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UNEXPECTED LACK OF EFFECT OF THE INVASIVE AMERICAN MINK ON THE NESTING SURVIVAL OF FOREST BIRDS

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Abstract · Nest predation by invasive mammalian predators can cause major impacts on native bird populations. The American Mink (*Neovison vison*) was recently introduced in Navarino Island, southern Chile, where it established itself as a new terrestrial mesopredator on the island, with documented impacts on waterfowls' breeding success. However, little is known about the effects of minks on forest birds' reproduction. Here, we investigated nest predation rates by native predators and the invasive mink on open-cup nesting forest birds by using artificial and natural nests. In six different plots, we deployed a grid of 14 (7 X 2) artificial nests spaced by 50 m and at random heights from the ground. We used camera traps in each nest to identify predators. At each plot, we estimated the relative abundance of predators using camera traps, Sherman traps, and bird point counts. We estimated nest survival probability as a function of nest age, concealment, distance to the river, and height. Additionally, we monitored 43 natural nests of five open-cup nesting bird species. Contrary to what was expected, the mink was not a main predator of the nests and preyed upon only one natural nest. The native raptor Chimango Caracara (*Milvago chimango*) was the main nest predator, preying on 39.8% of the artificial nests and 27% of the natural nests. We also found evidence that Chimango Caracaras learned to associate the artificial nests with the egg reward. We argue that the lower abundance of mink in the forest and a mismatch between mink peak activity patterns and bird breeding phenology can result in low depredation. Mink impacts may be more pervasive during summer months, on fledglings, or when mink activity peaks, and more research should be conducted to assess these questions. Our results are valuable to better understand mink impacts on biodiversity and to prioritize conservation actions on species more severely affected.

Resumen · **Inesperada falta de efecto del visón norteamericano invasor sobre la supervivencia de nidos en aves de bosque.**
La depredación de nidos por parte de mamíferos invasores puede causar grandes impactos sobre las poblaciones de aves. El visón norteamericano (*Neovison vison*) fue recientemente introducido en isla Navarino, al sur de Chile, donde logró establecerse como un nuevo mesodepredador terrestre en la isla, afectando negativamente el éxito reproductivo de especies de aves acuáticas. Sin embargo, poco se sabe sobre los efectos que el visón tiene sobre la reproducción de aves de bosque. En este trabajo investigamos la tasa de depredación de nidos por parte de depredadores nativos y del visón invasor sobre nidos de copa de aves de bosque, usando nidos artificiales y naturales. En seis parcelas diferentes desplegamos una cuadrícula de 14 (7 X 2) nidos artificiales, espaciados por 50 m y a alturas aleatorias del suelo. Usamos cámaras trampa en cada nido para identificar a los depredadores. En cada parcela, estimamos la abundancia relativa de los depredadores mediante el uso de cámaras trampa, trampas Sherman y puntos de conteo de aves. Estimamos la probabilidad de supervivencia en función de la edad del nido, su ocultamiento, su distancia al río y su altura. Además, monitoreamos 43 nidos naturales de cinco especies de ave con nidos en copa. Contrario a lo esperado, el visón no fue un depredador importante de nidos, depredando solo un nido natural. El ave rapaz nativa, el caracara chimango (*Milvago chimango*), resultó ser el principal depredador, depredando el 39,8% de los nidos artificiales y el 27% de los nidos naturales. También encontramos evidencia de que los caracara chimango aprendieron a asociar los nidos artificiales con la recompensa de los huevos. Creemos que la menor abundancia de visones en el bosque y la disociación temporal entre el pico de actividad de los visones y el de la reproducción de las aves puede estar resultando en una baja tasa de depredación por parte del visón. Sin embargo, los impactos del visón pueden ser más importantes en el verano, sobre los volantones, o cuando la actividad de los visones alcanza su punto máximo. Nuevas investigaciones deberán abordar estos puntos. Nuestros resultados contribuyen a un mejor entendimiento del impacto del visón sobre la biodiversidad y a priorizar las acciones de conservación en las especies más afectadas por este.

Key words: Bird nesting success · Cape Horn Biosphere Reserve · Invasive species · Nest predation

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INTRODUCTION

Nest predation is one of the main causes of reproductive failure in birds (Martin 1995, Thompson III 2007). It can shape bird reproductive strategies (Fontaine & Martin 2006), habitat and nest site selection (Lima 2009), and affect population dynamics (Robinson et al. 1995, Thompson III 2007). Nest predation becomes extremely relevant for bird populations that encounter novel invasive predators: predatory effects can be devastating for native birds (Bellard et al. 2016), particularly with mammalian invasive predators (Blackburn et al. 2004, Doherty et al. 2016). In fact, 87 bird species have become extinct and many are becoming increasingly endangered due to mammalian invasive predators in the last 500 years (Doherty et al. 2016). Bird species that have evolved in the absence of terrestrial predators, such as many insular species, are generally more vulnerable to the introduction of mammalian predators given that they evolved reproductive strategies in their absence and lack antipredator responses (Sih et al. 2010).

One well known invasive predator with documented negative effects on bird populations is the American Mink (*Neovison vison*; hereafter: mink). The mink, native to North America, is a mid-sized, semi-aquatic mustelid introduced at the beginning of the twentieth century to many regions worldwide for the value of its fur (Larivière 1999a). This invasive carnivore has had drastic effects on ground nesting bird populations in several islands of Europe, mainly involving sea birds and waterfowl species (Ferreras & Macdonald 1999, Bonesi & Palazon 2007, Brzezinski et al. 2012). Similarly, population declines of waterfowl species have been documented in lakes with mink presence in continental Patagonia in South America (Peris et al. 2009, Pescador et al. 2012).

The mink has recently established its southernmost breeding population in the Cape Horn Biosphere Reserve (CHBR) in southern Chile. After several individuals escaped—or were deliberately released into the wild—from fur farms, the species invaded Tierra del Fuego Island, Argentina (Jaksic et al. 2002), from where it dispersed into Navarino Island in Chile at the end of the twentieth century (Rozzi & Sherriffs 2003). This island is home to a diverse forest avian community, encompassing 34 species from 20 families (Ippi et al. 2009). Up until the introduction of the mink, most of the CHBR was naturally free from terrestrial-mammal mesopredators. Nonetheless, the mink established itself as a novel terrestrial mesopredator, with reported significant impacts on the reproductive success of waterfowl species nesting along the marine shoreline (Schüttler et al. 2009). Information on mink effects on forest birds, however, remains limited, many times anecdotal, and with contrasting results. Maley et al. (2011) identified the mink as an important predator, whereas Ibarra (2007) did not find evidence of the mink as a main predator, but these artificial nest studies have not been validated with natural nests (Thompson III & Burhans 2003, Moore & Robinson 2004).

In this study, we aimed to: (i) evaluate and compare the mink and other predators' nest predation rates on open-cup nesting forest birds, using artificial and natural nests, and (ii) test the effects of the distance to rivers and height from the ground on nest survival probability in artificial nests. Passerine birds represent between 9 and 11% of prey biomass consumed by minks on Navarino Island (Schüttler et al. 2008, Crego et al. 2016), where these mammals are known to be active in riparian areas along freshwater ecosystems (Schüttler et al. 2010). Additionally, many songbird species in the island build their nests on the ground, a potential reproductive strategy that evolved in the absence of terrestrial predators (Jara et al. 2019); therefore, we hypothesized that the mink is an important predator of forest bird nests. We predicted that mink nest predation would be higher at closer distances from rivers and on nests placed closer to the ground, which would result in a lower survival probability near rivers and at ground level.

METHODS

Study area and study design. The study was conducted in Navarino Island (68°W, 55°S, 2500 km^2), Chile, at the southern end of the sub-Antarctic Magellanic forest ecoregion. It includes evergreen forests dominated by *Nothofagus betuloides* and *Drimys winteri*, as well as deciduous forests dominated by *N. pumilio* and *N. antarctica*. The island presents a mountainous landscape with a maximum elevation of 1000 m a.s.l. The climate is oceanic and cold, with a mean annual temperature of 6 ± 5°C and a uniform annual precipitation of 467.3 mm (Rozzi & Jiménez 2014).

Artificial nest experiment. We selected six forest plots (50 x 300 m) along the northern coast of Navarino Island, accessible and adjacent to a river. Plots were separated more than 1 km from each other to increase the chances of accounting for different mink territories (Figure 1A). Plots were also located more than 50 m from the forest edge to avoid edge effect on nest predation (Paton 1994). During October 2015 we set two lines of seven nests, separated by 50 m, at the six plots. Nests were also spread 50 m from each other along each line. Each line started at the river's shore and extended perpendicularly towards the forest (Figure 1B). We built artificial nests measuring 15 cm in external diameter based on a half sphere plastic structure covered by lichens (*Usnea* spp.), one of the main materials used by forest birds to build their nests in this region (Altamirano et al. 2012) (Figure 2). Each nest was randomly set at a height between 0 and 1.5 m from the ground, which covers the average nest height for the five most common forest passerines in the study area (Jara et al. 2019). We placed one fresh commercial quail egg and two clay eggs in each artificial nest to the color and shape of the Austral Thrush (*Turdus falcklandii*) eggs. We used nitrile gloves during manipulation to avoid human odor from affecting the treatments. Nests were active for a period of 13 days, which corresponded approximately to the mean number of incubation days for the forest passerines in the area (Jara et al. 2019). Given the difficulties to identify predators from nest remains (Larivière 1999b), we used camera traps set 1–2 m from the nests. A nest was considered predated when at least one egg showed marks or was removed. Because we had a limited number of camera traps, we first ran plots 1, 2, and 3, and then plots 4, 5, and 6.

We estimated the degree of visual concealment of each nest as the percentage of a circle 25 cm in diameter in its center obscured by foliage (in 10% increments). We estimated horizontal and vertical concealment within 1 m from a nest in the four cardinal directions and 1 m above, and averaged these five estimates (Martin et al. 1997). We started

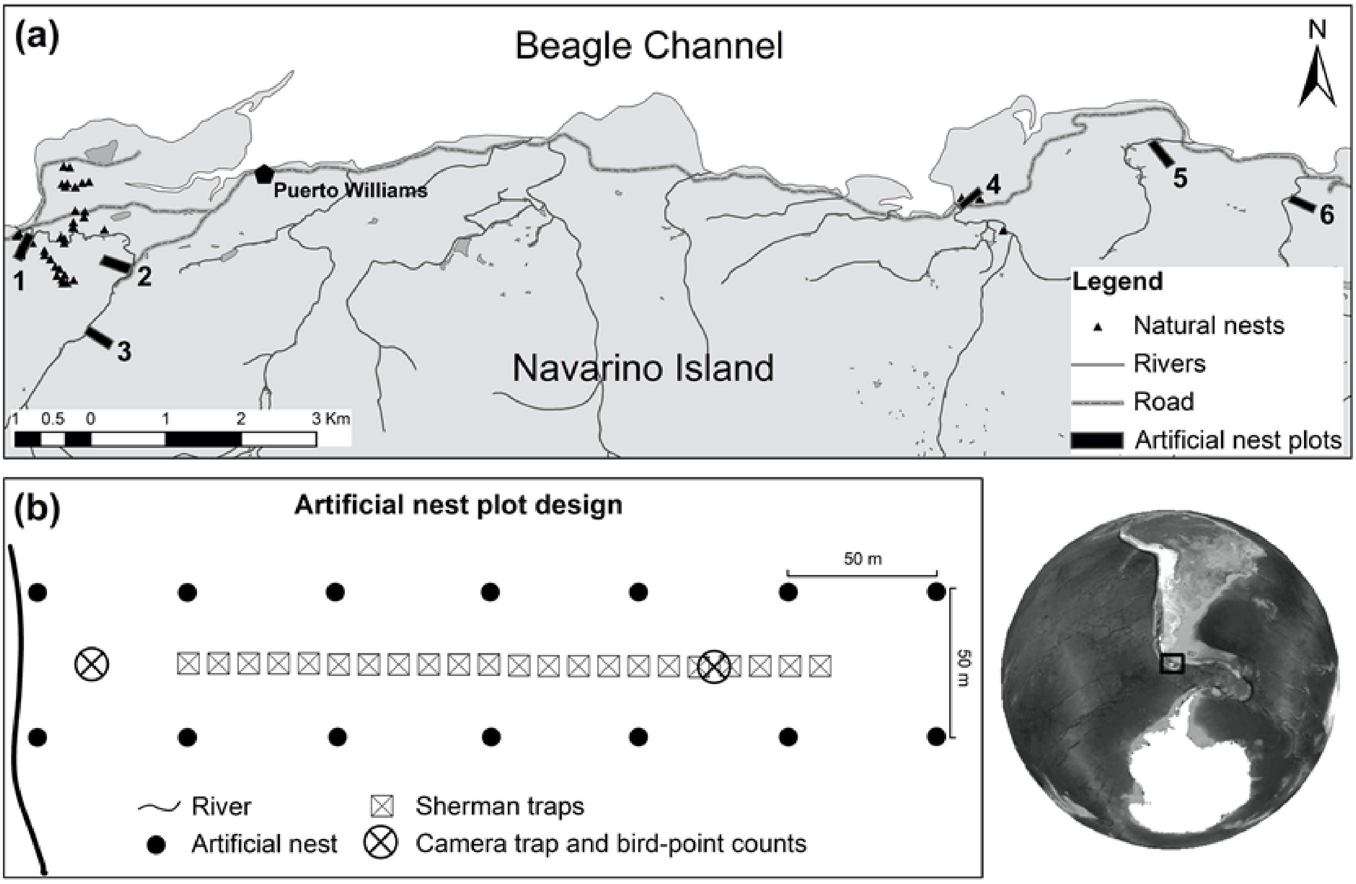

Figure 1. (A) Map showing the location of artificial nest experimental plots and natural nests to study mink predation on open-cup forest nesters along the northern slope of Navarino Island, southern Chile. (B) Each artificial nest plot was composed of 14 artificial nests (and its accompanying camera trap) set in two lines of seven. Each line started at the river and went into the forest. At each plot we conducted bird counts and installed two camera traps to estimate potential predator relative abundance, and ran a line of 22 Sherman traps.

counting the exposure days on the midnight of the day the nest was set. We considered the day of predation as the failing day.

Predator relative abundance. A previous study conducted on Navarino Island identified two main predators of open-cup artificial nests: minks and Southern House Wrens (*Troglodytes musculus*) (Maley et al. 2011). Another study also reported the Chimango Caracara (*Milvago chimango*) and the Crested Caracara (*Caracara plancus*) as the main predators of open-cup artificial nests (Ibarra 2007). Other potential predators in the area include six mammal and three bird species: two native rodents (*Abrothrix xanthorhinus* and *Olygorizomys longicaudatus*), introduced house mice (*Mus musculus*), domestic dogs (*Canis lupus familiaris*), domestic cats (*Felis catus*), feral pigs (*Sus scrofa*), Magellanic Woodpeckers (*Campephilus magellanicus*; Jiménez and Barroso, pers. observ.), Chilean Hawks (*Accipiter chilensis*), and Austral Pygmy-Owls (*Glaucidium nana*) (Rozzi & Jiménez 2014).

We estimated predator relative abundance using a combination of techniques. To estimate relative abundance of minks, dogs, cats, and feral pigs at each plot, we set two camera traps at 20 m and 225 m from the river shore (Figure 1B). Cameras were baited with canned fish placed in a punctured can secured to the ground (in pilot studies we proved this bait to be effective in detecting all these species on Navarino Island). We placed the cameras at 30-40 cm from the ground and 2-4 m away from the bait. We set each camera to trigger three pictures per detection, with a delay time of 60 s. Cameras were active 24 h/day during the 13 days of nest exposure. We estimated each predator species' relative abundance per plot as the number of detections per 100 trap nights (we assumed that two detection events were independent if > 60 min passed between detections). We also conducted bird point counts during three consecutive days at the same locations where the camera traps were installed (Figure 1B) for periods of 10 minutes, between 6:00 h and 9:00 h, and using a 50 m fixed radius (Jiménez 2000). We estimated relative bird abundance at each plot as the mean number of individuals per species detected, per 10 min of observation. Finally, to estimate small rodent abundance we set a line of 22 Sherman live traps at each plot, starting 50 m from the river towards the interior of the forest (Figure 1B). Traps were baited with rolled oats and were left active for three days and three nights. We checked traps early in the morning. All rodents were identified to species, ear-tagged and released. All animal capture and handling procedures followed guidelines set by the American Society of Mammologists (Sikes & Gannon 2011). We estimated small rodent relative abundance as the minimal number of individuals known alive (MNKA) per plot (Krebs 1966). To avoid affecting the nests by repeated visits to the plots, we sampled bird and small rodent relative abundances after we finished the nest experiment.

Statistical analysis. We estimated nest survival probability for the artificial nests using a Bayesian framework (Royle & Dorazio 2008), with JAGS 3.4.0 (Plummer 2016) and package

Figure 2. (a) Camera trap set up to monitor an artificial nest. (b) Artificial nest with one quail egg and two clay eggs. (c) Austral Thrush nest with blue eggs. (d) Chimango Caracara preying on an artificial nest, removing a clay egg. (e) Nest of a White-crested Elaenia with two chicks, showing the use of lichens as nest material. (f) Chimango Caracara predating on a nestling.

R2jags for R, version 3.6.1 (R Development Core Team 2016). To test the hypothesis that if mink predation occurred, it would be higher on ground nests and closer to rivers, we estimated nest survival probability for artificial nests as a function of distance to the river, nest height, and the quadratic effect of these two covariates. Nest concealment and nest age were included as covariates. We expected nest fates at each plot to be correlated and thus modeled the plot as a random effect (Royle & Dorazio 2008).

We did not find evidence of correlation among covariates that could produce multicollinearity effects on the models (all $\rho < 0.6$). We standardized all covariates to a mean of 0 and a standard deviation of 1 for the analyses. We used non-informative priors and three Markov Chain Monte Carlo (MCMC) chains to find 50,000 posterior samples of the parameters of interest after a 20,000 burn-in period and a thinning rate of 1:10. We evaluated model convergence using the Gelman-Rubin diagnostic, which should be close to 1 for each parameter when convergence is reached (Gelman & Rubin 1992). We evaluated model fit by calculating the Bayesian p-value, which estimates the probability of simulated data being more extreme than the observed data, with values near 0.5 indicating a good fit (Gelman et al. 1996). We based the statistical significance of parameters on 95% credible intervals not overlapping zero.

We then performed a forward sequential model selection procedure based on the Deviance Information Criterion (DIC; Spiegelhalter et al. 2002). To do so, we compared the null model with models that incorporated the different covariates, aiming to compare models with an increasing level of complexity to the model with the natural variability. If more than one covariate resulted informative (with a lower DIC than the null model), we continued building a more nested complex model with the forward stepwise procedure. We selected the model with the lowest DIC as the most parsimonious.

Natural nests searching and monitoring. Even though artificial nests are easy to study, they can provide biased estimates of predation rates given that they differ from natural nests in many important aspects (e.g., egg type, odor, nest material, no parental activity). This makes the validation of results in comparison to natural nests necessary (Thompson III & Burhans 2003, Moore & Robinson 2004). Therefore, between October 2015 and January 2016 we actively and opportunistically searched, located, and monitored nests of open-cup nesting species close to (1 km radius) three of the same plots where artificial nests were placed (Figure 1A). We selected plots 1, 2, and 6 for logistical convenience. We used the parents' behavior, opportunistic encounters, and a thermal imaging device (FLIR One, 2014 © FLIR® Systems, Inc.) to locate active nests.

We recorded the location for each found nest using a handheld GPS unit. For predator identification, we installed a camera trap close to each nest, at a position that minimized disturbance on it (Richardson et al. 2009). We monitored all nests in intervals between two to six days, until the nest failed or the young fledged, in order to complement the information provided by the camera traps. At each visit and before approaching the nest, we inspected the area to ensure that no predators were nearby. A nest was considered successful if at least one chick fledged. To infer if it had successfully done so when the nest was found empty (and the camera did not detect the event), we used cues around the nest. Copious amount of bird feces on its rim and/or below it, along with an intact structure, were considered indicators of a successful nest (Martin et al. 1997).

Raptor conditioning to artificial nests. We found that several artificial nests were predated by Chimango Caracaras during

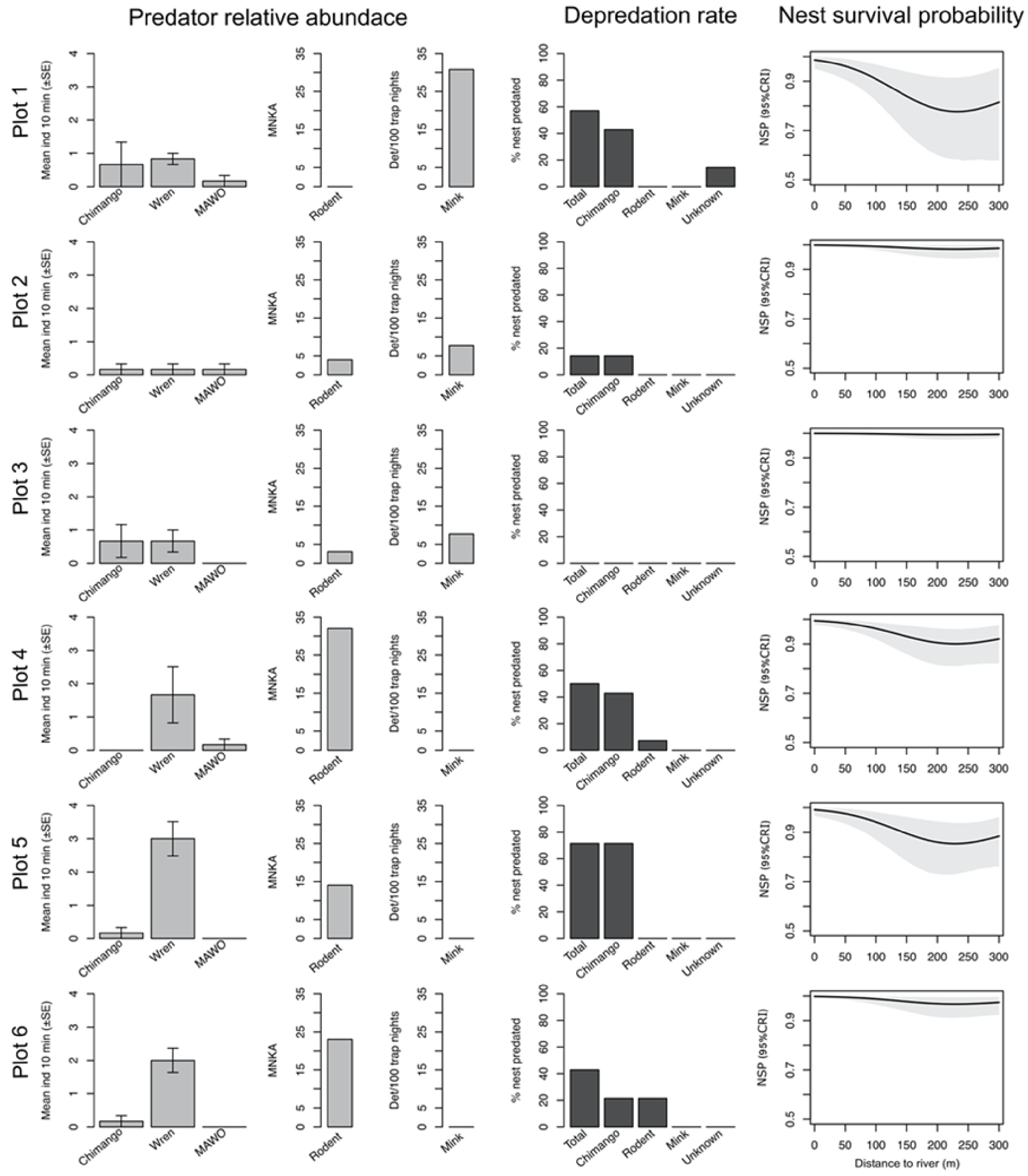

Figure 3. Predator relative abundances, artificial nest predation rate, and nest survival probability (95% credible intervals) as a function of distance to the river for the six plots, in order to investigate the effect of nest predation on open-cup forest birds on Navarino Island, Chile. Relative abundance was estimated as the mean number of individuals per 10 min of observation for birds, the minimal number known alive (MNKA) for small rodents, and the number of detections (>60 m between detections) per 100 camera trap nights for the American Mink. Chimango refers to Chimango Caracara, Wren to Southern House Wren, MAWO to Magellanic Woodpeckers, rodent to small rodents, and mink to American Mink.

short periods of time in four plots. We suspected that these birds of prey learned to associate clues of the artificial nests experiment's setting with the quail egg reward. For each nest and day (1 to 13) we calculated the percentage of neighboring nests (i.e., 50 m from the focal nest) that were predated by Chimango Caracaras up to that specific day. Since we were only interested in these caracaras, we discarded four nests predated by small rodents. To assess whether the probability of survival per day decreased as the number of neighboring nests predated by the caracaras increased, we modeled nest survival probability (NSP) as a function of the percentage of predated neighboring nests using plot as a random factor. We reasoned that after successfully eating a quail egg, the Chimango Caracaras would search nearby for more food (Larivière & Messier 1998), and predicted that if these birds were learning to associate artificial nest settings

Table 1. Artificial and natural nests of five passerine species predated by different predators during the 2015–2016 reproductive season in Navarino Island, Chile.

Predator	Nests predated (%)						
	Artificial nest (n = 83)	Total natural nests (n = 37)	Rufous-collared Sparrow (n = 15)	White-crested Elaenia (n = 9)	Patagonian Sierra-finch (n = 6)	Tufted Tit-tyrant (n = 5)	Austral Thrush (n = 2)
Chimango Caracara	39.75	27.02	26.67	33.33	33.33	20	0
American Mink	0	2.7	6.67	0	0	0	0
Small rodent (all)	12.12	0	0	0	0	0	0
Abrothrix xanthorhinus	6.06	0	0	0	0	0	0
Unknown	6.06	24.32	33.33	33.33	0	0	50
Abandoned	-----	5.4	0	2.7	0	2.7	0

Table 2. Model coefficients, 95% credible intervals, Deviance Information Criterion (DIC), and Bayesian p-values for the posterior distribution of the set of models used to investigate nest survival probability in artificial nests during October 2015. The most parsimonious Bayesian model (lowest DIC value) is found in bold. Covariates include the age of the nest, concealment, nest height above the ground, distance to the river, and the quadratic effect of these last two covariates. BP = Bayesian p-value.

Model	Covariates							DIC	BP
	Intercept	Age	Conceal.	Nest height	Nest height^2	Distance to the river	Distance to the river^2		
Mod1	3.61 (1.84 – 4.86)							210.7	0.46
Mod2	3.68 (1.88 – 4.87)	0.37 (–0.09 – 0.89)						211.0	0.38
Mod3	3.64 (1.93 – 4.88)		–0.38 (–0.90 – 0.09)					210.3	0.48
Mod4	3.64 (1.83 – 4.88)			0.06 (–0.33 – 0.48)				212.4	0.47
Mod5	3.70 (1.83 – 4.89)			0.09 (–0.33 – 0.50)	–0.08 (–0.47 – 0.32)			214.8	0.48
Mod6	3.65 (1.91 – 4.88)					–0.66 (–1.09 – –0.24)		202.7	0.48
Mod7	3.28 (1.25 – 4.81)					–0.94 (–1.62 – –0.38)	0.70 (0.12 – 1.36)	199.7	0.46
Mod8	**3.40** **(1.47 – 4.85)**		**–0.46** **(–1.02 – 0.06)**			**–0.99** **(–1.65 – –0.42)**	**0.62** **(0.06 – 1.26)**	**198.1**	**0.43**

(lichen structure or clay eggs) with the quail egg reward, then NSP would decrease (or the probability of the nest being predated by Chimango Caracaras would increase) as the percentage of predated neighboring nests predated rose.

Furthermore, the use of cameras has been shown to increase predation rates by attracting predators to such a conspicuous marker (Götmark 1992). Suspecting the potential conditioning of Chimango Caracaras to the camera trap placed in front of nests, we deployed 10 camera traps in front of unused open-cup nests from the previous year in plots 1 and 2, after we finished with the artificial nest experiments and while we were monitoring natural nests. After 13 days, we checked for predator visits to the nests. If Chimango Caracaras were indeed associating the camera trap with the quail egg reward instead of the artificial nest itself, we expected them to visit and inspect old empty nests with a camera. Otherwise, we assumed that these birds were attracted to the artificial nests either by the lichen structure, the clay eggs, or both.

RESULTS

Predator relative abundance. In terms of mammal predators, we detected a total of 12 mink visits to camera traps close to the river in plots 1, 2, and 3 (Figure 3). We did not detect activity from cats, dogs or pigs. The presence of two species of small rodents was recorded during the trapping period in five out of the six plots, the native *A. xanthorhinus* and the introduced *M. musculus*. Rodent abundance was low in plots 1, 2, and 3 (<4 MNKA), and high in plots 4, 5, and 6 (>14 MNKA; Figure 3). Regarding bird predators, we observed the Chimango Caracara in five out of the six plots, Southern House Wrens in all plots, and Magellanic Woodpeckers in plots 1, 2, and 4 (Figure 3). We did not encounter Crested Caracaras, Chilean Hawks, or Austral Pygmy-Owls during the sampling period.

Artificial nests predation. One nest was discarded because the camera trap failed and the nest disappeared entirely. Of the 83 remaining nests, 33 were predated (39.75%) by two predators: the Chimango Caracara and small rodents (Table 1). We could not identify the predators of two nests in plot 1. Chimango Caracaras predated a total of 27 artificial nests (81.81% of the preyed nests) and corresponded with the species being detected in the plots, but there was no relationship between its predation rate and its relative abundance (ρ = –0.36). Four artificial nests were preyed upon by small rodents (12.12%) in plots with high abundance of small rodents (ρ = 0.78). We identified the rodent twice as *A. xanthorhinus* from images, and rodent predation twice from teeth marks on clay eggs. Minks, Southern House Wrens, and Magellanic Woodpeckers did not predate on any artificial nests despite their presence in the plots (Figure 3). Moreover, a mink individual was detected walking behind one artificial nest, but no interaction occurred.

Based on the posterior distribution of the most parsimonious model, NSP was best explained by concealment and by the squared distance to the river (Table 2). Concealment had a non-significant negative relationship with NSP, with 95% credible intervals overlapping zero (Table 2). For distance to the river, NSP decreased towards middle values and increased again at the highest distance from the river (Figure

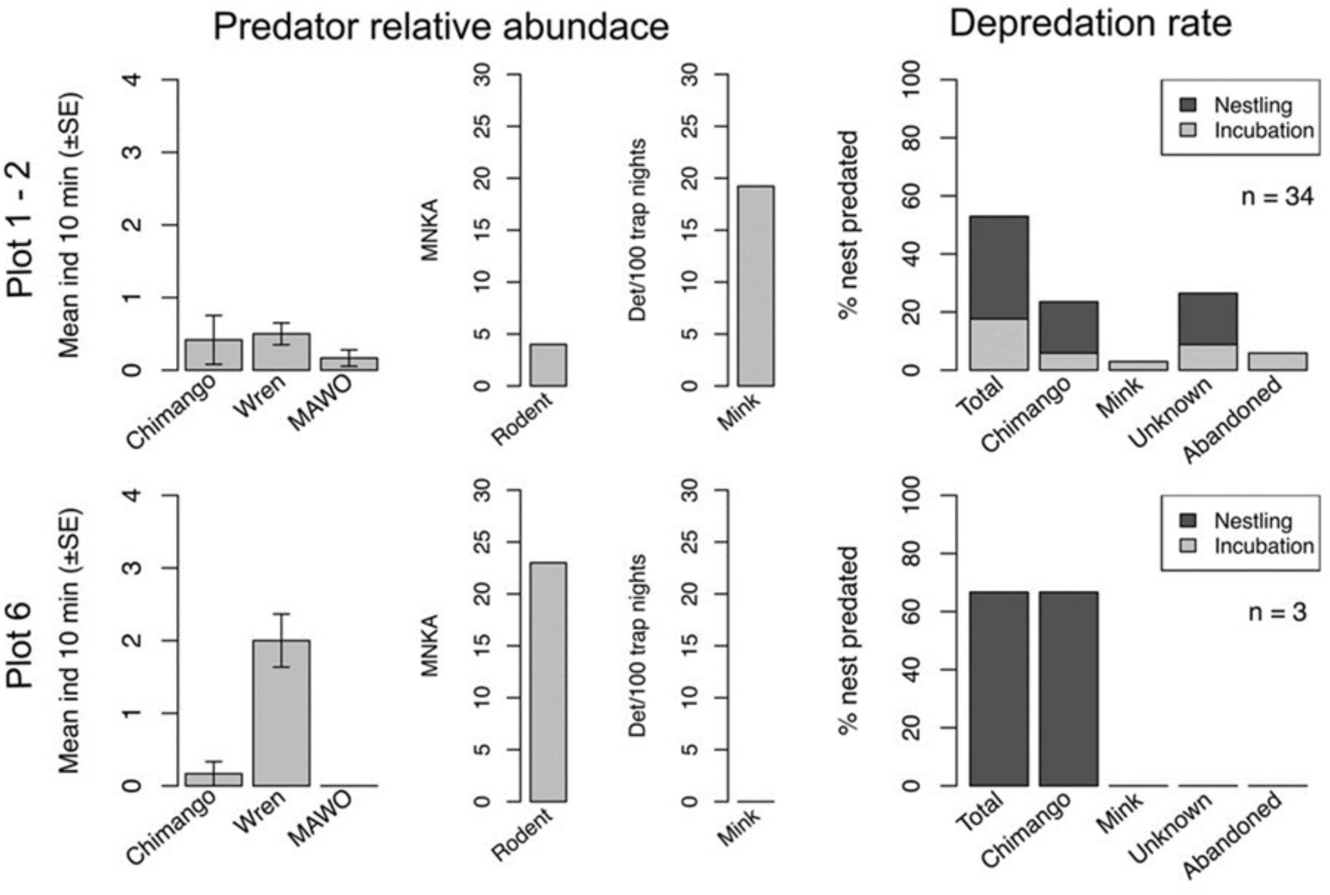

Figure 4. Predator relative abundances and depredation rate on open-cup forest bird nesters in Navarino Island, Chile. Relative abundance of predators was estimated during the artificial nests experiment. Relative abundance was estimated as the mean number of individuals per 10 min of observation for birds, as the minimal number known alive (MNKA) for small rodents, and as the number of detections (>60 m between detections) per 100 camera trap nights for the American Mink. Chimango refers to Chimango Caracara, Wren to Southern House Wren, MAWO to Magellanic Woodpeckers, Rodent to small rodents, and Mink to American Mink.

3).

Natural nests predation. We found and monitored a total of 43 nests belonging to the following species: Rufous-collared Sparrow (*Zonotrichia capensis*; 16), White-crested Elaenia (*Elaenia albiceps*; 13), Patagonian Sierra-Finch (*Phrygilus patagonicus*; 6), Tufted Tit-Tyrant (*Anairetes parulus*; 5), and Austral Thrush (*T. falcklandii*; 3). We found 39 nests near plots 1 and 2, and four more close to plot 6. Eight nests were abandoned: two due to unknown reasons (4.6%), whereas six (14%; one from the Rufous-collared Sparrow, one from the Austral Thrush, and four from White-crested Elaenias) were abandoned the day after the camera trap was set. We thus assumed that these nests were abandoned because of the disturbance. Discarding these six nests, predation accounted for 54% of apparent nest failures (Table 1). Chimango Caracaras predated 10 nests (27%), minks predated one (3%; located 109 m from the river), and we could not identify the predator in nine occasions (26.5%; Figure 4). We did not detect other predators of natural nests. In plot 1 and 2, predation by Chimango Caracaras and minks corresponded to the fact that both species were present in the area. On the other hand, neither Southern House Wrens nor small rodents preyed on nests, even though they were abundant in plots 1, 2, and especially 6 (Figure 4).

Raptor conditioning to artificial nests. Predation rate by Chimango Caracaras was 47% higher for artificial nests than natural nests (39.75% vs. 27%). Based on the posterior distribution of the model, NSP decreased as the percentage of neighbor nests predated by Chimango Caracaras increased (–0.33 [95% CRI: –0.79 – 0.15]). Even though 95% CRI of the mean parameter overlapped zero, plots 1, 4, and 5 presented a marked negative relationship with the percentage of neighboring nests predated (Figure 5). In these three plots, Chimango Caracaras predated 42.8%, 42.8%, and 71.4% of the nests deployed, respectively. This result suggests that these birds learned to search in the area for more nests. Additionally, none of the 10 camera traps placed in front of an empty nest from the previous year recorded predator visits. Results suggest that the high predation rate observed was due to the Chimango Caracaras' association of the artificial nests with the food reward.

DISCUSSION

The primary goal of this study was to investigate potential predatory effects of the invasive mink on the reproduction of open-cup forest bird nesters. Our results show that, contrary to our hypothesis, the mink did not predate on passerine open-cup nesters. The main nest predator in this study was the native bird of prey Chimango Caracara. Two previous studies documented mink predation on artificial, open-cup forest nesters (Ibarra 2007, Maley et al. 2011), Our results were more in line with the work by Ibarra (2007), who identified the Chimango Caracara as the main predator of artificial

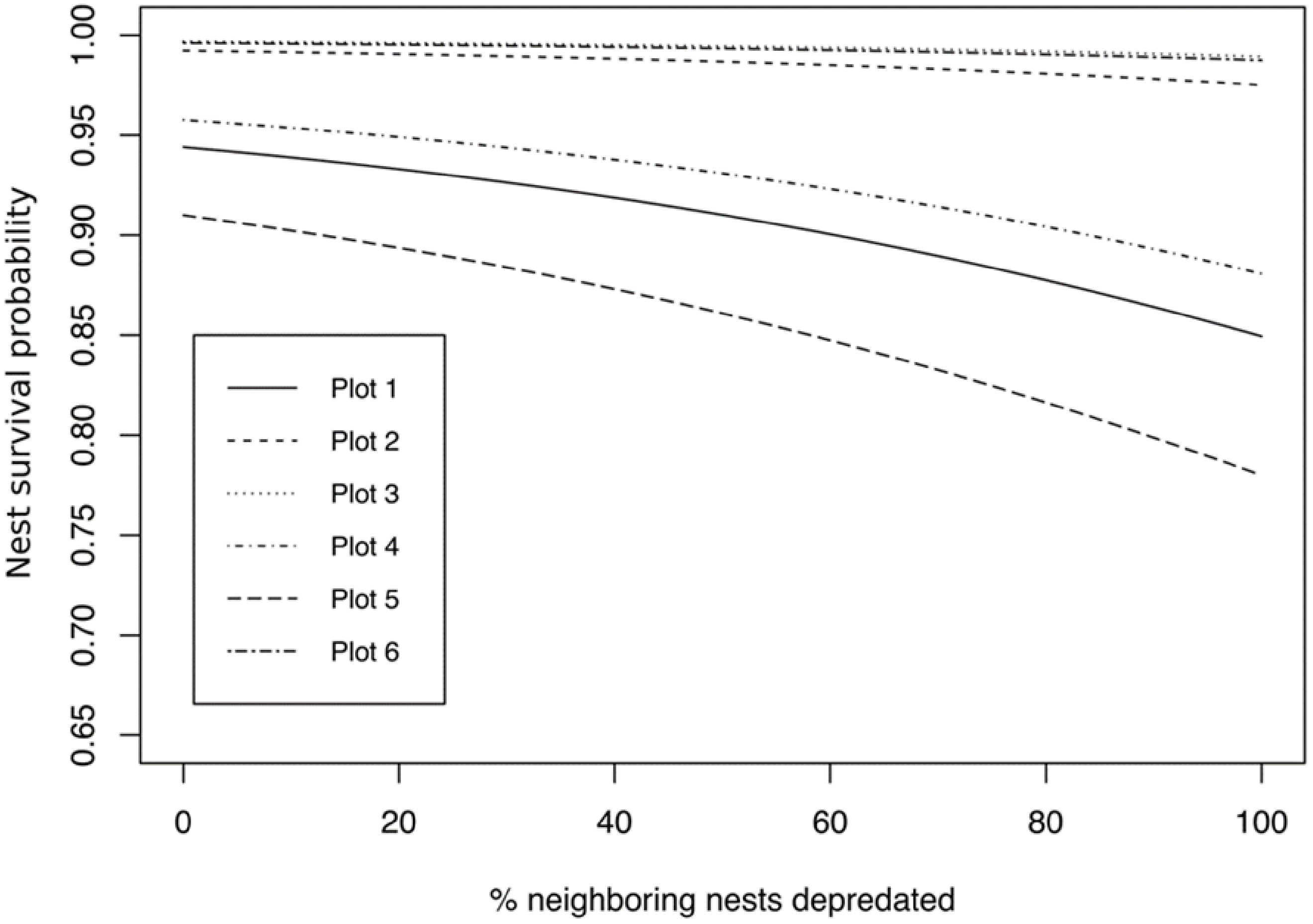

Figure 5. Nest survival probability for each plot of artificial nests as a function of the percentage of neighboring nests predated by Chimango Caracaras in Navarino Island, Chile.

nests (67.1% of all identified predation events) and only three predatory events by the mink in over 480 artificial nests deployed on inland wetlands. Similarly, we did not document minks preying on artificial nests, which is almost the same to the case of natural nests (only one mink predation event documented).

Minks are aggressive predators with high activity along riparian ecosystems (Larivière 1999a, Ahlers et al. 2015). We expected minks to have an effect on nests that were close to the ground near water courses. As a matter of fact, we detected mink activity near rivers, but only on half of the plots (i.e., 25% of the 12 camera traps deployed). The austral spring season on Navarino Island coincides with cold months, in which minks show low occupancy and activity (Crego et al. 2018), and are probably restricted to areas closer to dens (Dunstone & Birks 1983, Melero et al. 2011). Additionally, and in contrast to inland habitats, mink occupancy and abundance along the marine shoreline is high yearlong (Schüttler et al. 2010, Crego et al. 2018). The low abundance of minks in interior forests and the mismatch between mink activity and the reproductive phenology of forest birds might result in the mink having little impact on the breeding success of forest birds. This may explain the high predation impact that Schüttler et al. (2009) described on Flightless Steamer Ducks (*Tachyeres pteneres*) and Upland Geese (*Chloephaga picta*), as well as the high predation rate that Maley et al. (2011) observed on artificial nests along costal shrublands.

A higher mink abundance means a higher probability of this generalist predator finding a nest. However, mink occupancy and activity on Navarino Island expands towards inland habitats during the summer (Crego et al. 2018), when fledglings are more abundant. It is possible that the effect of mink on birds is more pervasive in the late summer (February-March) and on fledglings (Naef-Daenzer et al. 2001). Future research should be conducted to address these questions and with a larger sample size of natural nests. Nevertheless, knowing which habitats and species are being more affected by mink predation, it is important to prioritize management and conservation towards those species (e.g., Magellanic Woodpeckers, small native rodents and waterfowl species) (Schüttler et al. 2009, Jiménez et al. 2014).

The high predation rate by Chimango Caracaras that we documented on artificial nests suggests that this raptor is able to associate the nest, which seems more colorful than natural nests because of the lichens we used (see Figure 3B), with the quail egg reward. In fact, in three different occasions and in three different plots, two or three neighboring nests were predated consecutively within less than 60 min. The Chimango Caracara has a remarkable cognitive ability, with the ability to solve problems and obtain food in novel situations (Biondi et al. 2008; 2015). This ability poses future challenges for similar studies with artificial nests where Chimango Caracaras are present. However, this raptor appears to be the main predator in the system as it also was the main predator of natural nests.

Regarding other potential predators, we found contrasting results to Maley et al. (2011) involving Southern House Wrens. We did not document predation events by wrens, although they were abundant on the plots. We suspect that parents may keep small predators, such as wrens, away from the nest site. Nevertheless, previous studies documented conspecific and hetero-specific egg and chick destruction by House Wrens. This is a behavior described in other wren species as well, in which wrens respond by attacking and destroying eggs or nests that were experimentally set near their own nests (Kendeigh 1941). However, this behavior seemed to be more of a response to territoriality than predation *per se* (Kendeigh 1941). Additionally, we documented four mice predation events on artificial nests. There is a possibility that some of the unidentified predators on natural nests were rodents, given that the sensibility of camera traps to small animals is more variable (Rowcliffe et al. 2011). However, we detected multiple rodents moving near artificial nests without interfering with the eggs, whereas we did not record rodents on natural nests. We are currently studying the potential role of parental care in keeping these small mammals away from natural nests (Jara pers. com.). Our results are consistent with those from Schüttler et al. (2009), which showed small rodents preying on artificial nests but not on natural nests. More research is needed regarding the potential effect of the exotic *M. musculus,* since it can cause severe conservation problems on insular bird populations as it adapts to the new isolated conditions, increases its body size and develops its predatory behavior–something known as “insular syndrome” (Adler & Levins 1994, Cuthbert et al. 2016).

In conclusion, we found that the Chimango Caracara was the main nest predator. However, predation could be overestimated because these raptors seem to be able to learn how to find artificial nests quickly. Contrary to our predictions, we found that the invasive American Mink did not affect forest bird breeding success, as it only predated one natural nest. Nonetheless, cameras failed to detect the predator on natural nests in nine occasions, which is why the mink could have been responsible for predation at certain times. A larger sample size is needed to confirm our findings.

Additionally, a plausible explanation for our results on mink nest predation in forest birds, compared to waterfall species (e.g., Bonesi and Palazon 2007, Peris et al. 2009, Schüttler et al. 2009, Brzezinski et al. 2012, Pescador et al. 2012), could be associated with low mink abundance in forest habitats in relation to that on the marine coastline, as well as the mismatch between the breeding season of forest birds and the period of mink activity. This spatio-temporal mismatch could provide nesting forest birds with an opportunity to avoid mink predation. More research is needed to understand if minks are preying on birds nesting in late summer or on fledglings because late summer coincides with higher mink activity, even in areas away from water. Meanwhile, the information provided in this study is valuable to have a better understanding of the impacts the mink has on biodiversity and to prioritize management and conservation actions on those species more severely affected.

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