponding, respectively to the GPS accuracy, and a quarter of the calculated net distance displacement of Magellanic woodpeckers (see Barraquand et al., 2008). The proper FPT scale, *r* value at which $S(r)$ reached its maximum value, was determined by visually examining plots of $S(r)$ against *r*. From $S(r)$ plot examination, a set of 36 trajectories were retained out of 62 trajectories (Table S2; Fig. S2). When we did not observe a maximum value of $S(r)$, we assumed that the path traced by the woodpecker was random and did not represent a movement pattern including different behavioral modes, such as shown by the eighth trajectory of woodpecker 3 (Fig. S2). However, we considered proper FPT scales for trajectories where a local maximum was observed, such as the one shown by the first trajectory of woodpecker 4 (Fig. S2).

Habitat variables

Foraging habitat quality was estimated as the remote sensing-based Plant Senescence Reflectance Index (PSRI), which distinguishes between tree decay states based on the spectral carotenoid/chlorophyll ratio, with increasing values for increasing tree decay (Soto et al. 2017). We used a high-resolution (0.50 m) multispectral imagery from WorldView-2 sensor (2014) and an image segmentation algorithm to identify individual trees, estimate their PSRI and classify them by species of tree (e.g., Vergara et al. 2016; Soto et al. 2017). We used the digital supervised classification and a Bayesian maximum likelihood algorithm carried out by Soto et al. (2017) in order to classify habitat types as based on forest structure and habitat composition. From this habitat classification, we distinguished old-growth forest, second-growth forest, the dominant tree species of old-growth forest (*N. antarctica, N. betuloides* and *N. pumilio*), open upland habitats (including shrub and meadows) and open lowland habitats (peatlands and beaver ponds, the latter were excluded from further analysis). The PSRI values of the subpolar forest range from -2.7 to 0.4 (Soto et al., 2017).

We measured the percentage of habitat use by woodpeckers (Table 1) as the percentage of different vegetation at site scale (circles with the center on the position of the trajectory of each individual, described above). This means, the amount of area that the vegetation covers divided by the circle area and multiplied by 100. On the other hand, the mean PSRI was measured at site level (within circles) and at the study area (Table 1).

Statistical modelling

We assessed the association between FPT and habitat variables using Linear Mixed Effects models (LME) (Douglas et al., 2015). Habitats variables (i.e., predictors in the LME) were characterized within every circle (of radius *r*) on each trajectory. Based on the vegetation classification of each habitat variable at the circle scale (here referred to as "site" scale), we estimated the percentage of old-growth forest, second-growth forest, open upland habitats, open lowland habitats and the dominant *Nothofagus* species within old-growth forests. The mean PSRI was calculated for both spatial scales; all trees located at the site scale and at the trajectory scale (i.e. all trees across the trajectories), which was interpreted as the habitat quality at the home range scale (see Vergara et al. 2016).

The nature of movement data and its consequential spatial overlap between consecutive circles along trajectories prevented us from having independent data (Fig 2A). In order to avoid spatial autocorrelation in FPT data, we performed a randomization procedure, by randomly selecting subsets of not- overlapping circles for each trajectory (Fig 2B, 2C). Randomization procedure was repeated 1,000 times, resulting in 1,000 sets of trajectories, each containing trajectories with independent data for posterior LME analyses (see below).

The dependent variable (FPT) was divided by the area of each circle in order to obtain the time woodpeckers spent in an area of similar size (s/m^2), thus allowing comparison between trajectories with circles of different radii. The variance inflation factor (VIF) was used to check multicollinearity between the different habitats variables, with VIF > 10 indicating variables with high correlation (Craney & Surles, 2002). In order to drop correlated predictors, as based on VIF values, two alternative global models (each including a full set of independent predictors) were built (Table S3, Table S4, Table S5). The first global model included as predictors the cover (percentage) of dominant *Nothofagus* species, second-growth forest, open upland habitats and open lowland habitats, and the values of averaged PSRI at site and home range scales. The second global model included the same predictors of the first model, but replacing the percentage of each dominant *Nothofagus* species by the percentage of old-growth forest, as these variables were collinear. For each of the 1,000 data sets resulting from the randomization procedure (see above) we evaluated nested models containing all possible combinations of predictors for the first global model (total= 63 models) and the second global model (total= 30 models). The Akaike Information Criterion (AIC) and AIC weights were estimated for the 93 nested models fitted to each of the 1,000 independent data sets. The set of competing candidate models nested in the first global model (n=63,000 models) were supported (ΔAIC < 2) with a higher frequency (>80%) than that for the second global model (n=30,000; Fig S3). Therefore, we interpreted model coefficients from the best-supported models derived from the first global model. We computed model averaged coefficients based on the AIC weights for 1,000 different sets of candidate models using the RMark package of the software R. The resulting distribution of the model averaged coefficients was used to quantify p-values as the proportion of coefficient values greater than zero (if the mean was positive) or lesser than zero (if the mean was negative).

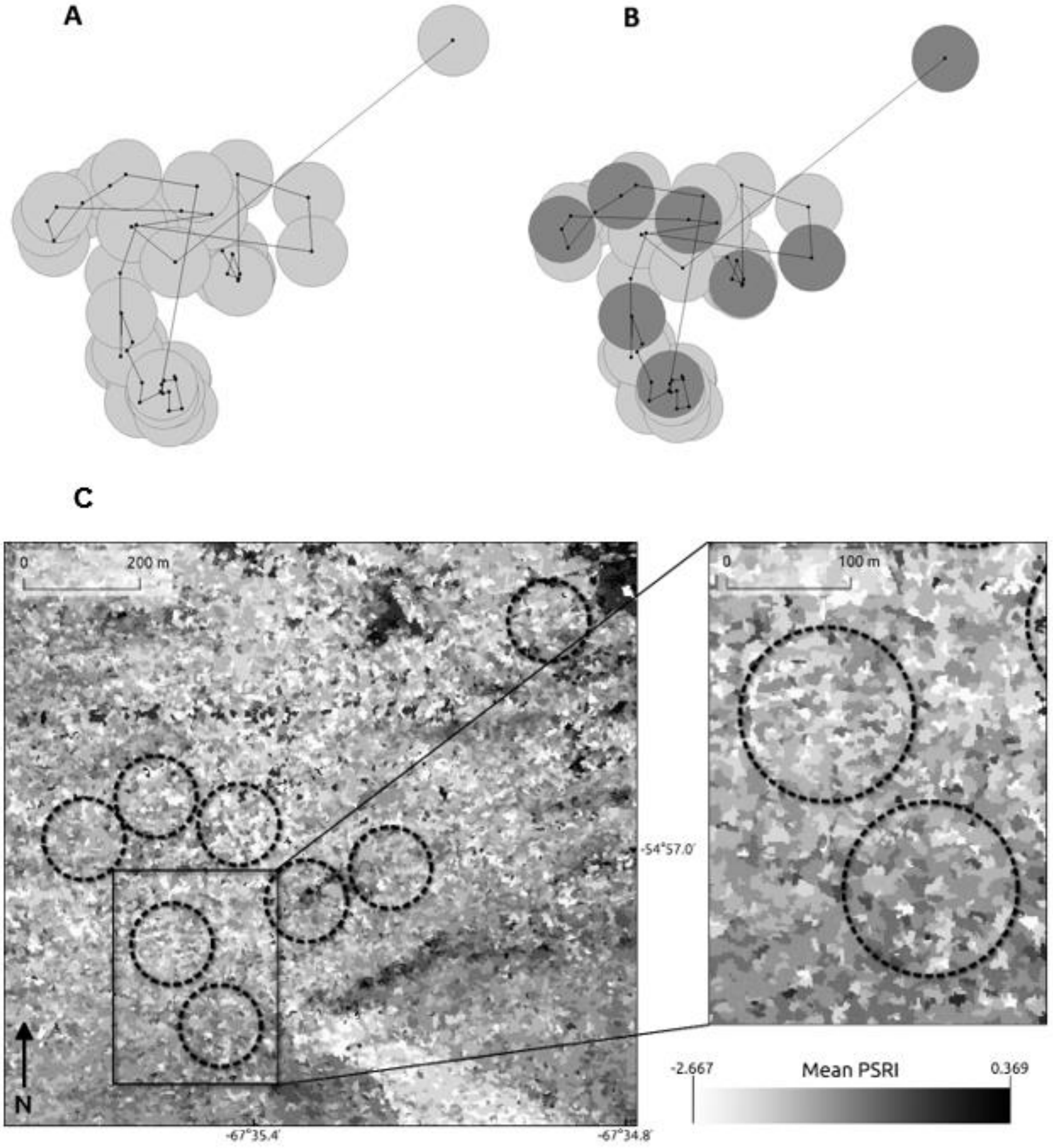

Fig. 2. Fifth trajectory of the woodpecker number 10, which represents the overlapping of the circles (A), the randomly selected circles (B), the circles used in this research with the mean Plant Senescence Reflectance Index classification of the habitat (PSRI) and a zoom of two of the circles used (C).

RESULTS

The cover percentage of *Nothofagus pumilio, N. betuloides* and *N. antarctica* were 29.2%, 29.5% and 6.4%, respectively (Table 1). Although forest stands in old growth stage of succession covers 45.3% of the land, forest disturbances have resulted in some second-growth stands (20.2%). Shrublands and meadows (upland open areas) covered the 10.2% of the study area and the peatbogs and pond (lowland open areas) the 6.5% (Table 1).

The percentage of habitat used by woodpeckers at the site scale (within circles) was higher for *Nothofagus pumilio* and *Nothofagus betuloides* tree species (29.5% and 29.2%, respectively) (Table 1). *Nothofagus antarctica*, upland open areas and lowland open areas were less represented on the habitats used by woodpeckers at the site scale (Table 1).

Table 1 Cover percentage of the vegetation in the study area, the mean senescence index (PSRI) with the respective standard error, the vegetation in the habitat used by the woodpeckers and the mean PSRI with the respective standard error.

Vegetation	%Cover	%Habitat Use
N. antarctica	6.38	9.02 ± 1.11
N. betuloides	29.23	28.01 ± 2.47
N. pumilio	29.52	29.21 ± 2.19
Open Upland habitats	10.21	7.51 ± 1.06
Open Lowland habitats	6.49	4.93 ± 1.26
Mean PSRI	-1.41 ± 0.71	-0.73 ± 0.03

The maximum and overall speed of woodpeckers varied among and within the individuals (Table S1). The highest maximum speed was 4.1 (m/s) and the maximum overall speed was 148.2 (m/s).

The First Passage-Time (FPT) was affected by heterogeneity in habitat quality and composition, as shown by model averaged coefficients (Table 2). At the site scale, the increase of the cover of open habitats (upland and lowland) resulted in woodpeckers spending less time on each site, depicted by its negative significant effect of open habitats on FPT (Table 2; Fig 3). In addition, tree species composition also influenced the time woodpecker remained on each site, having a FPT marginally and negatively affected by the cover of the *N. antarctica*. In contrast, mean tree decay had a significant and positive effect at the site scale, meaning that woodpeckers spent more time on sites with higher tree decay, increasing the FPT (Table 2; Fig 3). At the home range scale, tree decay had a marginally significant positive effect on FPT (Table 2; Fig 3), with individuals staying in positions where tree decay along the trajectory was higher. The second growth forest did not have an effect on neither of the site and home range scales (Table 2).

Table 2 P-value and mean of model-averaged coefficients associated with habitat variables affecting the First Passage-Time (FPT) of Magellanic woodpeckers, with the respective standard errors.

Attributes	Mean_coefficients	p-value
PSRI (site level)	0.104 ± 0.09	0.043*
PSRI (homerange level)	0.612 ± 0.28	0.060^{ms}
N. antarctica (%)	-0.002 ± 0.001	0.087^{ms}
N. betuloides (%)	0.000 ± 0.002	0.659
N. pumilio (%)	0.000 ± 0.001	0.648
Open Upland habitats (%)	-0.004 ± 0.003	0.026*
Second-growth forest (%)	0.000 ± 0.003	0.606
Open Lowland habitats (%)	-0.003 ± 0.002	0.009**

*p<0.05; **p<0.01; ms= marginally significant (0.05 < p < 0.10)

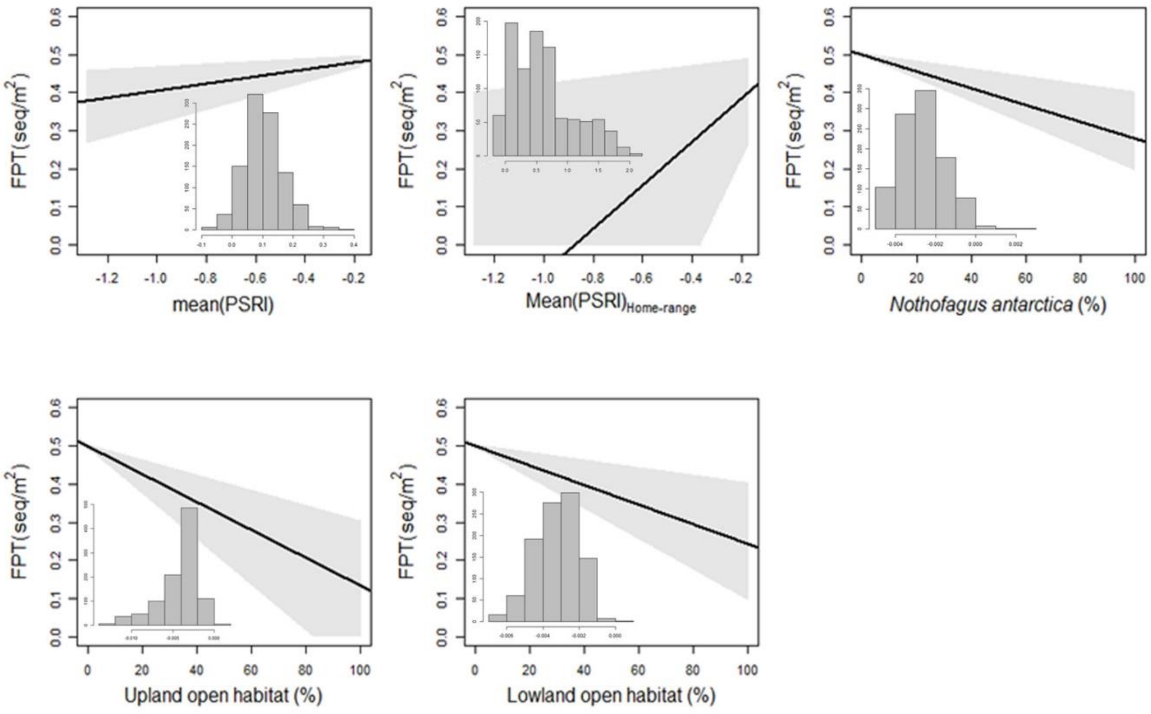

Fig. 3. Line charts and respective histogram of the variables that have a significant and marginal effect on the FPT.

DISCUSSION

Magellanic woodpeckers seems to guide movements based not only on foraging habitat quality at different scales, but also by the compositional heterogeneity in habitat. Magellanic woodpecker species have relatively stable territories, promoting the use of spatial memory to return to suitable sites (Vergara et al. 2015, see also Fagan et al. 2013). In addition, woodpeckers obtain information on foraging tree quality through either visually inspecting the trees in their vicinity while moving, or by probing tree sections (e.g., tree branches or trunks; Vergara et al. 2016). Furthermore, the positive (although marginal) effect of tree decay at the home-range scale on FPT suggests that space use and home range size adjustment are largely based on information Magellanic woodpeckers have on the quality of their home ranges (Soto et al., 2017; Ojeda & Chazarreta, 2014). The latter is not consistent with predictions of optimal foraging theory, according to which animals should leave patches faster when the environment is globally richer (Charnov 1976). However, our observations reveal Magellanic woodpeckers in poor foraging quality territories adopt a transient behavior (exploratory movement) more frequently than woodpeckers with more suitable territories (Vergara et al. *unpublished*). In addition, the residence time of woodpeckers in individual foraging trees is positively associated with the home range quality (Vergara et al., 2016), suggesting that individuals will spend more time at sites in which the home range foraging quality is higher.

The foraging behavior of Magellanic woodpeckers is similar to other woodpecker species around the world. *Picoides arcticus* do forage when surrounded by habitat of better quality (McKellar et al., 2015), and have a smaller home range in habitat of high quality (higher number of senescent trees) (Tingley et al., 2014). Similarly, *Colaptes auratus* fledglings occupy habitats of higher density of trees (Gow & Wiebe, 2014), suggesting that this type of habitat is more suitable for the specie.

Habitat composition was an important habitat attribute influencing woodpecker movements. Magellanic woodpeckers remained less time in sites containing open habitats, suggesting that woodpeckers tend to adopt a transient movement when moving across, or near to, meadows, shrub and peatlands. Although these findings are expected for species with a strong preference for forest habitat (as typically exhibited by woodpecker species), this result provides further guidance for protecting environments with high proportions of continuous, non-fragmented old-growth forest. Our field observations at this study site suggest that woodpeckers flying through open areas are more exposed to the attack of raptors, like the Southern Caracaras (*Caracara plancus*) and Chilean Hawk (*Accipiter chilensis*). Thus, our results could be interpreted as indicating that woodpeckers less likely to use forest boundaries, suggesting that conservations effort should consider protecting the remaining old-growth native forest, which should coalesce, so the open areas and edges will be reduced, especially in anthropogenic landscapes surrounding protected areas (Vergara et al. 2017b). Our results also provide insights into woodpecker's preferences for *Nothofagaceae* tree species composing old-growth forest ecosystems, as shown by the marginal negative effect of *N. antarctica* cover on the residence time of woodpeckers. Previous studies indicate woodpeckers staying less time foraging in *N. antarctica* trees than in *N. betuloides* and *N. pumilio* trees (Vergara et al. 2016), with a differing remotely-sensed decay of *N. antarctica* from the other *Nothofagus* species (Soto et al., 2017). These findings might suggest that woodpeckers foraging in old-growth forest of *N. antarctica* faces a distinctive, and possibly less abundant, assemblage of preys (i.e., saproxylic invertebrates) that is inherent to ecosystems with water saturated soils, as *N. antarctica* forest. However, Magellanic responses in environments with predominantly covered by *N. antarctica* deserve further exploration.

Particularly, woodpeckers were more prone to adopt an area restricted search (ARS) not only when moving across forest sites of better foraging quality, but also guiding their movements using home-range scale information and habitat characteristics represented here as tree species composition and forest age structure. The knowledge gained with this research have the potential to help conservation of Magellanic woodpeckers in landscapes subject to high pressures from anthropogenic land use change (e.g., Vergara et al. 2017b). With the use of these indicators it might be possible to distinguish the more suitable habitats for woodpeckers, leading to a better assessment of management solutions towards their conservation. This could be possible by restoring landscapes that already have human impact and preserving the remaining old-growth forest. Taking actions to preserve the Magellanic woodpecker would also help to preserve other forest species due to their ecological importance as primary cavity excavator of south Patagonian forest and even other possible important ecological roles (e.g. Soto et al., 2018).

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SUPPLEMENTARY MATERIALS

Table S1. Number of observations and the maximum and overall speed for every individual on each day.

ID	Day	Observations	Max_Speed (m/s)	Overall_Speed (m/s)
1	1	125	1.20	37.45
	2	254	2.75	116.66
	3	290	3.86	148.24
	4	311	3.10	134.41
	5	30	1.49	13.56
2	1	38	1.08	7.99
	2	100	1.57	25.14
	3	92	0.99	17.99
	4	87	0.89	14.59
3	1	37	1.63	6.46
	2	71	4.14	31.40
	3	62	1.76	18.19
	4	46	1.22	13.36
	5	71	1.75	22.95
	6	65	1.44	19.55
	7	62	1.91	23.52
	8	3	2.94	2.94
4	1	41	1.95	13.23
	2	68	2.53	21.92
	3	59	3.63	23.17
	4	72	3.76	34.26
	5	36	1.69	8.13
	6	6	0.83	1.47
5	1	17	1.12	3.97
	2	56	0.81	9.10
6	1	86	1.41	25.17
	2	11	1.03	2.37
7	1	47	1.96	26.65
8	1	62	1.11	14.72
	2	121	3.32	46.89
	3	96	1.11	30.05
9	1	11	0.50	1.32
	2	68	1.42	17.84
	3	56	0.80	10.38
	4	56	0.97	10.49
	5	55	1.50	13.26

Table S1. Continued.

ID	Day	Observations	Max_Speed (m/s)	Overall_Speed (m/s)
10	1	7	0.24	0.36
	2	37	0.94	8.97
	3	33	2.15	9.12
	4	47	0.81	9.45
	5	40	1.34	8.56
11	1	57	1.34	13.78
	2	129	2.14	37.19
	3	48	1.31	10.25
12	1	33	1.73	9.09
	2	32	1.53	7.66
	3	16	0.26	1.06
	4	1*	0.00	0.00
13	1	21	0.53	2.72
14	1	12	1.41	2.75
	2	60	0.56	7.99
	3	15	0.55	1.71
	4	4	0.26	0.38
15	1	15	0.42	1.86
	2	6	0.04	0.08
	3	4	0.15	0.16
16	1	13	0.89	2.29
	2	15	0.47	2.47
	3	2*	0.00	0.00
17	1	10	0.43	1.37
	2	109	2.35	22.68
	3	2*	0.00	0.00
18	1	84	1.10	22.22
	2	124	1.48	36.19
	3	117	1.36	33.64
	4	103	1.53	35.99
19	1	16	0.69	1.80
20	1	18	0.43	2.38
	2	3	0.07	0.07
21	1	11	1.09	1.65
22	1	14	1.27	2.37
23	1	28	0.68	5.29
	2	14	1.00	4.57
24	1	36	0.58	3.70
	2	14	0.86	2.12

*Insufficient observations

Table S2 Spatial scale (Radius) estimated using First Passage-Time (FPT) analysis applied to the movement trajectories of 18 different Magellanic woodpecker individuals (ID)

ID	Trajectory (n)	Radius (m)
1	1	70.29
1	2	157.71
1	3	143.14
1	4	50.86
1	5	21.71
2	2	133.43
2	3	133.43
3	4	138.29
3	5	46.00
3	6	41.14
4	1	138.29
4	2	84.86
4	4	80.00
4	5	99.43
5	1	123.71
6	1	70.29
6	2	80.00
7	1	50.86
8	1	128.57
9	1	89.71
9	2	133.43
9	3	216.00
9	4	99.43
10	2	70.29
10	5	70.29
11	3	157.71
12	4	31.43

Table S2 continued

ID	Trajectory (n)	Radius (m)
13	1	21.71
14	2	55.71
14	3	50.86
15	1	118.86
16	1	225.71
16	2	148.00
17	1	89.71
17	2	80.00
18	3	89.71

Table S3 Variance Inflation Factor (VIF) for habitat variables used in Linear Mixed Effects models accounting for the First Passage-Time of Magellanic woodpeckers

Attributes	VIF
N. antarctica (%)	17.5
N. betuloides (%)	66.7
N. pumilio (%)	76.3
Second-growth forest (%)	64.4
Old-growth forest (%)	78.6
Open Upland habitats (%)	1.6
Open Lowland habitats (%)	1.4
PSRI (site level)	6.6
PSRI (home-range level)	1.6

Table S4 Variance Inflation Factor (VIF) for habitat variables used in the first global Linear Mixed Effects model accounting for the First Passage-Time of Magellanic woodpeckers

Attributes	VIF
N. antarctica (%)	1.8
N. betuloides (%)	5.6
N. pumilio (%)	4.2
Second-growth forest (%)	5.5
Open Upland habitats (%)	1.6
Open Lowland habitats (%)	1.4
PSRI (site level)	6.5
PSRI (home-range level)	1.6

Table S5 Table 2 Variance Inflation Factor (VIF) for habitat variables used in the second global Linear Mixed Effects model accounting for the First Passage-Time of Magellanic woodpeckers

Attributes	VIF
Old-growth forest (%)	2.6
Open Upland habitats (%)	1.3
Open Lowland habitats (%)	1.2
PSRI (site level)	3.3
PSRI (home-range level)	1.3

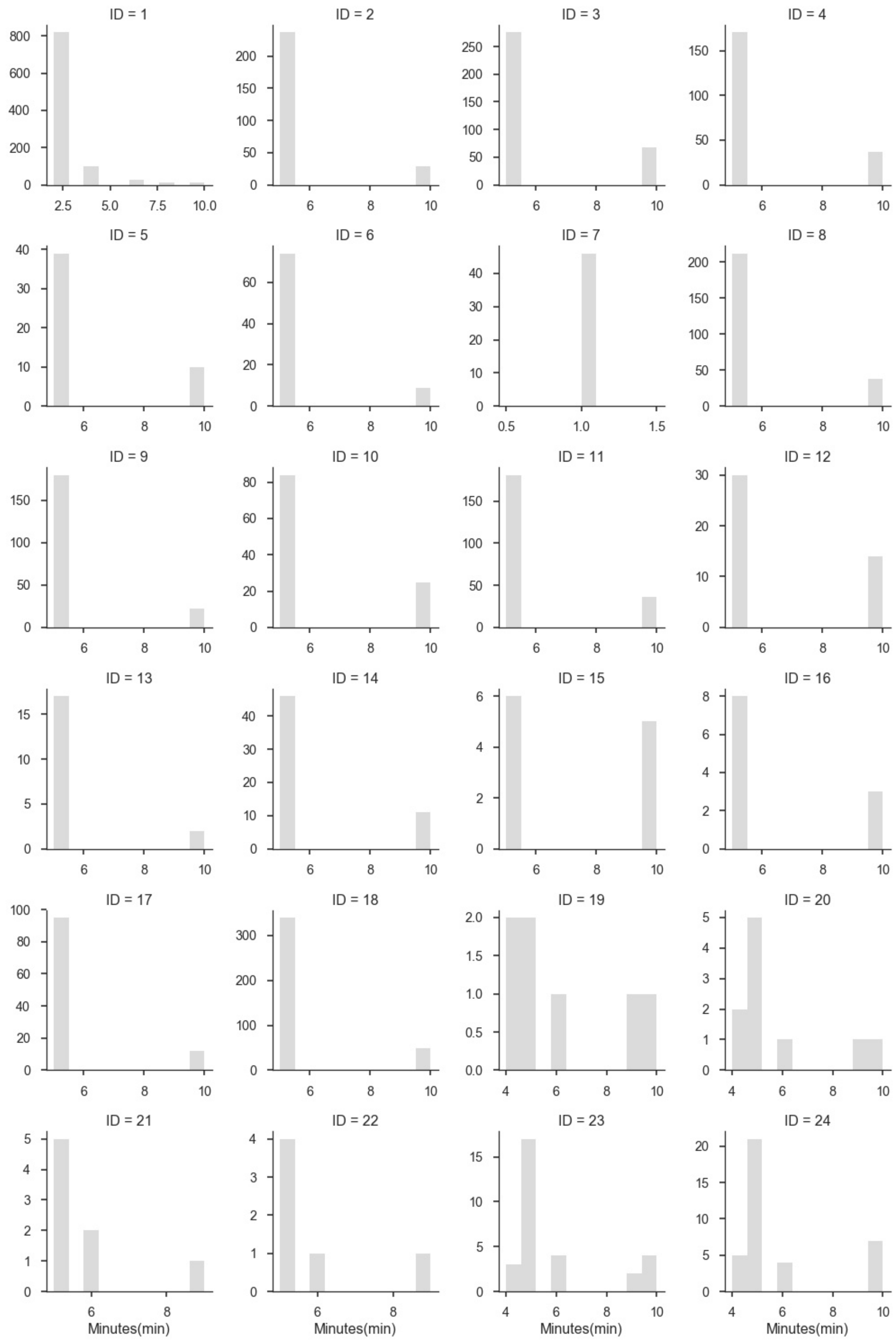

Fig. S1. Frequency histogram of the time lag (min) between relocation for every woodpecker.

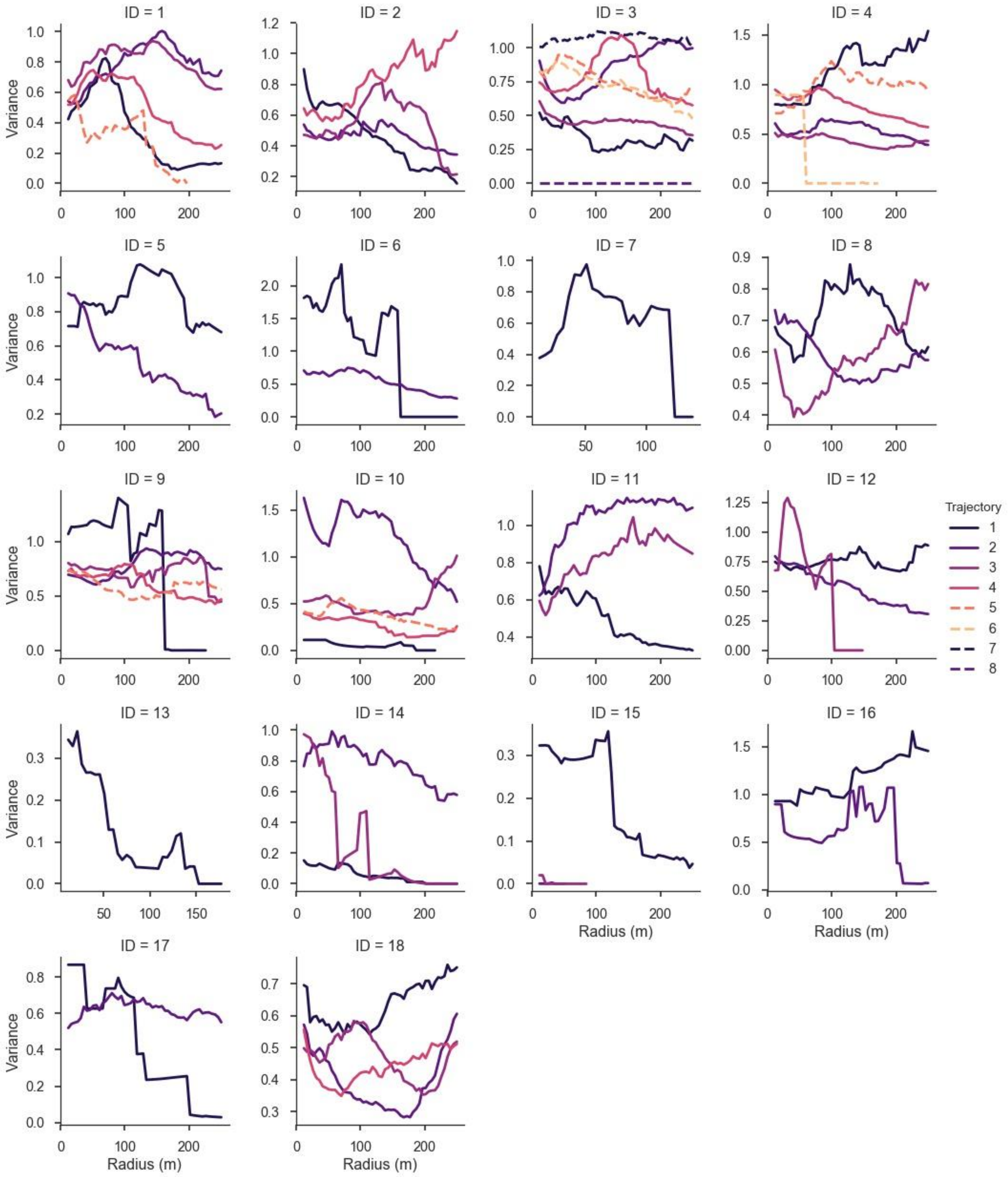

Fig. S2. Line charts showing the how the variance of the FPT changes with the radious for trajectories of 18 GPS-tracked Magellanic woodpeckers .

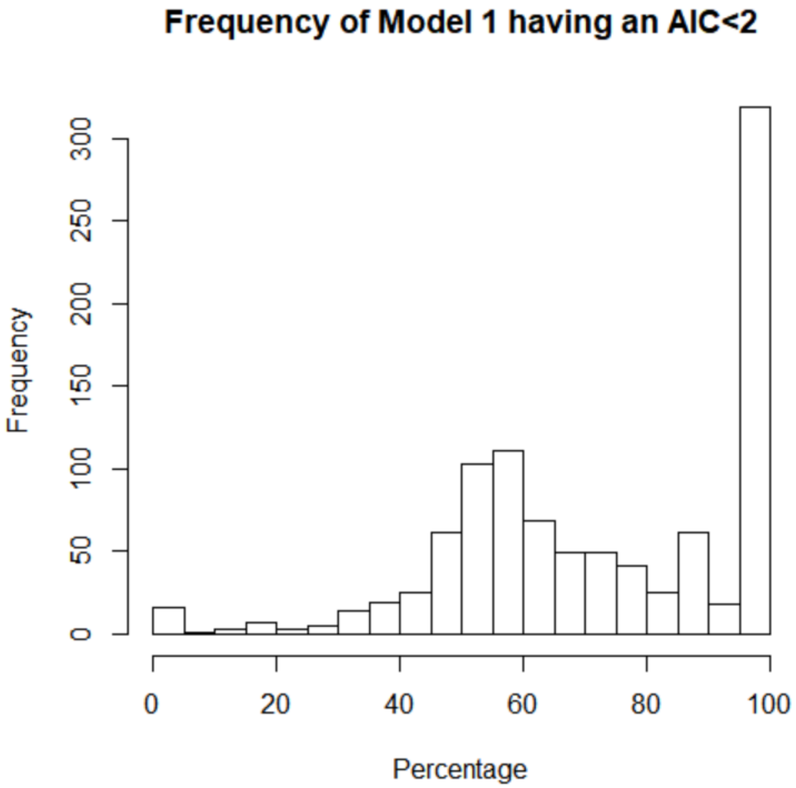

Fig. S3. The frequency in which models nested in the first global model fitted to 1,000 different FPT datasets had a ΔAIC < 2.