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Assessing Potential Predation Risk by Introduced Predators on Unattended Eggs in the Red-Tailed Tropicbird, *Phaethon rubricauda*, on Rapa Nui (Easter Island)

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Abstract

Anthropogenic impact has been heavy in remote oceanic islands, including the introduction of alien species, having negative effects on native seabirds. The isolated and subtropical Rapa Nui (Easter Island) is one of the few known breeding sites of the red-tailed tropicbird, *Phaethon rubricauda* in Chile (southeastern Pacific Ocean) where is listed as vulnerable. A relatively new breeding colony is found in the Rano Raraku volcano, where human-introduced species are present. We used hen eggs as a proxy for red-tailed tropicbird eggs to assess potential predation risk on unattended eggs. Each experimental egg was monitored by camera traps during 6 days. Three predatory species were identified on the records: the Brown rat *Rattus norvegicus*, the Polynesian rat *Rattus exulans*, and the raptor Chimango Caracara *Phalcoboenus chimango*. The most frequent species were the *Rattus* spp. A total of 45 predatory visits were recorded with a total time of 1.7 h, accounting for the 0.3% of the experimental time. Within this time of visits, all the potential predators spent time in both interacting activities (trying to prey on) and no-interacting activities with the experimental eggs. Only a Brown rat was able to prey on one of the eggs. Our results suggest that these invasive species are a low threat for unattended red-tailed tropicbird eggs at Rano Raraku, Rapa Nui. However, future research is needed to determine the potential negative effects over unattended red-tailed tropicbird nestlings that are easier for these predators to handle compared with an egg.

Keywords

breeding seabirds, new breeders, invasive species, subtropical oceanic islands, southeastern Pacific Ocean

Introduction

Human colonization in remote oceanic islands caused dramatic landscape changes and had negative consequences for their fauna, especially the avifauna (Anderson, 2002). An indirect but long-lasting anthropogenic disturbance was the widespread introduction of mammalian predators, including domestic animals such as cats, dogs, pigs, and goats (Krajick, 2005), as well as pests such as house mice (Bolton, Stanbury, Baylis, & Cuthbert, 2014) and rats (Jones et al., 2008). Anthropogenic impact has been reduced in some previously impacted oceanic islands (e.g., Gaskin, 2011; Hatfield, Reynolds, Seavy, & Krause, 2012). In contrast, the isolated and subtropical Rapa Nui (Easter Island) is inhabited by around 6,000 people and annually receives around 80,000 tourists. One of the inherent human-induced threats for seabirds breeding at Rapa

Nui is past and current presence of introduced predators. The red-tailed tropicbird, *Phaethon rubricauda*, is the only native seabird that still nests on Rapa Nui itself

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(Jaramillo, Johnson, Rothfels, & Johnson, 2008; Steadman, 1995). The congener species *Phaethon lepturus* has also been recorded breeding on the cliffs of Poike on the eastern side of the island but in lower numbers compared with *P. rubricauda* (P. Lazo [National Forest Corporation ranger], personal communication, November 16, 2016; Marin & Caceres, 2010).

The red-tailed tropicbird is widely distributed in tropical regions of the Pacific and Indian Oceans (del Hoyo, Elliott, & Sargatal, 1992). It is globally listed as “least concern” by the International Union for Conservation of Nature (BirdLife International, 2017); however, the Australian breeding population of the red-tailed tropicbird is currently listed as near threatened due to predation by feral cats and Black rats (Garnett, Szabo, & Dutson, 2010). Similarly, the breeding colonies at southeastern Hawaiian Islands are threatened by introduced predators (VanderWerf & Young, 2014). In Chile, in the southeastern Pacific Ocean, breeding colonies are only found on the subtropical ecoregion of Rapa Nui and Salas y Gomez island and on the Desventuradas Islands (Aguirre, Johow, Seeger, Johow, & Rubio, 2009; Schlatter, 1987). The species is currently listed as vulnerable by the Ministry of the Environment, Chile (2017). Adults are monogamous, have biparental care (Boland, Double, & Baker, 2004), and lay only one egg each season (E. A. Schreiber, 1996). The chicks are semialtricial, they hatch with their eyes closed but are covered in down (Nice, 1962). At Rapa Nui, the red-tailed tropicbird breed mainly on the cliffs of Poike (Jaramillo et al., 2008; Marin & Caceres, 2010) and on the inner and outer slope of the Rano Raraku volcano (Flores, Lazo, Campbell, & Simeone, 2017; Marin & Caceres, 2010). Rano Raraku is one of the most visited sites of the Rapa Nui National Park. At the entrance of the park, at this site, there are several facilities (coffee shop, stores, a picnic area, and trash bins) with high tourist affluence and trash accumulation. Consequently, there is a permanent presence of mammalian predators, such as dogs and cats (usually fed by tourists), and pests, such as *Rattus* spp. and the mice *Mus musculus*, which are known to feed on human organic waste. The introduced raptor bird Chimango Caracara *Phalcoboenus chimango*, is found and breed at Rano Raraku (Marin & Caceres, 2010). The Argentine ant, *Linepithema humile*, is also present at red-tailed tropicbird nests at Rano Raraku, and there is a potential for ants recruitment to pipping eggs (shell cracking at hatching; Varela, Luna, & Luna-Jorquera, 2018).

There are two breeding seasons for the red-tailed tropicbird at Rapa Nui, a “winter season” starting around April to June and a “spring season” starting around September to November each year. Flores et al. (2017) registered 53 nests at Rano Raraku considering the spring seasons of 2014 and 2015 and reported a breeding

success of 38% and 27%, respectively. We surveyed part of the colony on September 2016 and registered 13 active nests with red-tailed tropicbirds incubating an egg. After a visit on October 2016, we found that all those 13 nests were empty. The eggs were lost for unknown causes, but predation by introduced species is one of the possibilities. The red-tailed tropicbird colony at Rano Raraku is relatively new, being regularly used since 2007 (Flores et al., 2017), and it may contain a high proportion of new or young breeders, as suggested for the red-tailed tropicbird colony at O’ahu, Hawaii, which started around 2005 (VanderWerf & Young, 2014). Inexperienced breeders (i.e., young or first breeders) may leave eggs unattended because of deficient coordination of incubation shifts (B. A. Schreiber & Schreiber, 1993). Unattended eggs have been observed in Rano Raraku, and predation was assumed after the loss of eggs (Flores et al., 2017) but without any evidence of predators attacking the eggs. Likewise, the impact of eggs consumption by introduced predators on the breeding success is unknown. The goal of this study was to assess the potential predation risk on unattended red-tailed tropicbird eggs at Rano Raraku, Rapa Nui. We performed a simple experiment using hen eggs as a proxy for red-tailed tropicbird eggs placed in previously used nests. We evaluated (a) how fast unattended eggs are visited by a potential predator, (b) the most frequent predatory species visiting unattended eggs, (c) for how long each predatory species try to depredate an unattended egg and perform other activities at nest, (d) the successful predatory events by species, (e) which type of nest is most frequently visited by predators (exposed vs. protected), and (f) whether the distance of the nests to the entrance of the park correlates with the frequency of mammalian predators encounters at nests (considering that the entrance of the park is a source of organic waste).

Methods

Study Site and Experimental Design

Rano Raraku is a broad volcanic cone rising from an open plain in the south east of Rapa Nui (27°07’S, 109°17’W). It was the main source of the volcanic tuff used for moai (anthropomorphic statues) carving (Richards et al., 2011). Most red-tailed tropicbird nests are associated with moais or rocks (considered to be protected), others are situated on the slopes dominated by the introduced molasses grass (Flores et al., 2017; considered to be exposed).

On November 18, 2016, we surveyed the most active breeding sector in the outer slope of the Rano Raraku volcano (Flores et al., 2017; Figure 1). We covered a large area of this sector, and we found one red-tailed tropicbird incubating an egg, all the other nests that we observed



Figure 1. Rano Raraku volcano at Rapa Nui. The square indicates part of the breeding area that was surveyed and where experimental eggs were placed at empty red-tailed tropicbird nests.



Figure 2. One of the empty red-tailed tropicbird nests at Rano Raraku used in this study showing an experimental egg and a Bushnell Camera Trap.

were empty but recently used as confirmed by the presence of feces, down, and feathers (personal observation). On November 20, 2016, three hen eggs of free-living birds raised at Rano Raraku were placed in three of the empty nests (one egg per nest). Each experimental egg was monitored by a Bushnell Camera Trap settled in each nest to record the visits and behavior of potential predators (Figure 2). The following day, nests were checked in the morning and evening to attempt to determine diurnal and nocturnal predators. None of the eggs were depredated. After each inspection, eggs and cameras were changed to other nests. On the second day, the same procedure was performed. Again, none of the eggs were depredated. Therefore, on the third day, eggs and cameras were

placed in other nests and were left with no further change during 4 days. Since the third day, the nests were checked every day at 20:00 until the end of the experiment (6 days in total). A total of 15 nests were used and categorized in terms of the potential protection for the breeding birds. Ten nests were categorized as “protected” (totally or partially covered by rocks or moais or inside crevices) and five as “exposed” (covered by grass only).

Video Analyses

All videos were analyzed using the Behavioral Observation Research Interactive Software (Friard, Gamba, & Fitzjohn, 2016). We registered the predatory species that visited each nest. We constructed an ethogram for each predatory species recorded, registering the cumulative time they spent in activities of interaction and no-interaction with the experimental eggs. The activities considered as interaction were handling, biting, sniffing, kicking, pecking, and eating the eggs. The activities we considered as no-interaction were grooming, walking, standing, sniffing around the area ignoring the egg, hunting insects, and eating anything else than the eggs.

Potential differences in predation threat between the two nests categories were analyzed by standardizing the frequency of predator's visit to the survey time for each replicate. Then, we employed a Generalized Linear Model (GLM) procedure with a binomial probability structure because the response variable is a ratio (number of visits/survey time). The distance of the nests

to the entrance of the park was calculated using the Q-Gis software (2017) using GPS data. We used the Pearson's product moment correlation coefficient to test whether the distance of the nests to the entrance of the park correlates with the frequency of mammalian predators encounters at nests. To analyze the data, we used R (R Core Team, 2012).

Results

Cameras settled in the nests recorded a total of 524.6 h ranging from 9.1 to 96.5 h per nest (Table 1). The difference in the recorded time was given by the fact that eggs and cameras were changed during the first 2 days of the experiment and then were left unchanged (see "Methods" section for details). Three potential predatory species were identified on the records: the Brown rat *Rattus*

norvegicus, the Polynesian rat *Rattus exulans*, and the raptor Chimango Caracara *P. chimango* (Figure 3). The Brown rat was identified in five nests and the Polynesian rat in one nest; however, in nine nests, it was not possible to discriminate among the *Rattus* species because their diagnostic characters could not be clearly observed on the records. Nests 2, 3, 7, 8, and 9 (one exposed and the other four protected) were not visited by any predator (Table 1). The meantime elapsed until the first visit to the experimental eggs by any potential predator was 3.6 h ranging from 44 min to 8 h and 15 min (Table 1). A total of 45 predatory visits were recorded (Table 1). The total time of predatory visits at nests considering all the potential predators was 1.7 h (Table 2), which correspond to approximately 0.3% of the total recorded time (524.6 h). The most frequent visitors were *Rattus* species with the 94.3% of the total records and accounting for

Table 1. Records of the Visits by Potential Predators to Simulated Unattended Eggs in Nests of the Red-Tailed Tropicbird, *Phaethon rubricauda*.

Nest ID	Nest category	Total time recorded (h)	First predator species	First visit (h:min)	Others predator species	Visits	Total time at nests (min)	Nest distance to entrance (m)
1	P	9.6	<i>Rattus</i> sp.	4:55	—	1	0.07	478
2	P	9.4	—	—	—	0	—	463
3	E	9.1	—	—	—	0	—	381
4	P	14.0	<i>Rattus</i> sp.	7:47	—	1 ^a	—	461
5	E	13.9	<i>Rattus</i> sp.	2:31	<i>Rattus</i> sp.	3	1.8	N/R ^b
6	P	13.7	<i>Rattus</i> sp.	2:12	—	1	0	359
7	P	9.5	—	—	—	0	—	369
8	P	9.5	—	—	—	0	—	346
9	P	9.4	—	—	—	0	—	347
10	E	96.5	<i>Rattus</i> sp.	2:26	<i>Rattus</i> sp.	3 ^c	0.27	340
					Polynesian rat	3	2.17	
					Brown rat	1	23.47	
11	E	96.5	<i>Rattus</i> sp.	1:15	<i>Rattus</i> sp.	9 ^a	1.65	N/R ^b
					Brown rat	2	9.7	
12	E	95.9	<i>Rattus</i> sp.	3:03	<i>Rattus</i> sp.	5	5.05	N/R ^b
					Brown rat	3	7.12	
					Chimango Caracara	2	8.05	
13	P	46.1	Brown rat	8:15	Brown rat	2	20.13	347
14	P	45.9	<i>Rattus</i> sp.	0:44	<i>Rattus</i> sp.	7 ^a	13.47	359
					Brown rat	1	9.22	
15	P	45.6	<i>Rattus</i> sp.	2:34	—	1 ^a	—	478

Note. Nest category: P (protected), totally or partially covered by rocks or moais, or inside crevices; and E (exposed), covered by grass only. Total time recorded: total time of video records at nests. First predator species: first predator recorded visiting each nest. First visit: time elapsed until the first visit to the nests by a potential predator. Other predator species: other predators registered at nests. Visits: the number of visits of predator species. Total time at nests: total time of predators presence at nest. Nest distance to entrance: the linear distance between the nests and the entrance of the park.

^aOne of the visits was only captured by a picture and, therefore, there was not record of the duration of the visit. ^bDistance not recorded. ^cTwo of the visits were only captured by pictures and, therefore, there was not record of the duration of that visits.



Figure 3. Potential predators recorded visiting simulated unattended eggs in nests of the red-tailed tropicbird, *Phaethon rubricauda*. (a) Brown rat *Rattus norvegicus*, (b) Polynesian rat *Rattus exulans*, and (c) Chimango Caracara *Phalcoboenus chimango*.

Table 2. Number of Video Records and Time Spent by Potential Predators Visiting Simulated Unattended Eggs in Nests of the Red-Tailed Tropicbird, *Phaethon rubricauda*.

Predator species	Visits		Time	
	Records	%	Minutes	%
<i>Rattus</i> spp.	18	51.4	22.3	21.8
Brown rat	12	34.3	69.6	68.2
Polynesian rat	3	8.6	2.2	2.1
Chimango Caracara	2	5.7	8.1	7.9
Total	35		102.2	

the 92.1% of the total time of predator's presence at nests (Table 2). Chimango Caracara was found in only the 5.7% of the total records and accounted for the 7.9% of the total time of predator's presence at nests (Table 2).

Most rat specimens were recorded at night hours, with only three visits at daylight. The raptor Chimango Caracara was only recorded at the Nest 12 (categorized as exposed). The two visits of this raptor occurred during daylight on 2 consecutive days. It was not possible to determine whether these visits were from the same individual or not. The first visit lasted less than 2 min and the second visit lasted 6 min. In both encounters, the avian predator attempted repeatedly to break the experimental egg by kicking and pecking it without success.

Ten encounters were not considered in the analyses of the time spent in interaction and no-interaction activities because of the inadequate angle of the camera did not allow to categorize the activities at nests or because the encounters were only captured by pictures (see Table 1). The meantime of interacting and no-interacting activities for each species is presented in Table 3. The proportions of the activities of the predator species registered in the ethograms are presented in Figure 4. The Polynesian rat spent more time in no-interacting activities than interacting with the experimental eggs, while the Brown rat spent more than 50% of the time interacting with the experimental egg than in other no-interacting activities (Figure 4). Chimango Caracara also spent more than

50% of the time kicking and pecking the experimental egg attempting to break it (Figure 4). For all the rats of the genus *Rattus* which were not possible to identify the species, the most frequent activities at nest were walking and sniffing anything else than the experimental egg and eating other food resources (e.g., insects). The proportion of the time spent in activities of interaction with the experimental egg was less than 20% of total time at nest (Figure 4).

Only one egg was successfully broken and depredated. This egg was settled at Nest 10, and the predator was identified as a Brown rat. The visit lasted a total of 23 min and was the longest predatory visit recorded in this experiment. The rat broke the experimental egg after 6 min of interaction with the egg and was recorded eating the egg for more than 4 min.

There was no significant difference in the frequency of predatory visits between protected and exposed nests (deviance test = 0.1402, $\text{Pr}(> \text{Chi}) = 0.7081$). Finally, there was no correlation between the distance of the nests to the entrance of the park and the frequency of mammalian predators encounters at nests (Pearson's correlation = -0.316 ; $p = .317$).

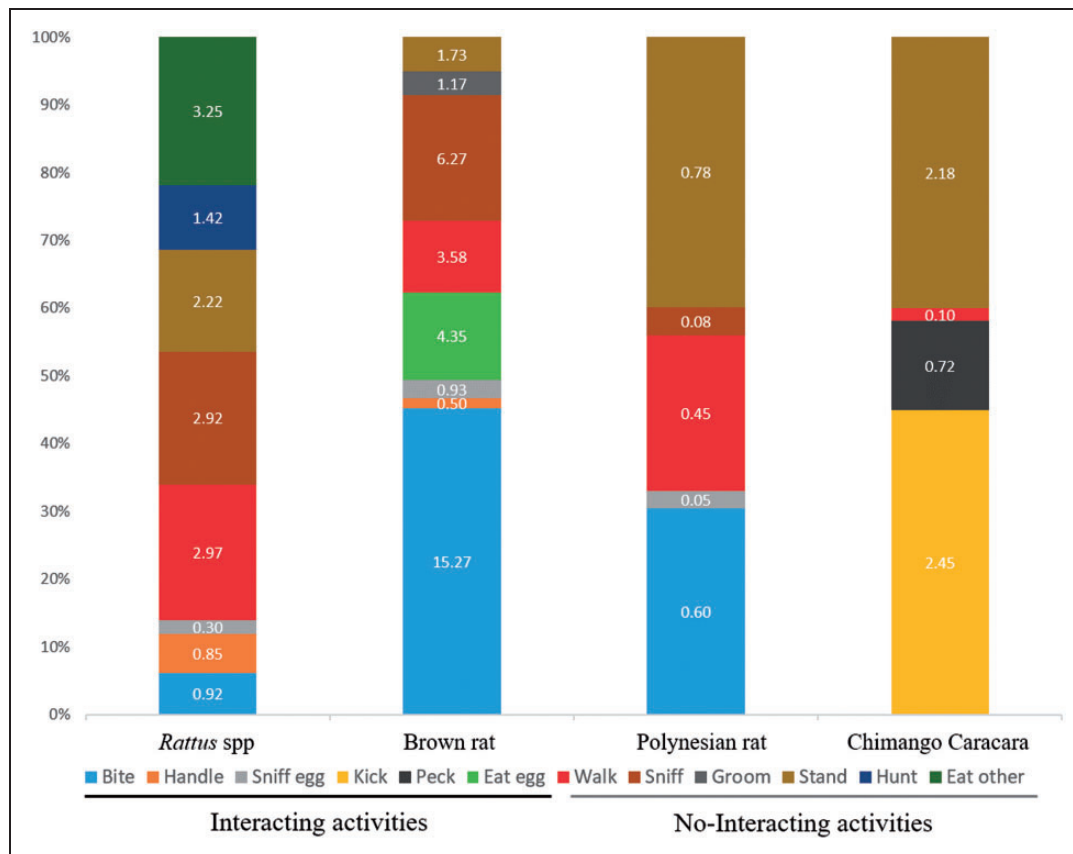
Discussion

Invasive species are a severe threat for island ecosystems (Krajick, 2005). Native seabirds of oceanic islands are especially vulnerable because they have not evolved defense against introduced mammalian predators (Furness & Monaghan, 1987). The Black rat *Rattus rattus*, the Brown rat *R. norvegicus*, and the Polynesian rat *R. exulans* have a profound impact on seabirds populations because of their successful spread to most island environment coupled with their generalist diet (reviewed by Harper & Bunbury, 2015; Jones et al., 2008). Among these three rat species, the review of Jones et al. (2008) found that the Black rat has the largest population-level impact on seabirds, followed by the Brown rat and the Polynesian rat. The Brown rat is widespread on Rapa Nui, while the Polynesian rat has been previously recorded at Rano Raraku (Flores, 2017). In our experiment,

Table 3. Meantime Spent at Nests of the Red-Tailed Tropicbird, *Phaethon rubricauda*, by Potential Predators in Interacting and No-Interacting Activities With Simulated Unattended Eggs.

Predator species	Number of records per species	Meantime of predator at nest (range; min)	Meantime of interacting activities (range; min)	Meantime of no-interacting activities (range; min)
<i>Rattus</i> spp.	18	1.2 (0.07–4.77)	0.1 (0–0.85)	0.7 (0.07–2.2)
Brown rat	12	5.8 (0.08–23.5)	1.75 (0–9.52)	1.07 (0.08–2.13)
Polynesian rat	3	0.72 (0.17–1)	0.22 (0.15–0.5)	0.43 (0.12–0.87)
Chimango Caracara	2	4.03 (1.82–6.23)	1.58 (0.32–2.85)	1.15 (0.92–1.37)

Note. Interacting activities were sniffing, handling, biting, kicking, pecking, and eating the experimental egg. No-interacting activities were walking, sniffing anything else than the eggs, grooming, standing, hunting insects, and eating others items different from the experimental eggs.

**Figure 4.** Proportion (%) of the total time and total time (min) spent at nests of the red-tailed tropicbird, *Phaethon rubricauda*, by potential predators in interacting and no-interacting activities with simulated unattended eggs.

we found that rats did not represent a significant threat to simulated unattended eggs deployed at red-tailed tropicbird nests. Our results regarding the low predatory success recorded in this experiment are similar to those found by Prieto, Gonzalez-Solis, Ruiz, and Jover (2013) after offering open and intact hen and gull eggs to Black rats, where none of the intact hen eggs were broken by rats and only one of the intact gull eggs was effectively broken and preyed. However, rats fed largely on previously opened eggs (Prieto et al., 2013). Similarly, in a manipulative experiment in New Caledonia, it was

found that Black and Polynesian rats ate only small and medium eggs (Duron, Bourguet, De Meringo, Millon, & Vidal, 2017). Together, our experiment and the mentioned previous studies show that rats may be constrained to prey on large eggs. In contrast, in an experiment to study the potential effect of rat predation on Humboldt Penguins colonies off the coast of north-central Chile, Simeone and Luna-Jorquera (2012) found that experimental hen eggs were mostly preyed on by rats and that consumption rates were high. Black rats preyed on the 70.8% of the eggs placed at Pajaros Island (29°S,

$n = 72$), and Brown rats consumed the 52.6% of the eggs deployed at Albarrobo Island (33°S, $n = 76$). An explanation to these contrasting results can be found in Zarzoso-Lacoste, Ruffino, and Vidal (2011). This study suggested that the susceptibility of seabird eggs to rat predation varies among islands and depends on several interacting factors, such as habitat structure, food availability, bird and rat population densities, and social learning behavior (i.e., rats may learn to prey on large eggs), among others (Zarzoso-Lacoste et al., 2011, and references there in). It is important to highlight that although this and previous studies have found low or no depredation of large eggs by rats, unattended nestlings may be at a higher risk. In the specific case of the red-tailed tropicbird, it was found that depredation of Polynesian rats on young nestlings was heavy, accounting for the 89% and 100% of total nestling loss on 1964 and 1965, respectively on Kure atoll (Hawaii; Fleet, 1972). Therefore, although only one of the rat predatory attempts was successful, our results should raise concern about the potential impact of rats on unattended nestlings at Rano Raraku. The lack of correlation between the distance of the nests to the entrance of the park (340–478 m) and the frequency of rats' encounters at nests may indicate that the distances do not significantly influence the presence of rats at the experimental area.

The other invasive species that tried to depredate on one of the experimental eggs was the raptor Chimango Caracara *P. chimango*. Within the total time of visits (less than 0.1% of the recorded time), Chimango Caracara tried insistently to break an experimental egg by kicking and pecking it without success. However, their innovative and learning abilities coupled with their capacity to transmit novel behaviors through social learning (Biondi, Guido, Bo, Muzio, & Vassallo, 2015) raise the question whether Chimango Caracara specimens at Rano Raraku can eventually find the way to effectively depredate on red-tailed tropicbird eggs. Nonetheless, the presence and behavior of this raptor bird is a significant threat for red-tailed tropicbird unattended nestlings that are probably easier for these predators to catch and handle compared with an egg.

Although the size of red-tailed tropicbird eggs (mean length = 5.6 cm, mean width = 5.0 cm) is similar to the size of the hen eggs used in this study (mean length = 5.4 cm, mean width = 4.0 cm), an analysis with scanning electron microscopy (Hitachi SU-3500) showed that the egg shell of the red-tailed tropicbird is significantly thicker than the egg shell of the hen eggs used in this study (Wilcoxon test, $T = 0$, $n = 9$, $p = .023$). Although egg resistance may not depend on the thickness only, these results suggest that it would be even more difficult to rats and Chimango Caracara to break a red-tailed tropicbird egg than a hen egg.

Thus, considering that predators visits lasted only the 0.3% of the total experimental time, that only one egg was successfully broken and preyed, and that red-tailed tropicbird eggs are thicker than the hen eggs used in this study, we suggest that rats and Chimango Caracara are a low threat for unattended red-tailed tropicbird eggs at Rano Raraku, Rapa Nui (Easter Island).

Nevertheless, it is worth noting that our experiment was conducted in the absence of breeding birds in the area. It may be possible than in an active colony predatory attempts to unattended eggs increase if the presence of breeding birds acts as a cue for these generalist's predators. Similarly, the absence of breeding birds during our experiment may also explain the lack of camera records of other potential predators (i.e., dogs and cats; Flores et al., 2017), which are probably attracted by the birds.

Implications for Conservation

The presence of human-introduced predators on this relatively new colony at Rano Raraku on Rapa Nui should raise concern and motivate research regarding the potential pervasive effects on unattended red-tailed tropicbird nestlings. It is possible that this area is one of the few available sites in the South Pacific Ecoregion for new or young breeders born in Rapa Nui, Salas y Gomez and Desventuradas Islands, the only relatively close breeding areas for the species.

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Declaration of Conflicting Interests

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