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Research Paper

The Magellanic Woodpecker's role in its assemblage: a case study of cavity provisioning and habitat selection in the world's southernmost forests

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ABSTRACT. Woodpeckers are adept cavity excavators and various species, i.e., secondary cavity-users (SCUs), may depend on these cavities. Birds use specific habitat attributes to increase their likelihood of survival, but these attributes vary among cavity users. We examine the role of cavity provisioning by Magellanic Woodpeckers (*Campephilus magellanicus*, MAWO, 275–347 g), the largest woodpeckers in South America. From 2015–2017 on Navarino Island, Chile (55° 4' 0.12" S, 67° 40' 1.2" W), we (1) assessed SCU densities and richness; (2) compared assemblage cavity use between MAWO-excavated and non-excavated cavities; and (3) determined which habitat attributes influence cavity use by MAWOs and the SCU assemblage. We found 12 SCU species ranging from ~11–447 g; Thorn-tailed Rayadito (*Aphrastura spinicauda*, ~12 g) was the most abundant (i.e., 9.24 individuals/ha) and frequent SCU that used non-excavated cavities. Magellanic Woodpeckers selected taller and larger-diameter *Nothofagus* trees to excavate their cavities, which were placed higher off the ground and had wider cavity entrances compared to those used by SCUs. Of the used cavities, MAWOs provided a small proportion to the SCU assemblage in general. Specifically, small passerines rarely used cavities provided by this large woodpecker, matching findings elsewhere globally. However, their cavity provisioning may be an important resource for larger birds, particularly raptors and parakeets. Moreover, MAWOs may play a key part in other ecological roles, e.g., by providing foraging and oviposition sites for birds and insects, respectively, or by vectoring wood-decay fungi. Additionally, we found evidence that SCUs use MAWO-enlarged foraging holes as nesting cavities; therefore, MAWOs may provide an ecological service for the broader SCU assemblage, but via a different mechanism than simply cavity excavation. We suggest researchers determine if MAWO-provided cavities increase SCU fitness or reproductive success. Further, we suggest researchers check cavities to determine if they are internally excavated and provide accurate information on cavity use, particularly if management and conservation decisions are made based upon these data.

Le rôle du Pic de Magellan dans son assemblage : une étude de cas sur la disponibilité de cavités et la sélection de l'habitat dans les forêts les plus méridionales du monde

RÉSUMÉ. Les pics sont d'habiles excavateurs de cavités et diverses espèces, c'est-à-dire des utilisateurs secondaires de cavités (USC), peuvent dépendre de leurs cavités. Les oiseaux utilisent des attributs spécifiques d'habitat pour augmenter leurs chances de survie, mais ces attributs varient d'un utilisateur de cavité à l'autre. Nous avons examiné le rôle de fournisseur de cavités des Pics de Magellan (*Campephilus magellanicus*, PIMA, 275-347 g), les plus grands pics d'Amérique du Sud. De 2015 à 2017 sur l'île de Navarino, au Chili (55° 4' 0.12" S., 67° 40' 1.2" O.), nous avons (1) évalué les densités et la richesse des USC; (2) comparé l'utilisation de cavités par l'assemblage d'USC entre les cavités creusées par les PIMA et les cavités non creusées; et (3) déterminé quels attributs de l'habitat influent sur l'utilisation de cavités par les PIMA et l'assemblage d'USC. Nous avons trouvé 12 espèces d'USC allant de ~11-447 g; le Synallaxe rayadito (*Aphrastura spinicauda*, ~12 g) était l'USC qui utilisait des cavités non creusées le plus abondant (c.-à-d. 9,24 individus/ha) et le plus fréquent. Les Pics de Magellan ont choisi des *Nothofagus* plus hauts et de plus grand diamètre pour creuser leurs cavités, qui étaient placées plus haut du sol et avaient des entrées de cavités plus larges que celles utilisées par les USC. Les cavités creusées par les PIMA représentaient une faible proportion des cavités utilisées par l'assemblage d'USC, en général. En particulier, les petits passereaux ont rarement utilisé les cavités creusées par ce grand pic, ce qui correspond à ce qui a été observé ailleurs dans le monde. Cependant, les cavités de PIMA peuvent constituer une ressource importante pour les oiseaux de plus grande taille, comme les rapaces et les perruches. En outre, les PIMA peuvent jouer un rôle clé dans d'autres fonctions écologiques, par exemple en fournissant des sites de recherche de nourriture et de ponte pour les oiseaux et les insectes, respectivement, ou en transportant des champignons décomposeurs de bois. De plus, nous avons trouvé des indications que les USC utilisent les trous de recherche de nourriture agrandis par les PIMA comme cavités de nidification; par conséquent, il est possible que les PIMA fournissent un service écologique à l'ensemble des USC, mais au moyen d'un mécanisme différent de la simple excavation de cavités. Nous recommandons aux chercheurs de déterminer si les cavités fournies par les PIMA augmentent la condition physique ou le succès de reproduction des USC. Enfin, nous suggérons aux chercheurs de vérifier les cavités pour déterminer si elles sont creusées à l'intérieur et de fournir des informations précises sur l'utilisation des cavités, en particulier si des décisions de gestion et de conservation sont prises sur la base de ces données.

Key Words: *Campephilus magellanicus; Cape Horn; conservation; excavator; secondary cavity-user*

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INTRODUCTION

For birds, using tree cavities for nesting, roosting, and/or refuge has several advantages over open cups including increased temperature stability, shelter from the elements (Aubry and Raley 2002), and protection from predators (Jackson and Jackson 2004). Thus, cavities are often the safest breeding locations for many forest birds (Wesołowski 2007). Woodpeckers are the most capable avian cavity excavators because their bodies are well-adapted for this rigorous and arduous role (Cockle et al. 2012), and woodpecker cavities often are used by other species, i.e., secondary cavity-users (hereafter SCUs) unable to excavate their own cavities (Bednarz et al. 2004, van der Hoek et al. 2020).

Although some SCUs use woodpecker-excavated cavities, they may not depend upon them (Wesołowski 2007) because non-excavated cavities exist. Non-excavated cavities can form via broken tree limbs, hollow stumps, crevices behind bark (Aitken and Martin 2007), or decay processes via termites or fungi (Tidemann and Flavel 1987). Non-excavated cavities are particularly common in old-growth forests (Rozzi et al. 1996, Ibarra et al. 2020). Thus, these cavities may be used more frequently by the SCU assemblage than woodpecker-excavated cavities (Cockle et al. 2019, Ibarra et al. 2020). However, in temperate and boreal forests, decay processes may be slower than cavity excavation (e.g., van der Hoek et al. 2020); therefore, if SCUs do mainly rely on primary cavity-users (e.g., woodpeckers), then a decrease in woodpecker populations may have cascading effects on the SCU assemblage (Nappi et al. 2015). Consequently, in temperate forests (Bednarz et al. 2004) and other forest types, e.g., boreal (Pakkala et al. 2018a), woodpeckers may serve as keystone species.

Regardless of forest type, birds select specific habitat characteristics for cavity placement to minimize the likelihood of competition with ecologically similar species (Wesołowski 2007) and predation (Aitken and Martin 2007), to provide safety from adverse environmental conditions (Aitken and Martin 2007), and to increase the probability of breeding success and survival (e.g., Nilsson 1984, Di Sallo and Cockle 2022). However, these characteristics may not necessarily increase nest success (Chiavacci et al. 2014) nor are they necessarily important predictors of nest survival (Newlon and Saab 2011). Notably, SCU cavity selection may be limited if non-excavated cavities are in short supply because SCUs need to rely on habitat characteristics chosen by excavators (Aitken and Martin 2007). Regardless, excavators (e.g., woodpeckers; Martin et al. 2004) and SCUs (e.g., passerines; Nilsson 1984) often vary in their selection of habitat characteristics (e.g., Bonaparte et al. 2020).

Once woodpeckers select a specific location, the complex process of excavating begins. Woodpeckers primarily excavate in dying or dead wood (Aitken and Martin 2007). The interior remains well-insulated because cavity wall thickness decreases thermal conduction and increases heat retention, especially in larger trees (Wiebe 2001). Further, the live exterior retains strength to support the cavity (Jackson and Jackson 2004), especially for large woodpeckers (Aubry and Raley 2002). Other factors both excavators and SCUs may favor include a specific diameter at breast height (DBH) size range, crown health, and tree height (Ojeda et al. 2007). Furthermore, cavity height, depth, and entrance diameter may deter non-climbing and large predators from reaching cavities, and a lower percentage of crown contact may prevent scansorial predation (Cockle et al. 2011a).

Multiple habitat characteristics are critical for woodpeckers as they excavate their cavities and for SCUs depending on these cavities (e.g., Ibarra et al. 2020, van der Hoek et al. 2020). Therefore, understanding the relationship between the selection of habitat characteristics by excavators and cavity use by SCUs requires further investigation. Additionally, this understanding is relevant for conservation and management decisions to increase or retain species richness and possibly influence reproductive success or fitness, particularly of avian cavity-nesting species.

We investigate the role of the largest South American woodpecker, the Magellanic Woodpecker (*Campephilus magellanicus*, hereafter MAWO), as cavity provisioner. In the southern temperate and sub-Antarctic forests of South America, the MAWO has been identified as a charismatic species and tentatively has been proposed as an ecological keystone species (Arango et al. 2007). However, the ecological roles provided by MAWOs need to be further studied. It has been widely documented that MAWOs excavate the largest cavities in South American temperate forests, providing nest and roost sites for themselves and some SCUs including mammals such as bats, rodents, and marsupials, reptiles such as lizards (Ojeda 2004), and various avian species (Altamirano et al. 2017). Because MAWOs provide a habitat component that otherwise may be limited in southern hemisphere forests, they have been hypothesized to be a keystone species and may be vital for maintaining the diversity of taxa in the ecosystem they inhabit (Ojeda 2004, Arango et al. 2007).

Magellanic Woodpeckers are the main cavity excavators and the only woodpecker species in the Cape Horn Biosphere Reserve, Chile (Rozzi and Jiménez 2014). The only other cavity excavator that also inhabits the sub-Antarctic Magellanic forests in the Cape Horn Biosphere Reserve is the White-throated Treerunner (*Pygarrhichas albogularis*; Sandvig et al. 2020). However, it is considered a weak excavator and would only provide smaller cavities to the SCU assemblage because it is ~24 g (Rozzi and Jiménez 2014). Moreover, it is relatively uncommon on Navarino Island (Rozzi and Jiménez 2014, Novoa et al. 2024). In comparison, MAWO adults are an order of magnitude larger (275–347 g; Wynia et al. 2019); thus, they provide larger cavities for the SCU assemblage. Because the Cape Horn Biosphere Reserve is located at subpolar latitudes (55° 4′ 0.12″ S, 67° 40′ 1.2″ W), no herpetofauna inhabits these forests, and the bat and rodent assemblage is limited (Rozzi and Jiménez 2014). Therefore, among vertebrates, MAWOs are providing cavities primarily for the avian assemblage.

Researchers have studied various aspects of cavity-nesting assemblages in South American forests; however, most research has been conducted at lower latitudes on the mainland (e.g., Altamirano et al. 2017, Cockle et al. 2019, Ibarra et al. 2020). Therefore, this study, which was conducted on an island at higher latitudes, can elucidate interactions among the avian cavity-nesting assemblage in the world's southernmost temperate forests.

Our study focused on the relationship between avian cavity-nesting species richness and densities, cavity use, and habitat selection. As such, our first objective was to determine avian SCU richness and densities to assess which species were available to use excavated and non-excavated cavities. Although researchers previously assessed avian species richness and relative abundance on Navarino Island (i.e., Anderson and Rozzi 2000, Ippi et al. 2009), the latest data collection occurred 12–14 years prior to this study. Thus, it was prudent to reassess these values to provide a contemporary portrayal of the avian assemblage available to use both MAWO-excavated and non-excavated cavities. Importantly, these descriptive data may provide pertinent information for future long-term studies of avian assemblage dynamics including species richness and density trends. Our second objective was to locate excavated and non-excavated cavities to identify which were used by SCUs. We also assessed the degree to which MAWOs were potentially impacting the assemblage. Specifically, we predicted the larger-sized MAWO-excavated cavities may be an important resource for larger-bodied SCUs (e.g., raptors and parakeets). Our third and final objective was to determine if MAWOs and SCUs using non-excavated cavities selected specific habitat characteristics and to assess if these characteristics differed and to what degree. As previously mentioned, birds select cavities for various reasons. Thus, we explored the habitat attributes that may influence cavity use by MAWOs and the SCU assemblage in the southernmost forests of the world. Explicitly, we focused on habitat characteristics thought to be important for MAWOs (Ojeda et al. 2007) and SCUs (Cockle et al. 2011a) on the mainland at lower latitudes and not only explored habitat characteristics for each cavity-user type (i.e., MAWO and SCU) but also compared habitat characteristics between MAWOs and SCUs.

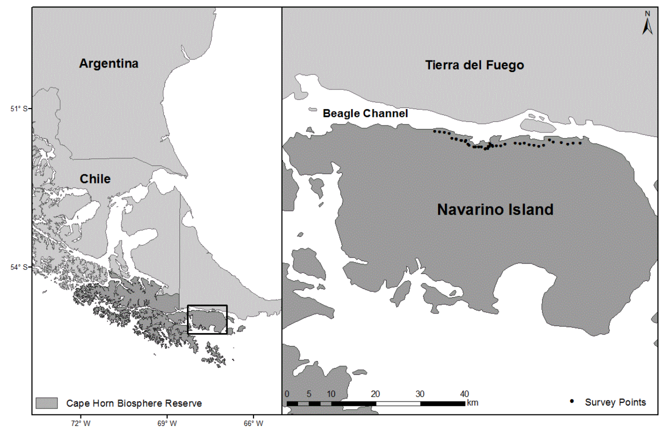
METHODS

Study site

The MAWO is a resident species throughout its range in Argentina (Ojeda 2004) and Chile (Ippi et al. 2009) and the temperate forests of Navarino Island, Chile (55° 4′ 0.12″ S, 67° 40′ 1.2″ W; Fig. 1) likely host the highest density of MAWOs throughout Chile (Rozzi and Jiménez 2014). Our study site, Navarino Island, is 2528 km² (Lombardi et al. 2011) and part of the Cape Horn Biosphere Reserve, which protects an extensive archipelago located in the Magellanic sub-Antarctic ecoregion at the southern end of South America (Rozzi et al. 2012). Average monthly temperatures range from 7–11 °C and monthly precipitation from 15–55 mm (Rozzi and Jiménez 2014, Rozzi et al. 2020). Relatively harsh climatic conditions exist throughout the year (Wynia et al. 2019, Quilodrán et al. 2022). Most forest stands on Navarino are composed of three *Nothofagus* spp., i.e., Magellanic Coigüe (*Nothofagus betuloides*), Lenga (*N. pumilio*), and Ñirre (*N. antarctica*), and Winter's bark (*Drimys winteri*; Soto et al. 2017). Anthropogenic influences on Navarino include timber harvest, the introduction of invasive species, and burning and clearing forests for pastureland (Rozzi and Jiménez 2014).

On Navarino Island during austral summers 2015–2017 and spring 2016, we estimated SCU species richness and densities and MAWO density using standardized point counts (e.g., Jiménez 2000) because this method is efficient and cost-effective, especially in forested habitats (Reynolds et al. 1980). Given that MAWO densities are approximately 1 family group/100 ha (Ojeda and Chazarreta 2014; J. E. Jiménez, *unpublished data*), we established 30 forested point-count stations spread ~1 km apart along the accessible, northern coast of Navarino Island to reduce detecting the same woodpecker families repeatedly. We used a random numbers generator in which each value (i.e., 0–9) corresponded to a value at 50-m increments (0 = 50 m, 1 = 100 m, etc.). Thus, each point-count station was located randomly between 50–500 m ($\bar{x}$ = 200 m) from the road to reduce a potential road effect. We sampled each point-count station for a 10-min interval 3 or 4 times (i.e., monthly) during the austral breeding season from 0430–1230 hr because activity patterns of avian species vary throughout the day (Reyes-Arriagada et al. 2015). We recorded detections, both visual and aural, and the direction of individuals from each point-count location (Jiménez 2000). We detected species within a 100-m radius in 10-m intervals. For each survey, we recorded whether species were detected aurally or visually, estimated detection distance from survey point (m), and time.

Fig. 1. Navarino Island, Chile (55° 4' 0.12" S, 67° 40' 1.2" W), where in 2015–2017, we explored avian secondary cavity-user (SCU) richness and densities, cavity use by Magellanic Woodpeckers (*Campephilus magellanicus*) and SCUs, and habitat selection by cavity users. Survey points indicate point-count locations. Darker gray on left map indicates Cape Horn Biosphere Reserve. Figure from Wynia et al. (2019).



During austral summer 2016, we broadcasted playbacks of Rufous-legged Owl (*Strix rufipes*; https://www.xeno-canto.org, XC61728) and Austral Pygmy-Owl (*Glaucidium nana*; https://www.xeno-canto.org, XC61749) during nighttime surveys (i.e., 2130–0330 hr) to account for SCU owl species. We broadcasted vocalizations via a speaker (Altec Lansing Mini H20 model IMW257) at ~55 dB for ~15 s for each owl species 3 times (i.e., approximately every 3.5 min) during separate, 10-min periods (for a total of 20 min per survey, which included both owl species) three times during the season. We conducted the nighttime owl surveys at matching road-side points (similar to Ibarra et al. 2014a and Norambuena and Muñoz-Pedreros 2018), to the 30 diurnal, forested point-count locations.

During austral spring and summer 2016–2017, we added a Barn Owl (*Tyto alba*) playback (https://www.xeno-canto.org, XC53439) to our nighttime surveys (i.e., 2040–0315 hr) because this species was incidentally recorded during the previous season. We conducted this survey four times, but reduced our survey length to 5 min per owl species (for a total of 15 min per survey) and broadcasted playbacks twice per species (i.e., every 2.5 min); notably, only 3% (n = 6/202) of owl responses from the previous season occurred after 5 min. For both seasons, we randomized the playback order to reduce potential playback effect, and we randomized all starting survey points during each survey period to prevent visiting the same location around the same time on every survey. We recorded the same parameters as described above.

During austral summers 2015–2016 and spring 2016, we searched for excavated and non-excavated cavities radially from point-count locations to identify cavity use by the SCU assemblage. Observers (2–4) walked 3, linear 100-m transects (i.e., 120° to and from the point-count center) and scanned trees for cavities using binoculars. Observers also searched opportunistically while engaging in other research activities. Moreover, many MAWO cavities were found from previously identified locations (G. E. Soto, *personal communication*). We also followed adults carrying prey items and the sound of nestlings begging to locate cavities. For MAWOs, we searched for fresh woodchips on the ground as a sign of recent cavity excavation (Ojeda 2004) and followed adults when possible (Chazarreta et al. 2010).

We conducted most of our cavity searches at the end of the austral breeding season; therefore, we were interested in determining overall cavity use and not just locating active nests. We define the term use as either a physical presence or evidence left behind in the cavity. Because the latter occurred more frequently, we are unsure of the use type by SCUs (e.g., nesting, roosting, shelter, searching for or storing food). Moreover, we checked unused cavities once per season, and non-excavated cavities were not checked after the season they were found.

Once a cavity was located, we attached a wireless camera with white LEDs (https://www.ibwo.org, Little Rock, Arkansas, USA) to a 15-m extendable pole (Engineer Supply Crain CMR Series Measuring Ruler- Model CMR-50; Lynchburg, Virginia, USA) and inserted the camera into the cavity. We observed and recorded the contents with a wireless monitor below (https://www.ibwo.org, Little Rock, Arkansas, USA).

After cavities became inactive, we evaluated MAWO and SCU cavity use by measuring habitat characteristics (e.g., Martin et al. 2004, Wesołowski 2007) at the cavity tree and a random-paired site, which was a minimum of 15 m from the cavity (Ojeda et al. 2007). The tree nearest to the plot center was used as the potential cavity tree for the random plot. To evaluate cavity tree selection characteristics for MAWOs and SCUs, we used a modified Breeding Biology Research and Monitoring Database protocol (BBIRD; Martin et al. 1997) at three scales: patch, tree, and cavity. For the patch scale, we established an 11.3-m radius circular plot around the tree and recorded the number of small (8.1–23.0 cm DBH), medium (23.1–38.0 cm DBH), and large (> 38.0 cm DBH) trees, and small (≤ 12.0 cm DBH; > 1.4 m tall) and large (> 12.0 cm DBH; > 1.4 m tall) snags. Additionally, we recorded elevation (m) using a GPS, estimated percent canopy cover using a spherical densiometer, and mean canopy height using a clinometer. At the tree scale, we determined species, height (m), DBH (cm) using a DBH tape, crown die-back (Ojeda et al. 2007), and decay status (Thomas et al. 1979). Data recorded for each cavity at the cavity scale included cavity type (excavated or non), cavity height from ground (m) using a measuring tape taped to the extendable pole, entrance height and width (cm) using binoculars to read metric rulers taped to the extendable pole, and aspect (degrees) using a compass.

Statistical analyses

We performed all statistical analyses with R statistical software 3.6.0 (R Core Team 2019). We set the significance level at 5% and reported 95% confidence limits (CLs) and means with standard errors (SEs). Using boxplots, we checked for and removed several outliers not representative of the vegetation community (i.e., $n > Q3 + 1.5 * IQR$; interquartile range). We tested for multicollinearity among predictors (there was none, i.e., no variance inflation factor [VIF] value was > 10; package usdm; Naimi et al. 2014). However, several global models were significantly overdispersed ($\hat{c} > 1$); therefore, we calculated a quasi-Akaike information criterion corrected for small sample size ($QAIC_c$; Burnham and Anderson 2002) and reported the $QAIC_c$ values when applicable.

We used the R package Distance (Miller et al. 2019) to estimate avian densities from point-count data because Distance accounts for detection probability with regard to distance (Miller et al. 2019). We used an information-theoretic approach with AIC (Burnham and Anderson 2002) to determine which of three detection function models best fit the density estimates of our species: half-normal, uniform with cosine adjustment terms, and hazard rate with simple polynomial adjustment terms (Miller et al. 2019). We applied the principle of parsimony if $\Delta AIC < 2$ and used an absolute goodness of fit test to select the best-supported model (Miller et al. 2019). We reported density estimates in individuals/ha.

Species used in these analyses were selected based on their degree of cavity dependency (Altamirano et al. 2017). We could not fit a detection function for MAWOs because their detectability did not diminish with distance (i.e., aural detections could be heard frequently at distances > 100 m; Wynia et al. 2019); therefore, we reported densities for the avian SCU assemblage. Moreover, Thorn-tailed Rayadito (*Aphrastura spinicauda*) failed all absolute goodness of fit tests for the three detection functions; therefore, we ran a uniform model without the cosine adjustment.

After assessing SCU species richness and densities, we analyzed habitat data. In addition to determining if MAWOs and SCUs using non-excavated cavities were selecting specific habitat characteristics compared to random-paired sites, we compared habitat characteristics between MAWOs (using their excavated cavities) and SCUs (using non-excavated cavities) to determine if there were differences between the two groups. We created our nine total a priori global generalized linear models (GLMs) for each scale (i.e., patch, tree, and cavity) for each category (i.e., MAWO vs. random, SCU vs. random, and comparing MAWOs vs. SCUs) based on all habitat variables described in the methods and relevant interactions. We created all possible model combinations (package MuMIn, function dredge; Barton 2020) and used an information-theoretic approach with AIC_c (Burnham and Anderson 2002) to select the best-supported model. We used the $QAIC_c$ approach for all overdispersed models. We applied the principle of parsimony if $\Delta AIC_c < 2$. For the patch scale, we chose to only include the total number of trees and snags in our global

Table 1. Density estimates (individuals/ha) with standard errors (SEs) for avian secondary cavity users and one weak excavator (White-throated Treerunner, *Pygarrhichas albogularis*) on Navarino Island, Chile, 2015–2017. Model indicates the best-supported model using an information-theoretic approach with Akaike information criterion (AIC; Burnham and Anderson 2002). Abbreviations are as follows: Haz rate poly: hazard rate with simple polynomial adjustment terms; Uniform cos: uniform with cosine adjustment terms; and Uniform: no cosine adjustment terms. Cavity dependence categories are as follows: obligate: > 90% of nests in tree cavities; facultative: 10.1–90%; marginal: 1–10%; and incidental: < 1% (Altamirano et al. 2017). Mean mass (g) ± SD and n from Rozzi and Jiménez (2014), except Barn Owl (*Tyto alba*; Bozinovic and Medel 1988).

Species	Scientific name	Mass (g) ± SD	*n*	Cavity dependence	Model	Estimate (individuals/ha)	SE
Thorn-tailed Rayadito	*Aphrastura spinicauda*	12.1 ± 1.2	1374	Obligate	Uniform	9.24	0.91
Patagonian Sierra-Finch	*Phrygilus patagonicus*	23.0 ± 1.4	1224	Marginal	Uniform cos	2.24	0.17
Southern House Wren	*Troglodytes aedon*	10.7 ± 0.9	319	Obligate	Uniform cos	2.14	0.26
Austral Thrush	*Turdus falcklandii*	91.6 ± 6.1	76	Facultative	Uniform cos	2.02	0.24
White-crested Elaenia	*Elaenia albiceps*	15.9 ± 1.1	817	Incidental	Uniform cos	1.94	0.16
Rufous-collared Sparrow	*Zonotrichia capensis*	23.3 ± 1.5	246	Incidental	Uniform cos	1.35	0.17
Austral Parakeet	*Enicognathus ferrugineus*	188.8 ± 7.2	5	Obligate	Haz rate poly	0.90	2.44
Black-chinned Siskin	*Spinus barbatus*	16.5 ± 1.2	401	Incidental	Haz rate poly	0.63	0.17
Chilean Swallow	*Tachycineta leucopyga*	16.1 ± 1.3	51	Obligate	Uniform cos	0.57	0.08
White-throated Treerunner	*Pygarrhichas albogularis*	23.5 ± 1.3	34	Obligate	Uniform cos	0.48	0.11
Rufous-legged Owl	*Strix rufipes*	447.0 ± 12.7	2	Obligate	Half-normal	0.17	0.07
Barn Owl	*Tyto alba*	310.0 ± NA	NA	Obligate	Uniform cos	0.08	0.04
Austral Pygmy-Owl	*Glaucidium nana*	69.9 ± 10.6	13	Obligate	Haz rate poly	0.07	0.03

models to reduce the number of predictors. If either predictor was included in the best-supported model, we would have run additional analyses separating the trees and/or snags by size to tease apart their significance.

Crown dieback was a significant predictor of cavity selection for MAWOs in mainland Argentina (Ojeda et al. 2007); however, crown dieback and tree decay were correlated in our study ($r = 0.68$, $P < 0.001$). Crown dieback was not a significant predictor of MAWO cavity selection ($P = 0.22$); therefore, we used decay level in our global model. To determine the magnitude of the effect of influential predictors, we computed odds ratios for every *n*-unit increase based on biologically meaningful values for managers (Newlon and Saab 2011) and reported 95% CLs. If CLs included 1, the predictor had no influence on the likelihood of a MAWO or SCU selecting that predictor (i.e., habitat characteristic).

We used a chi-square goodness of fit test to determine if MAWOs were selecting a specific tree species for their cavities. We observed (i.e., $n_{(o)}$) three tree species ($n_{(o)} = 117$ trees with known species) used for cavity excavation, and from Soto et al. (2017), we converted area estimates (ha) of these three species from Navarino Island to set approximate percentages for each expected value (i.e., $n_{(e)}$) for tree species, i.e., 52% Coigüe ($n_{(e)} = 61$), 25% Lenga ($n_{(e)} = 29$), and 23% Ñirre ($n_{(e)} = 27$).

RESULTS

We identified 12 SCU species and 1 weak excavator (White-throated Treerunner) on Navarino Island (Table 1). Thorn-tailed Rayadito had the highest density of all recorded SCUs, followed by Patagonian Sierra-Finch (*Phrygilus patagonicus*), Southern House Wren (*Troglodytes aedon*), Austral Thrush (*Turdus falcklandii*), and White-crested Elaenia (*Elaenia albiceps*; Table 1). All owl species had the lowest densities (Table 1). Furthermore, Thorn-tailed Rayaditos were the most frequently identified SCU using non-excavated cavities (Table 2; Fig. 2A), followed by Austral Parakeets (*Enicognathus ferrugineus*; Table 2), even though Austral Parakeets had a relatively low density (Table 1).

Table 2. Contents of Magellanic Woodpecker (*Campephilus magellanicus*) excavated (Ex) and non-excavated (Non) cavities observed mostly during austral summers 2015–2016 and spring 2016 on Navarino Island, Chile. All listed species are obligate cavity nesters. Cavity starts had a(n) (non-)excavated entrance, but no internal depth.

	2015		2015–2016		2016		Total	
	Ex	Non	Ex	Non	Ex	Non	Ex	Non
Magellanic Woodpecker	15	0	6	0	7	0	28	0
American Kestrel (*Falco sparverius*)	0	0	0	0	1	0	1	0
Austral Pygmy-Owl (*Glaucidium nana*)	2	0	1	0	2	0	5	0
Austral Parakeet (*Enicognathus ferrugineus*)	0	2	0	3	2	1	2	6
Chilean Swallow (*Tachycineta leucopyga*)	0	0	0	1	0	2	0	3
Southern House Wren (*Troglodytes aedon*)	0	0	0	1	0	3	0	4
Thorn-tailed Rayadito (*Aphrastura spinicauda*)	0	0	0	1	0	16	0	17
Feathers	1	0	0	2	0	0	1	2
Grass nest	3	0	3	3	1	1	7	4
Twig nest	1	0	0	1	0	6	1	7
Rodent	0	0	0	0	1	0	1	0
Scat	2	0	4	0	1	0	7	0
Water	1	0	0	0	0	0	1	0
Unused	42	0	10	1	9	0	61	1
Unknown	0	0	2	0	5	0	7	0
Cavity start	24	9	5	1	6	0	35	10
Total	91	11	31	14	35	29	157	54

We found and recorded the contents of 142 MAWO-excavated cavities and 54 non-excavated cavities over 3 field seasons. We located 91 excavated cavities during our first field season (2015) and rechecked 20% ($n = 18$) and 37% ($n = 34$) during the second (2015–2016) and third (2016) field seasons, respectively. We found an additional 26 excavated cavities during the second field season, rechecked 69% ($n = 18$) of these during the third season, and found 25 additional excavated cavities during the third and final field season.

Fig. 2. (A) Thorn-tailed Rayadito (*Aphrastura spinicauda*) at its non-excavated cavity. (B) Male Magellanic Woodpecker (*Campephilus magellanicus*, MAWO) in a MAWO-excavated cavity. (C and D) Southern House Wren (*Troglodytes aedon*) cavities (C circled in yellow) within MAWO-enlarged foraging holes, surrounded by other MAWO foraging holes. We found (A and C) austral summers 2015–2017 and O. Barroso located (B) summer 2013 all on Navarino Island, Chile, and G. E. Soto located (D) on mainland Chile (40° 46' 28.92" S, 72° 12' 25.56" W) summer 2017. Images (A and C) by A. L. Wynia, (B) by O. Barroso, and (D) by G. E. Soto.

We checked excavated cavities 212 times over the course of 3 field seasons. In addition to the contents of the 142 cavities we found, 15 cavities varied in their contents over time. For example, one cavity contained woodpecker feathers the first field season, was empty the second, and contained a nesting Austral Pygmy-Owl the third. Another cavity was empty during the first two field seasons but had an unidentified rodent the third season. If the contents were the same over time, no additional contents were recorded for a specific cavity; hence, we recorded the contents of 157 cavity checks (Table 2).

Of the 157 excavated cavities checked, at least 18% (*n* = 28) were actively used by MAWOs (Table 2; Fig. 2B). The majority of these contained their feathers (*n* = 25), but three cavities contained juveniles (*n* = 2 alive, *n* = 1 deceased). We identified three mid-sized species that used excavated cavities: American Kestrel (*Falco sparverius*, *n* = 1), Austral Pygmy-Owl (*n* = 5; Fig. 3A and 3B,

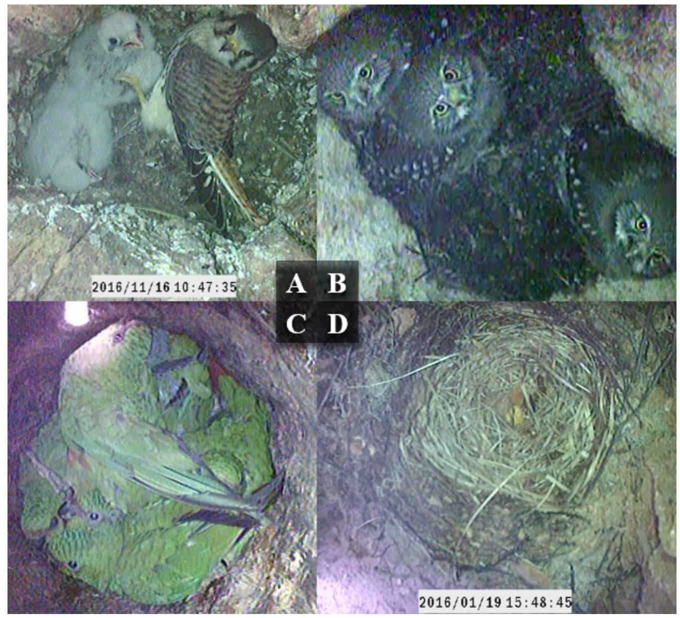


Fig. 3. Cavity contents: (A) American Kestrel (*Falco sparverius*), (B) Austral Pygmy-Owl (*Glaucidium nana*), (C) Austral Parakeet (*Enicognathus ferrugineus*), and (D) grass nest. We found (A) and (B) in Magellanic Woodpecker (*Campephilus magellanicus*)-excavated cavities and (C) and (D) in non-excavated cavities. All contents indicate use by secondary cavity-users and were found on Navarino Island, Chile, 2015–2017. Images by A. L. Wynia.

respectively), and Austral Parakeet (*n* = 2). Notably, all three species are obligate cavity nesters (i.e., > 90% of their nests occur in tree cavities; Altamirano et al. 2017). We also detected a pile of down feathers in another excavated cavity and seven grass nests and one twig nest created by passerines in others. Additionally, we found a rodent (*n* = 1) and mammalian scat (*n* = 7); 1 excavated cavity was filled with water, 61 were unused, 7 contained unidentified contents, and 35 were cavity starts (i.e., woodpeckers excavated an entrance, but there was no internal depth; Table 2).

We identified four avian species using non-excavated cavities. Importantly, non-excavated cavities were not checked after the season they were found. Species identified included Austral Parakeet (*n* = 6, Fig. 3C), Chilean Swallow (*Tachycineta leucopyga*, *n* = 3), Southern House Wren (*n* = 4), and Thorn-tailed Rayadito (*n* = 17); additionally, 2 cavities contained feathers of unidentified species, and 4 had grass nests (Fig. 3D) and 7 had twig nests created by passerines (Table 2).

Regarding habitat selection, the best-supported models at the patch scale for all three categories (i.e., MAWO vs. random, SCU vs. random, and comparing MAWOs vs. SCUs) were the nulls (i.e., intercept models; Table 3). The best-supported model at the tree scale for MAWOs was DBH, for SCU: DBH and tree height, and for comparing both: DBH, tree height, and their interaction (Table 3). The best supported model at the cavity scale for comparing both was cavity height from ground and entrance width (Table 3).

Table 3. Results of model selection for a priori generalized linear models (GLMs) with $\Delta AIC_c < 2$ containing potentially influential habitat characteristics and interaction effects at three different scales (i.e., patch, tree, and cavity) for each category, i.e., the response variables: Magellanic Woodpeckers (*Campephilus magellanicus*, MAWOs) vs. random, secondary cavity-users (SCUs) vs. random, and comparing MAWOs vs. SCUs, that may influence MAWO and SCU cavity tree selection on Navarino Island, Chile, 2015–2017. Abbreviations are as follows: k = number of parameters, $\Delta(Q)AIC_c$ = difference in corrected Akaike's information criterion ($\Delta[Q]AIC_c = [Q]AIC_{ci}$ - min. $[Q]AIC_c$), ω_i = model weight (i.e., explanatory power), and LL = log likelihood. † indicates $QAIC_c$, ‡ indicates the best-supported model for each scale, DBH indicates diameter at breast height, and : indicates an interaction effect.

Scale	Candidate Model§	k	$\Delta(Q)AIC_c$	ω_i	LL
MAWO patch†	Null‡	1	0.00	0.70	-43.66
	Number of snags	2	1.70	0.30	-43.44
MAWO tree†	DBH (cm) + tree height (m)	3	0.00	0.54	-66.65
	DBH‡	2	0.32	0.46	-67.87
SCU patch†	Null‡	1	0.00	0.38	-34.66
	% canopy + number of snags	3	0.01	0.38	-32.44
	Number of snags	2	0.93	0.24	-34.03
SCU Tree	DBH + tree height‡	3	0.00	0.47	-30.16
	DBH + decay	6	0.80	0.32	-26.84
	Decay	5	1.58	0.21	-28.53
MAWO vs. SCU patch†	Null‡	1	0.00	0.43	-39.08
	Number of snags	2	1.61	0.19	-38.81
	Number of trees	2	1.61	0.19	-38.81
	% canopy	2	1.73	0.18	-38.87
MAWO vs. SCU tree	Tree height + DBH + tree height:DBH‡	4	0.00	0.57	-38.62
	Tree height	2	1.86	0.22	-41.75
	DBH + decay + tree height:DBH	9	1.99	0.21	-33.57
MAWO vs. SCU cavity	Height from ground (m) + cavity width (cm)‡	3	0.00	0.73	-31.45
	Height from ground + cavity width + cavity height (cm)	4	1.95	0.27	-31.36

§ The lowest $(Q)AIC_c$ values for each scale were 89.39, 139.54, 71.40, 66.83, 80.23, 85.80, and 69.12, respectively.

Table 4. Parameter estimates with standard errors (SE) and odds ratio estimates with 95% confidence limits (CL) for the odds of habitat selection characteristics and interaction effects at two different scales (i.e., tree and cavity) influencing the likelihood of Magellanic Woodpecker (*Campephilus magellanicus*, MAWO) and secondary cavity-user (SCU) tree and cavity use on Navarino Island, Chile, 2015–2017. * indicates a significant parameter (i.e., CL does not include 1), DBH indicates diameter at breast height, and : indicates an interaction effect.

			Odds Ratio	
Scale	Parameter	Estimate ± SE	Estimate	95% CL
MAWO tree	Intercept	-1.63 ± 0.81	1.22	0.31-4.83
	DBH (cm)*	0.03 ± 0.02	2.81	2.74-2.88
SCU tree	Intercept	-0.58 ± 0.95	1.75	0.27-11.36
	DBH*	0.06 ± 0.02	2.88	2.75-3.01
	Tree height (m)*	-0.15 ± 0.07	2.37	2.07-2.72
MAWO vs. SCU tree	Intercept	-9.33 ± 3.36	1.00	0.001-719.01
	DBH*	0.14 ± 0.06	3.16	2.81-3.56
	Tree height*	0.65 ± 0.22	6.75	4.37-10.44
	DBH:Tree height*	-0.09 ± 0.004	2.70	2.68-2.71
MAWO vs. SCU cavity	Intercept	-7.92 ± 1.87	1.00	0.03-39.41
	Height from ground (m)*	0.80 ± 0.18	9.16	6.41-13.07
	Cavity width (cm)*	0.58 ± 0.18	5.94	4.17-8.46

Specifically, at the tree scale, MAWOs chose trees with greater DBHs ($\bar{x}$ = 56.40 ± 2.35 cm, n = 53, P = 0.03) compared to random-paired sites ($\bar{x}$ = 47.70 ± 2.31 cm, n = 50); for every 5-cm increase in DBH, the odds of a MAWO using a tree were 2.81 times more likely (Table 4). Similarly, trees used by SCUs had greater DBHs ($\bar{x}$ = 49.44 ± 3.18 cm, n = 25, P = 0.01) compared to random-paired sites ($\bar{x}$ = 40.82 ± 3.53 cm, n = 25), but were shorter ($\bar{x}$ = 12.19 ± 0.98 m, n = 25, P = 0.04) compared to random-paired sites ($\bar{x}$ = 14.35 ± 1.38 m, n = 25); the odds of an SCU using a tree were 2.88 times more likely as DBH increased by 5 cm, and 2.37 times more likely as tree height decreased by 1 m (Table 4).

When comparing habitat characteristics between MAWO and SCU cavities at the tree scale, MAWOs selected trees greater in DBH ($\bar{x}$ = 56.40 ± 2.35 cm, n = 53, P = 0.02) than did SCUs ($\bar{x}$ = 49.44 ± 3.18 cm, n = 25), and taller ($\bar{x}$ = 17.33 ± 0.84 m, n = 53, P = 0.003) than SCUs ($\bar{x}$ = 12.19 ± 0.98 m, n = 25); the odds of a MAWO using a tree were 3.16 times more likely than a SCU as DBH increased by 5 cm, and 6.75 times more likely as tree height increased by 1 m (Table 4). Moreover, the interaction effect between DBH and tree height was significant (z = -2.31; P = 0.02); i.e., the influence of one variable was reduced by the other variable (Table 4). For example, as DBH increased, there was a stronger, positive effect for shorter trees, i.e., there was a higher probability the cavity was used by a MAWO (Fig. 4).

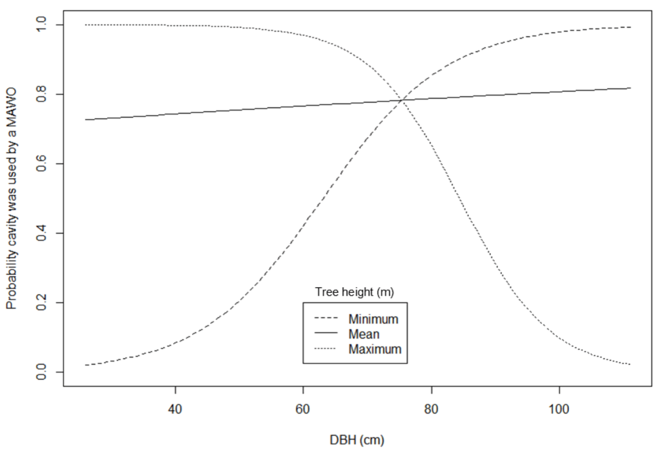
At the cavity scale, MAWO-excavated cavities were higher in trees ($\bar{x}$ = 7.46 ± 0.19 m, n = 83, P < 0.001) than non-excavated SCU cavities ($\bar{x}$ = 3.58 ± 0.40 m, n = 34) and MAWO cavities had wider entrances ($\bar{x}$ = 8.68 ± 0.15 cm, n = 83, P = 0.001) than did those used by SCUs ($\bar{x}$ = 5.41 ± 0.60 m, n = 34); the odds that a cavity was excavated and used by a MAWO (vs. non-excavated and used by a SCU) were 5.94 times higher with each 1-cm increase in cavity entrance width, and 9.16 times higher with each 1-m increase in tree height (Table 4).

Of all the cavities we located, we only found one cavity in a species other than *Nothofagus*; one Thorn-tailed Rayadito cavity was in Notro (*Embothrium coccineum*). Although all MAWO-excavated cavities were in *Nothofagus* spp., we did find a significant difference in tree species selection (χ^2 = 25.40, df = 2, P < 0.001). Magellanic Woodpeckers avoided placing cavities in Ñirre ($n_{(o)}$ = 5, $n_{(e)}$ = 27, P < 0.001); however, the remaining two species were not selected more or less than expected (i.e., Magellanic Coigüe: $n_{(o)}$ = 69, $n_{(e)}$ = 61, P = 1.00; Lenga: $n_{(o)}$ = 43, $n_{(e)}$ = 29, P = 0.28).

DISCUSSION

Our most abundant SCU species (Table 1) are similar to the most relatively abundant species reported in Anderson and Rozzi (2000), Ippi et al. (2009), and Rozzi and Jiménez (2014), which also were conducted on Navarino Island. In most studies, Thorn-tailed Rayadito was the most abundant obligate cavity-dependent species; however, caution should be used when interpreting the density estimate in our study because the model fit was sub-standard. Of the obligate cavity users (excluding owls) reported

Fig. 4. Probability that a cavity was used by a Magellanic Woodpecker (*Campephilus magellanicus*, MAWO) instead of a secondary cavity-user as related to DBH (diameter at breast height; cm) and tree height (m; legend) on Navarino Island, Chile, 2015–2017.



in these studies, Chilean Swallow and White-throated Treerunner had low abundances, whereas Patagonian Sierra-Finch and Southern House Wren were consistently abundant.

Moreover, our SCU density results are comparable to those in Lenga forests on Tierra del Fuego, Argentina (Lencinas et al. 2009), albeit our Thorn-tailed Rayadito density is slightly higher. Furthermore, our top five most abundant SCU species are similar to the top four abundant species in various habitat types also on Tierra del Fuego, Argentina (Benitez et al. 2022).

Regardless of density and abundance, a limited number of SCUs used MAWO-excavated cavities in our study. Specifically, small passerines rarely used cavities excavated by the large MAWO. This result is similar to findings elsewhere in the world where large woodpecker cavities are rarely used by small passerines (Cramp and Simmons 1985, Bull and Jackson 1995). Specifically, similar to our findings in sub-Antarctic Magellanic forests, in a study on the role of Three-toed Woodpeckers (*Picoides tridactylus*) in a cavity-using community in boreal forests in Finland, woodpecker cavities were used infrequently by passerines (Pakkala et al. 2018b). However, as reported elsewhere in the world (e.g., Cockle 2010, Cockle et al. 2011b, Butler et al. 2013, van der Hoek et al. 2017), we did find that larger, non-passerine avian species, particularly raptors and parakeets, used cavities excavated by the large Magellanic Woodpecker in our system.

Notably, we found evidence of SCUs using MAWO-enlarged foraging holes as nesting cavities (Fig, 2C; $n = 2$, Southern House Wren and an unknown species). This also has been reported on mainland Chile (G. E. Soto, *personal communication*; Fig. 2D). Therefore, MAWOs may be providing an additional ecological service for the smaller members of the SCU assemblage, albeit through another mechanism, as MAWOs enlarge previous foraging holes or rotted wood while foraging. A traditional MAWO-excavated cavity may not be used frequently by many smaller SCUs, but MAWO-enlarged foraging holes may provide an unrecognized opportunity of cavity provision. However, more research should be conducted both on Navarino Island and throughout the MAWO's range to assess this hypothesis.

Woodpecker cavities were not used substantially by small SCUs on Navarino Island, which may have occurred for various reasons. First, Navarino Island occurs at a high latitude (55 °S) with relatively harsh climatic and windy conditions occurring throughout the year (Rozzi and Jiménez 2014, Wynia et al. 2019, Aguirre et al. 2021). Therefore, it is likely the much smaller passerines avoided using large MAWO-excavated cavities with fewer thermoregulation benefits (Dawson et al. 2005). Second, MAWOs depredate SCUs (Ojeda and Chazarreta 2006; J. E. Jiménez, *personal observation*); therefore, using a cavity created by a predator likely would increase the chance of predation because MAWOs frequently check and use their older cavities within their territories throughout the year. Not only do MAWOs depredate SCUs, but other species such as raptors (Ibarra et al. 2014b, Ruiz et al. 2018) do as well. Thus, a larger cavity entrance allows a broader array of species access to cavity contents (Cockle et al. 2011a). Research suggests that species select cavity entrances relative to their body size to reduce predation risk (e.g., Manikandan and Balasubramanian 2018, but see Di Sallo and Cockle 2022). Third, we conducted our research in old-growth forests in which non-excavated cavity density is higher than in secondary forests in southern Chile (Ibarra et al. 2020). Thus, it is likely SCUs had more non-excavated cavities available to them and therefore, they likely do not need to rely on MAWO-excavated cavities in old-growth forests on Navarino Island (where MAWOs may depredate and thermoregulation costs would increase).

We identified three larger avian species using MAWO-excavated cavities on Navarino Island. Notably, American Kestrels, Austral Pygmy-Owls, and Austral Parakeets likely could defend against a MAWO attack, which may explain why these species and not the smaller, defenseless passerines used MAWO cavities more frequently. Although sample sizes are limited, all five Austral Pygmy-Owl nests were found in MAWO-excavated cavities, as were two of the eight Austral Parakeet nests, and the one American Kestrel nest. Moreover, Beaudoin and Ojeda (2011) reported Rufous-legged Owls (*Strix rufipes*) nested in MAWO-excavated cavities. Although we did not observe this in our study, it is possible this species uses MAWO-excavated cavities on Navarino. Thus, MAWO cavities may be a vital resource for larger avian species, particularly raptors. Similarly, Three-toed Woodpecker cavities were an important resource for Eurasian Pygmy-Owls (*Glaucidium passerinum*) in boreal forests in Finland (Pakkala et al. 2018b). Notably, these predators may have cascading effects on their local ecosystems, which may result in a potential keystone role for MAWOs. However, further research should test this hypothesis.

We also have evidence of cavity use by passerines, likely a duck, rodents, and bats, although species could not be identified. The down feathers may have belonged to a Speckled Teal (*Anas flavirostris*; Jiménez and White 2011). The rodent was likely a long-tailed pygmy rice rat (*Oligoryzomys longicaudatus*) because this is the only scansorial mammal inhabiting Navarino Island and the Cape Horn Biosphere Reserve (Crego et al. 2018, Cañón et al. 2024). The most likely bat species include Southern big-eared (*Histiotus magellanicus*), lesser big-eared (*H. montanus*), Chiloe little brown (*Myotis chiloensis*), and red (*Lasiurus borealis*; Iriarte 2008).

We conducted most of our research at the end of the austral breeding season. Therefore, our cavity use sample sizes are likely reduced because avian breeding phenology varies among SCUs (Jara et al. 2019). Also, we checked unused cavities once per season. Thus, we surveyed a limited time species had available to use cavities and may have missed an occurrence if the individual used it at a different time, did not leave evidence (e.g., fecal matter, feathers) behind, or the evidence was of low quality (e.g., degraded). Importantly, empty cavities do not imply cavities are unused; therefore, if possible, future researchers should deploy cameras recording 24-hr/day (Zahner et al. 2017) or that are motion-activated to capture cavity use.

In addition to underestimating cavity use, researchers conducting ground surveys may overestimate the number of excavated cavities available for use (Koch 2008). We defined a MAWO cavity as having internal depth; however, 25% (n = 35/142) of MAWO cavities were actually cavity starts (i.e., there was no internal depth). Therefore, researchers need to check cavities with cameras or other technology to determine if they are indeed suitable for use, especially if conservation and management decisions are made based upon cavity hole or entrance estimates. Although cavity starts may be used by some species, cavity starts should be distinguished from fully excavated cavities.

Our finding that at the assemblage level, SCUs use non-excavated cavities more frequently than MAWO cavities agrees with previous research in South American subtropical (Cockle et al. 2011b) and temperate rainforests (Altamirano et al. 2017). However, our results were biased toward finding MAWO-excavated cavities and by re-checking only MAWO-excavated cavities. Therefore, more intensive nest searches and more frequent cavity rechecks should be conducted to determine accurate reuse rates of MAWO and non-excavated cavities and the extent to which various SCU species depend on them.

As for habitat characteristics, the null model was best for all three comparisons (i.e., MAWO vs. random, SCU vs. random, and comparing MAWOs vs. SCUs), suggesting either the variables we measured at the patch scale were not appropriate to assess cavity use for MAWOs or SCUs, or perhaps the birds in our study do not select habitat characteristics at that scale. Similarly in subtropical forests of Argentina, patch-scale characteristics had little impact on nest-site selection of SCUs (Di Sallo and Cockle 2022).

At the tree scale, DBH was an important predictor of cavity use by MAWOs and SCUs compared to random-paired sites, which has been reported elsewhere for various primary and secondary cavity users across continents (e.g., Martin et al. 2004, Cockle et al. 2011a, Newlon and Saab 2011, de la Parra-Martínez et al. 2015, Altamirano et al. 2017, Segura 2017, Bonaparte et al. 2020). However, DBH (above a certain threshold) was a poor predictor for cavity use by MAWOs in Argentina (Ojeda et al. 2007). Both in our study and in Ojeda et al. (2007), MAWOs selected taller trees. Similarly, SCUs in Argentina (Cockle et al. 2011a) used cavities in taller trees. However, in our study, SCUs used cavities in shorter trees compared with random-paired sites and used cavities lower to the ground than MAWOs. Perhaps as Navarino has no native, terrestrial predators (Jiménez et al. 2014), SCUs may have evolved traits to use cavities lower to the ground to reduce predation pressure by the avian predator community.

Magellanic Woodpeckers excavate cavities with a teardrop-shaped entrance (Short 1970; Fig. 2B) and are selective about which trees they use. Of all available tree species within their range, MAWO cavities have been found only in *Nothofagus* spp. (Saavedra et al. 2011). Three *Nothofagus* spp. dominate the Navarino forests (Soto et al. 2017). Thus, we suggest MAWOs excavated their cavities more frequently in Coigüe because it is more abundant than Lenga and Ñirre in forests < 300 m.a.s.l. (Soto et al. 2017). Regardless of abundance, it is unsurprising MAWOs do not excavate cavities often in Ñirre because this species frequently contains many branches along its trunk, thus increasing the difficulty for woodpeckers to excavate and the potential risk of predation (e.g., Jiménez et al. 2014). Further, *Nothofagus* spp. have varying wood properties (Vergara et al. 2022 and references therein), which impact the MAWO's ability to excavate.

On Navarino Island, Winter's bark is less abundant than *Nothofagus* spp., which may be a contributing factor explaining why we did not locate any cavities in this species. However, other studies conducted elsewhere in South American temperate forests also report MAWOs primarily excavate their cavities in *Nothofagus* spp. (Vergara and Schlatter 2004 and references therein). It is also unsurprising MAWOs did not excavate in Winter's bark because this species decays externally to internally (A. L. Wynia, *personal observation*), making it unstable and unsafe for cavity use over time. *Nothofagus* spp., however, decay internally to externally due to heart rot (Veblen et al. 1996); therefore, cavities excavated in trees within this genus likely will be retained longer. Thus, based on decay pattern, MAWOs excavating cavities in *Nothofagus* spp. may be more likely to avoid predation risk (Wesołowski 2007), perhaps except for Ñirre with its many branches that may assist scansorial predators.

Management and conservation implications

Woodpecker species have been considered in forest management decisions because they often provide nest and roost sites for SCUs and are indicator species of habitat disturbance (Drever and Martin 2010), forest health, and avian diversity (van der Hoek et al. 2020). Woodpeckers are considered sensitive species by state and federal agencies because they are responsive to forest management and habitat condition (Dudley and Saab 2003). Specifically, the MAWO was likely a key cavity provider for larger SCUs in our study, and it could serve as an umbrella species for biodiversity conservation (Walpole and Leader-Williams 2002) because each family group occupies a relatively large range (i.e., one family group/100 ha; Ojeda and Chazarreta 2014; J. E. Jiménez, *unpublished data*). Moreover, the MAWO may fulfill other ecological roles by vectoring wood-decay fungi (e.g., Farris et al. 2004, Jackson and Jackson 2004, Jusino et al. 2015) and by providing oviposition sites for insects and foraging sites for birds (e.g., Aubry and Raley 2002). However, further research needs to be conducted to determine the MAWO's role in these ecosystem functions.

From a conservation viewpoint, the MAWO serves as a flagship species (Arango et al. 2007) and is culturally important (Ojeda and Chazarreta 2014). The MAWO is listed as Endangered or Vulnerable throughout its Chilean distribution (Servicio Agrícola y Ganadero 2015), one reason being ~33% of forested habitat has been lost within its range (Ojeda and Chazarreta 2014). Further, temperate forests of Chile are considered biodiversity hotspots, yet they are one of the most threatened forest biomes globally (Miranda et al. 2015). Therefore, understanding avian assemblage dynamics, including cavity requirements, and establishing accurate cavity counts would assist both management practices in South American temperate forests and conservation measures of the avian cavity-using assemblage.

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Author Contributions:

A. L. W., R. R, and J. E. J. conceived the ideas and designed the methodology; J. E. J. and R. R. secured funding; A. L. W., R. R., and J. E. J. collected data; A. L. W. analyzed data; A. L. W. led the writing of the manuscript; and A. L. W., R. R., and J. E. J. contributed to the drafts and gave final approval for publication.

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