







## RESEARCH NOTE

# Introduced mona monkey *Cercopithecus mona* is a key predator of bird nests in the endemic-rich Príncipe Island

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## Funding information

Mohamed bin Zayed Species Conservation fund, Grant/Award Number: 202523497; European Union's Horizon 2020 research and innovation program, Grant/Award Number: 854248; Portuguese Government's "Fundação para a Ciência e a Tecnologia", Grant/Award Numbers: CE3C (UIDB/00329/2020), CHANGE (LA/P/0121/2020)

## Abstract

Bird communities in oceanic islands tend to evolve under reduced predation, making them extremely susceptible to introduced predators. Príncipe Island (São Tomé and Príncipe, Central Africa) harbors 11 endemic bird species and eight introduced mammal species. To assess bird nest predation in Príncipe Natural Park, we deployed 55 artificial nests baited with quail eggs and monitored with camera traps. We recorded a 42% predation rate after 7 days. Out of 11 predation events recorded by camera traps, 10 were attributed to the introduced mona monkeys *Cercopithecus mona*. The likelihood of predation increased closer to communities, in higher nests, and in thinner trees. These remarkably high predation rates by an introduced species highlight the pressing need for a better understanding of how introduced species are affecting native biodiversity and ecosystem functioning on oceanic islands.

## KEYWORDS

artificial nests, camera trapping, introduced mammals, mona monkey, nest predation, oceanic island, Príncipe Island

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## 1 | INTRODUCTION

Island species tend to be more prone to extinction than their continental counterparts. The typical smaller distribution ranges, smaller (effective) population sizes, and lower genetic diversity (Frankham et al., 2002; James et al., 2016) make them more susceptible to stochastic events, demographic collapses, or inbreeding depression (Fernández-Palacios et al., 2021). Among island fauna, birds have higher extinction rates than other faunal groups (Matthews et al., 2022). By evolving in ecosystems with fewer predators, island bird species develop distinct physical (e.g., flightlessness), reproductive (e.g., reduced fecundity), and behavioral (e.g., predator naivety) traits that make them particularly vulnerable to anthropogenic changes (Jezierski et al., 2024). Indeed, at least 8% of the endemic island bird species have been driven to extinction by human activities in the past 500 years (Matthews et al., 2022). Currently, around half of all island bird species are threatened, especially due to introduced species, agricultural expansion, and biological resource use (Matthews et al., 2022).

Intensification of human traveling and land-use changes has facilitated the dispersal and establishment of non-native species (Russell et al., 2017; Salter et al., 2024). These species can have a wide range of impacts on ecosystems, directly or indirectly influencing demographic (Schoener et al., 2005; Young et al., 2017) or behavioral (Peck et al., 2014) traits of native biodiversity and, in extreme cases, leading to extinctions (Bellard et al., 2016; Courchamp et al., 2003; Russell et al., 2017). Introduced mammalian predators are particularly detrimental, being associated with over half of bird species extinctions worldwide (Doherty et al., 2016), and most noticeably in oceanic islands (Blackburn et al., 2004; Cooke et al., 2023; Courchamp et al., 2003).

Eggs and nestling predation by introduced species is especially damaging to bird communities, as it can lead to breeding failure and deeply impact population dynamics (Thompson, 2007; Vögeli et al., 2011). However, the level of impact depends on nesting and predator traits (Vetter et al., 2013). For example, natural ecosystems close to rural settings might have increased nest predation rates as these provide food that can sustain higher densities of predators throughout the year (Lamelas-López et al., 2020; Stirnemann et al., 2015). It is thus crucial to identify nest predator species, quantify their impacts, and determine which variables might facilitate predation (Lamelas-López et al., 2020; Menezes & Marini, 2017).

To assess potential predation risk by introduced mammals in Príncipe Natural Park, we deployed artificial bird nests, monitored with motion-triggered cameras. Although artificial nests can have different predation

rates when compared with natural nests, this can be bypassed by constructing artificial nests as realistic as possible (Berry & Lill, 2003; Davison & Bollinger, 2000). In cases where natural nests are difficult to find and/or monitor, artificial nests have been successfully used as a surrogate to study bird nest predation (e.g., Awoyemi et al., 2020; dos Santos et al., 2021), and when combined with motion-triggered cameras, allow to identify nest predators, study their behavior and evaluate how environmental variables affect nest predation (Cox et al., 2012; Meney et al., 2018; Weston et al., 2017). Specifically, we (1) measured nest predation rates, (2) quantified the relative importance of each predator species, and (3) assessed which variables best explained the likelihood of nest predation. We expect rats, cats and primates to be important predators during the incubation phase of tree nesting birds (Guedes et al., 2021; Lamelas-López et al., 2020; Stirnemann et al., 2015) and for predation rates to be higher in exposed and more accessible nests (Thompson, 2007) that are in more degraded environments and closer to human settlements (Lamelas-López et al., 2020; Stirnemann et al., 2015).

## 2 | METHODS

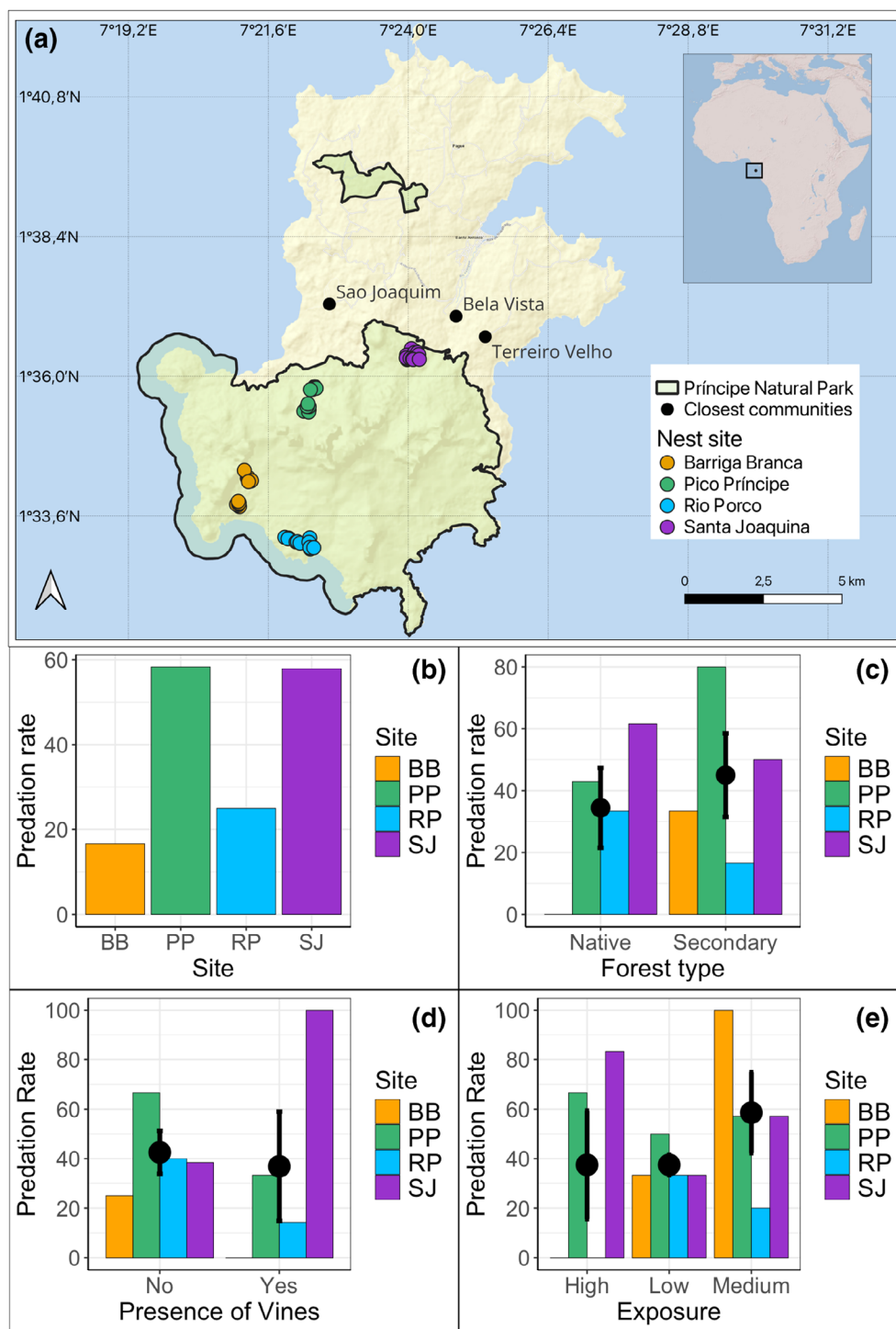
### 2.1 | Study area

Príncipe is an oceanic island in the Democratic Republic of São Tomé and Príncipe in the Gulf of Guinea, central Africa. The island (142 km<sup>2</sup>) has two main regions: the north, characterized by a mosaic of agricultural, agroforestry, and secondary forests where over 8200 people live (INE, 2017), and the uninhabited rugged center and south that harbor the remaining native forest, contained within the only protected area on the island, the Príncipe Natural Park (PNP; de Lima et al., 2022). Príncipe avifauna includes 11 species and 10 subspecies that are single-island endemics (Melo et al., 2022). All endemic birds nest in trees, including the only Critically Endangered bird species, the Príncipe thrush *Turdus xanthorhynchus* (Jones & Tye, 2006), only found in the PNP (Fundação Príncipe, 2019). Bats and shrews are native to the island (Rainho et al., 2022), but humans introduced cats, dogs, pigs, rats (*Rattus* sp.), mice (*Mus musculus*), mona monkeys *Cercopithecus mona*, and African civets *Civettictis civetta* (Dutton, 1994; Fundação Príncipe, 2019).

### 2.2 | Artificial nest experiment

Our study was conducted in four sites in the PNP and within the distribution range of the Príncipe thrush

**FIGURE 1** (a) Location of the study sites in Príncipe Island. Large dots represent artificial nest locations and are colored according to sites. Smaller black dots represent the communities that are closest to the artificial nests. Príncipe Natural Park (PNP) boundaries are shown in green. The inset on the top right shows the location of Príncipe Island compared to mainland Africa. (b) Predation rates of artificial nests by site (BB, Barriga Branca; PP, Pico Príncipe; RP, Rio Porco; and SJ, Santa Joaquina). (c) Predation rates by forest type. (d) Predation rates by presence of vines. (e) Predation rates by nest exposure levels. Black points and lines show, respectively, mean and standard error values for each variable group.



(Fundação Príncipe et al., 2021): Santa Joaquina, Pico Príncipe, Barriga Branca, and Rio Porco (Figure 1a). Distance between sites ranged between 2.5 and 6.7 km.

Between April and June 2021, during the breeding season of the thrush (Fundação Príncipe et al., 2021), we deployed 55 artificial nests in trees, made from roots and grass in a cup shape (c. 20 cm in diameter) mimicking thrush nests (Fundação Príncipe et al., 2021), baited with two fresh quail eggs and monitored using a motion-

triggered camera (Bushnell Trophy cam HD model 119776). Following a pilot study that showed that predation events consistently occurred within a 7-day time-frame, artificial nests were deployed for seven consecutive days, after which they were inspected for signs of predation (e.g., at least one broken or missing egg and shell fragments in nest or ground). Nests were distributed between native and secondary forest, the latter having signs of recent human disturbance, abundant

coconut or oil palm trees, and no mature native trees. Within each forest type, nests were at least 20 m apart, and the distance between nests in native and secondary forest varied from 200 to 600 m. All sites had 12 nests, equally distributed between forest types, except Santa Joaquina, which had 19 nests (12 nests in native forest and 7 in secondary forest; Table S1, Supporting Information).

## 2.3 | Characterizing nest location

We measured 10 variables at each nest, to characterize nest position, habitat, detectability, and accessibility. Namely we described site, forest type, nest height, tree height, nest exposure, tree circumference at breast height (CBH), presence of vines in the nest tree, canopy cover, elevation, and minimum distance to closest human settlement (DCC; Table S1). Nest height was measured from the ground to the base of the nest, using a tape measure, while tree height was estimated from the ground to the tip of the canopy by an experienced team member. Exposure was classified in three categories: low (i.e., inside cavities), medium (i.e., partially visible from the ground or canopy), or high (i.e., clearly visible from either the ground or canopy). Tree circumference at breast height (CBH) was measured with a measure tape. Canopy cover was estimated using a convex densiometer. Elevation and GPS location of nests and human settlements were taken using a Garmin Etrex 32x GPS with an accuracy of at least 15 m. Minimum distance to the closest human settlement (DCC) was measured using the “Distance Matrix” function in QGIS 3.30.2 (QGIS.org, 2024).

## 2.4 | Data analysis

Predation rates were calculated for each site, and by forest type, nest exposure category, and the presence of vines, as the percentage of predated nests, obtained by dividing the number of predated nests by the total number of nests (predated + not predated). Influence of nest traits on predation rates was assessed using Generalized Linear Mixed Models (GLMM) with binomial family distribution, through the “glmmTMB” function in the glmmTMB package (Brooks et al., 2017) in R (R Core Team, 2024). Nests with missing (six in Santa Joaquina and one in Pico Príncipe, all in native forests) or outlier values (one in Pico Príncipe in native forest and two in Barriga Branca in secondary forest) were excluded from the GLMM analysis, reducing the sample size to 45 nests (see Tables S1, S3). To avoid multicollinearity, we computed a correlation matrix between all variables

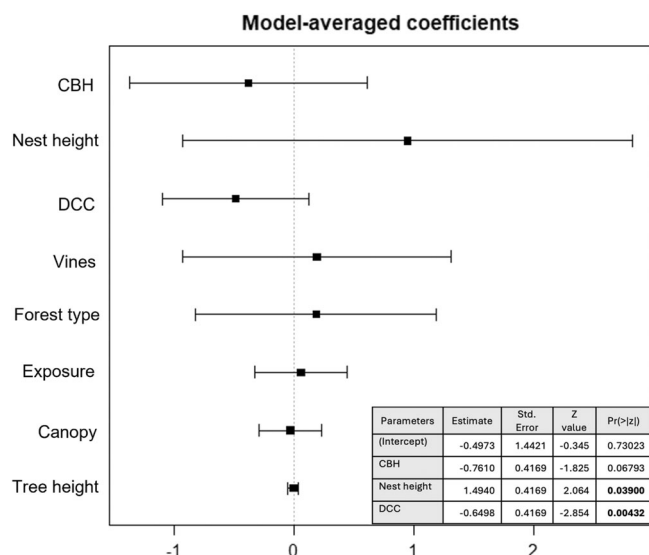
(Figure S1). Elevation was highly correlated with DCC ( $r = -0.95$ ,  $p < 0.001$ ), so we kept DCC because it is easier to interpret and due to its ecological relevance (only variable directly linked to human presence). The response variable was the occurrence of predation, while the fixed predictors were forest type, nest height, tree height, nest exposure, CBH, presence of vines, canopy cover, and DCC. We included site as a random intercept to control for the spatial grouping of nests resulting from the sampling design (see Figure 1a). Our statistical approach included a combination of three strategies to investigate effects on predator occurrence. All strategies relied on a model selection procedure, in which all possible models (excluding interactions) were fitted using the “dredge” function from the MuMIn package (Barton, 2024) in R (R Core Team, 2024). The corrected Akaike Information Criteria (AICc) were calculated for each model, and models were ranked based on their AICc values. From these results, we (1) used the sum of weights of AICc models to perform model averaging, thus obtaining average coefficients for the effect sizes of each variable, for which we then estimated the relative variable importance as a measure of how strongly it affected the occurrence of predation, (2) used the best ranked model in terms of AICc to further understand which were the most important variables explaining the predation occurrence, and (3) used the best model to interpret the statistical significance of the effects of the variables with the strongest model-averaged effects, and the variables that were selected based on their AICc. The combination of these three strategies enabled a robust and stringent statistical assessment, which is important to counteract any potential biases due to limited sample sizes.

## 3 | RESULTS

### 3.1 | Predation rates

Twenty-three (42%) of the 55 nests were predated. Each nest was only predated once (Table S1). The predation rate was higher in Pico Príncipe and in Santa Joaquina (both 58%) and lower in Rio Porco (25%) and in Barriga Branca (16%; Figure 1b). Secondary forests in Barriga Branca and Pico Príncipe displayed higher predation rates compared to the native forests at these sites (33% and 37% higher, respectively), while in Rio Porco and Santa Joaquina the predation rate was higher in native forest (respectively 17% and 12% higher than in the corresponding secondary forests; Figure 2c). The presence of vines only increased predation rates in Santa Joaquina (62% higher vs. 33% lower in Pico Príncipe, 25%





**FIGURE 2** Model-averaged (based on AICc weights) coefficients ( $\pm$ SE) of predictor variables included in all GLMMs testing different variable combinations to investigate the effect of nest conditions on predation occurrence. Inset table shows model results of the highest ranked GLMM according to AICc.

lower in Rio Porco and none Barriga Branca; Figure 2d). Predation rates were higher at the higher levels of nest exposure in Pico Príncipe and in Santa Joaquina, but at lower levels in Rio Porco and medium levels in Barriga Branca (Figure 2e). There was no predation in nests with high exposure in Barriga Branca and Rio Porco (Figure 2e).

### 3.2 | Predator identification

Camera traps failed to record the predation event in 13 out of 23 predated nests: in 12 cases due to equipment malfunction and in 1 case the camera was not triggered during the event (Table S1). In the remaining 10 events, nests were predated by mona monkeys (Figure S2).

### 3.3 | Drivers of nest predation

Nest height, CBH, and DCC were clearly the variables with the strongest averaged coefficient and effect size (Figure 2 and Table S2) and highest weight in model selection (Figure S3). These were also the ones included in the best ranked model according to AICc (Table S2). Statistical significance, measured using the best-ranked model, was below the 0.05 threshold for Nest Height and DCC, and slightly above this threshold for CBH (Table S2). Specifically, predation occurrence significantly increased closer to human settlements, at higher

nest placements, and in thinner trees (Figure 2 and Table S2).

## 4 | DISCUSSION

This study constitutes the first attempt to measure the risk of bird nest predation by introduced mammals in Príncipe Island. Through the combined use of baited artificial nests and camera trapping, we estimated nest predation rates inside the PNP at 42% after 7 days. Mona monkey was the only confirmed nest predator, affecting at least 43% of all predated nests. Finally, proximity to human settlements, higher nest placements, and thinner trees favored predation occurrence.

### 4.1 | High predation rates

The 42% predation rate we detected was high, considering it was measured for half of the average incubation period for *Turdus* sp. species. Introduced mammalian predators have been associated with increased predation of native bird nests in oceanic islands. For example, in Mauritius, 56% of the endangered Mauritius Fody *Foudia rubra* nests were predated by introduced black rats *Rattus rattus* and long-tailed macaques *Macaca fascicularis* (Safford, 1997). The PNP holds undisturbed forests and unique species, like the Príncipe thrush and the newly described Príncipe Scops-owl *Otus bikegila*, both of which are critically endangered (BirdLife International, 2023). The high predation rates we registered should be a major concern for the conservation of these threatened species but also to other endemics that rely on the PNP. Furthermore, considering mona monkeys occur across the island (Rainho et al., 2022), it would be important to assess bird nest predation outside the park.

### 4.2 | Bird nest predators

The only confirmed predator was the mona monkey, and even though we were not able to assign a species to over half of the predation events, predation rate by monkeys was undeniably high.

Mona monkeys were brought to Príncipe presumably between 500 and 350 years ago, following the slave trade during the Atlantic trade era (Glenn & Bensen, 2013). Today, thousands are estimated to roam the island (Glenn & Bensen, 2013). This primate is very adaptable, thriving in natural, rural, and urban areas (Olaleru et al., 2020). Its diet consists primarily of plant parts (Glenn, 1996; Goodwin, 2007; Howard, 1977) but also

includes cooked or processed food they scavenge from humans (Olaleru, 2017), as well as arthropods, lizards, eggs, and nestlings that they capture (Glenn, 1996; Glenn & Bensen, 2013; Goodwin, 2007; Howard, 1977). This versatility enabled them to become widespread in the islands where they were introduced (Glenn & Bensen, 2013).

Few primates have been successfully introduced to oceanic islands (e.g., mona monkeys in São Tomé and Príncipe and in Grenada (Glenn, 1997), green monkeys *Chlorocebus sabaeus* in Cape Verde and in Barbados, St. Kitts and Nevis (Hazevoet & Masseti, 2011), long-tailed macaques *Macaca fascicularis* in Mauritius (Safford, 1997)); however, they are suspected of having contributed to several bird extinctions. In Grenada, mona monkeys may have heavily preyed on an undescribed, now extinct, endemic species of *Amazona* parrot (Glenn, 1996). In Mauritius, long-tailed macaques are suspected to have contributed to the extinction of the dodo *Raphus cucullatus* and of the broad-billed parrot *Lophopsittacus mauritianus* (Hume, 2017).

The potential relevance of bird nest predation by mona monkeys in Príncipe is further supported by camera trap evidence showing them visiting a Príncipe Thrush nest five times over 2 months, with this disturbance presumably leading to its failure and abandonment (Guedes et al., 2021). In our study, on three occasions mona monkeys also visited artificial nests that had already been preyed on. It would be important to assess if this is opportunistic behavior, or if the same monkeys revisit nests on purpose, putting at risk subsequent attempts of reusing the nest and increasing predation rates.

It is possible that smaller predators, such as rodents, were less likely to trigger the camera traps and that their predation rates are thus underestimated, even though our camera traps managed to record a rat visiting an artificial nest that had already been preyed on by a monkey. Since introduced rodents are widely known to have severe impacts on bird nesting success (Delgado García et al., 2005; Duron et al., 2017; Lamelas-López et al., 2020), we cannot rule out the possibility that this species might also be a relevant nest predator. The same holds true for feral cats (Lamelas-López et al., 2020), which may have been overlooked either due to their apparent low abundance in the PNP (Fundação Príncipe, 2019) or due to the absence of some cues that they would normally seek to find nests (e.g., odor, sound, and bird movements; Davison & Bollinger, 2000).

### 4.3 | Drivers of nest predation

The likelihood of predation was positively related with the proximity to human settlements, higher nests and

thinner nesting trees, all of which might be linked to nest accessibility. Nest height and CBH had the strongest averaged-effect on predation occurrence, which is likely linked to the fact that higher nests on thinner trees might also facilitate detection and access to the monkeys, since they usually travel on the trees, and can more easily grip smaller trunks. Proximity to human settlements also had a strong effect to predation, which might be explained by the reliance of mona monkeys on crop raiding (Glenn & Bensen, 2013), possibly leading to higher population densities in the vicinities of the PNP, where plantations are more accessible.

Contrary to initial expectations, predation was not always higher in secondary forest (Lamelas-López et al., 2020; Stirnemann et al., 2015). Since native and secondary forests were sampled in the proximity of each other, this might be a matter of scale, linked to the adaptability of mona monkeys to explore resources across habitats. Although the home range of this species is not known, the distance between artificial nests on each forest type could easily be covered by a group of monkeys (Glenn & Bensen, 2013). Furthermore, the interface between these two forest types might be suitable for the species, since they might find more shelter in the taller native forests and more food in the secondary forests, which are often richer in introduced fleshy fruits and closer to crops (Rainho et al., 2022).

### 4.4 | Conservation implications

Some birds have changed their nesting behavior to avoid introduced predators, namely by relocating their nesting sites, altering nest heights, or shifting from ground to tree-nesting (Barros et al., 2016; Hamao & Higuchi, 2013; Peluc et al., 2008). However, these strategies might not be enough against a highly adaptable predator such as the mona monkeys (Glenn & Bensen, 2013). Nestboxes can be an efficient anti-predator method, especially for birds that nest in cavities, and can be adapted to prevent predation from climbing mammals through the use of passive barriers installed around the nestbox (Marcus et al., 2024). It would be important to test how nestboxes with the proper adaptations might reduce predation from mona monkeys in Príncipe, namely by installing them on trees that have traits that we have shown might reduce predation. To ensure the long-term feasibility of such measures, logistical and financial constraints should be considered. Monkey eradication is thought to be unfeasible in Príncipe due to their high abundance and ability to learn and avoid control, and due to the challenging terrain. Furthermore, it is a valuable game species, so it might be best to work with hunters to keep the monkey

population at low densities, thus minimizing potential conflicts between conservation and people living in Príncipe (Guedes et al., 2021). In New Zealand, several studies have shown that controlling introduced predators can have a significant decrease in bird nest predation (Remeš et al., 2012), indicating this might be the most feasible and effective solution.

The relevance of nest predation by mona monkeys in Príncipe is somewhat surprising, considering that many other introduced mammalian species occur on the island, including some that are widely known to affect nesting birds, like rodents and cats. Our results alert to the need for site-specific studies that assess how introduced species affect native biodiversity and for the potential risk of introducing primates on oceanic islands. To save the precious biodiversity of oceanic islands, preventive measures should be put in place to avoid further introductions and to control the populations of established introduced species.

## AUTHOR CONTRIBUTIONS

**Conceptualization:** P.G., R.L., and T.B. **Methodology:** All authors. **Fieldwork:** P.G., Y.S., A.P., A.A., and T.B. **Data analysis:** P.G., M.H., and R.L. **Writing – original draft:** P.G., M.H., and R.L. **Writing – review & editing:** All authors.

## ACKNOWLEDGMENTS

The project was funded by the Mohamed bin Zayed Species Conservation fund (project number 202523497) and received extra support via the European Union's Horizon 2020 research and innovation program under grant agreement No. 854248. The Portuguese Government's "Fundação para a Ciência e a Tecnologia" provided structural funds to CE3C (UIDB/00329/2020, <https://doi.org/10.54499/UIDB/00329/2020>) and to CHANGE (LA/P/0121/2020, <https://doi.org/10.54499/LA/P/0121/2020>). We thank Frazer Sinclair, for his dedication to the island biodiversity, which compelled him to write the project proposal for the MBZ grant.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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**How to cite this article:** Guedes, P., Henriques, M., Dos Santos, Y., Pedroso, A., Andrade, A., Glenn, M. E., Bensen, K. K., Bird, T., & de Lima, R. F. (2025). Introduced mona monkey *Cercopithecus mona* is a key predator of bird nests in the endemic-rich Príncipe Island. *Conservation Science and Practice*, e70095. <https://doi.org/10.1111/csp2.70095>