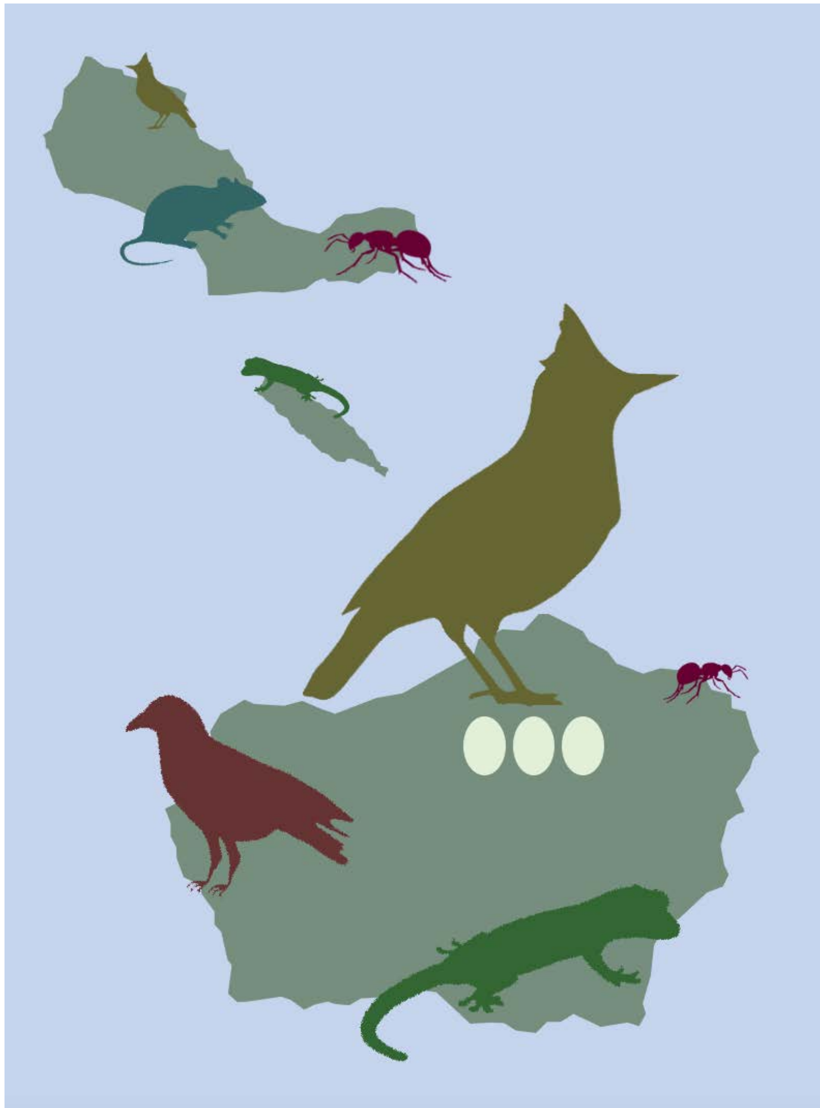
PREDATION RISK AND ADAPTATION OF THE CRITICALLY ENDANGERED RASO LARK, *ALAUDA RAZAE*, IN THE MARINE PROTECTED AREA OF SANTA LUZIA



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Summary

Abstract

In 2003, the Cabo Verde government created a marine protected area (MPA) that comprises three islands (Santa Luzia, Raso and Branco). This MPA, which is also known as Desertas MPA, is exceptionally important for nature conservation, both at a national and an international level. Notably, it holds the entire world population of the Critically Endangered Raso Lark (*Alauda razae*) one of the rarest and most threatened birds worldwide. This species was confined to Raso island until its translocation in 2018 to the nearby Santa Luzia Island. Its survival is high dependent on successful incubation time and minimal predation risk.

In this project, we sought to assess and understand the possible predation risk of the critically endangered Raso lark in the Desertas islands, using principally artificial nest experiments. Our aims were to (*i*) identify the different potential predators present in these different ecosystems (e.g. mammals, birds, reptiles); (*ii*) estimated more precisely the presence of introduced rodents, on the different areas with bait trapping; (*iii*) assessed the relative impact of predator species on experimental nest survival compared to the original Raso island ecosystem. For that, we studied on the tree desert islands with the particular and unique possibility to compare their different ecological situations; (1) Raso island = Historical Presence; (2) Santa luzia island = Recent Translocation (in disturbed environment); and (3) Branco island = Absent.

Unfortunately, our rodent trapping confirmed the presence of mouse (*Mus musculus*), but only on the Santa Luzia Island. Our artificial nest experiments suggested a heavy predatory impact on eggs. We identified at least two different types of likely predation of nests: nocturnal (assigned to mice), affecting 0-20% of eggs, and diurnal (assigned probably to brown-necked raven *Corvus ruficollis*), affecting up to 100% of eggs. Currently, the Raso lark nest success rates remain poorly studied but it is considered to be very naturally low on Raso island, which is free of any introduced mammals, owing to heavy predation by the giant gecko *Tarentola gigas*, itself a threatened species. However, in our study, the Raso lark population does not seem to be really impacted by this reptile. Our results with artificial nests coupled with camera traps seems to go in this direction with an absence of direct predation. The adaptation of this bird to different ecosystems and predation pressure will be crucial for its long- term survival. This preliminary study was a first step to better understand the Raso lark ecology and this possible adaptation to this new environment.

1. Context

Biological invasions represent one of the global drivers of biodiversity loss [1]. They often alter ecosystem structure and function, and their effects feedback to other elements of global change [2]. The invasion of oceanic islands by non-native predators may lead to dramatic effects on island ecosystems [3-4]. Insular populations may be more vulnerable to predation not only because they are smaller and confined to fewer specific habitats but also because they have evolved in the absence of predators and individuals may therefore lack anti-predator adaptations exhibited by continental species [5]. Invasive predators, in contrast, are often ecological generalists that can successfully colonize a wide range of habitats on islands.

One of the most important taxa concerning biological invasions on islands is mammals. A small number of mammal species are responsible for most of the damage to invaded insular ecosystems: rats, cats, goats, rabbits, pigs and a few others [4]. Among them, commensal species of rodents; The Norway rat *Rattus norvegicus*, the Black rat *Rattus rattus*, the Pacific rat *Rattus exulans* and the House mouse *Mus musculus* have been introduced to more than 80% of the world's islands, including many uninhabited and inhospitable islands (e.g. arid islands with no water; [6-9]). Their negative impacts may be visible on flora, invertebrates and island native seabirds, which frequently include endemic species.

Islands are key habitats for nesting seabirds, largely because the absence or scarcity of terrestrial predators enhances reproductive success. It is therefore that introduced mammals have become widespread on islands with breeding bird colonies, probably because seabirds constitute a major source of animal food items [6, 8, 10-11]. Because of the naivety of many of these island organisms to predation and the consequential lack of behavioral, morphological and other life history anti-predator responses, the impact of mammals on island faunas and floras has been devastating, often leading to local or even global extinction [3-4]. Birds are particularly sensitive to predators, especially during their reproduction stage. During nesting, predators may affect seabird eggs, chicks and adults. To cope with these threats, many islands undertake invasive predator control or eradication projects to conserve and restore bird populations (e.g., [8, 12-14]). The results of these programs are not always easy to estimate because of possible direct and indirect chain reactions [15]. However, positive effects are frequently cited, particularly on nesting success (e.g. [9, 16]).

Nest success monitoring can help evaluate the short-term effects of predators on birds and may be a good proxy for bird population dynamics [9]. However, this monitoring has many limitations such as the high number of nests to be monitored to obtain accurate results and the possible perturbation during the nest checking. For this reason, researchers use more frequently artificial nests when assessing predator-induced risk to bird nests [17-20]. Researchers can study the influence of many parameters on the predation rate (shell resistance, egg size, color, location, smell, etc. [20-21], to test different hypothesis and predator strategies.

In 2003, the Cabo Verde government created a marine protected area (MPA) that comprises three islands (Santa Luzia, Raso (7 km2) and Branco (3 km2)) and the surrounding sea (593.9 km2). This MPA, which is also known as Desertas MPA, is exceptionally important for nature conservation, both at a national and an international level. Notably, it holds the entire world population of the Critically Endangered Raso Lark (*Alauda razae*) one of the rarest and most threatened birds worldwide. This species was confined to Raso island until its translocation in 2018 to the nearby Santa Luzia Island [22]. Its survival is high dependent on successful incubation time and minimal predation risk. We therefore carried out a first preliminary study following this translocation on the success rate of Raso larks in this new environment (2021, [23]). We firstly identified potential predators through bait trapping on Santa Luzia. Secondly, we assessed the relative impact of predator species on experimental nest survival. Unfortunately, we found *Mus musculus* in all sites with a density two-fold higher in the southern area. Our artificial nest experiments suggested a heavy predatory impact on eggs. We identified at least two different types of likely predation of nests: nocturnal (assigned to mice), affecting 25–50% of eggs, and diurnal (assigned probably to brown-necked raven *Corvus ruficollis*), affecting up to 100% of eggs. Currently, the Raso lark nest success rates remain poorly studied but it is considered to be very naturally low on Raso island, which is free of any introduced mammals, owing to heavy predation by the giant gecko *Tarentola gigas*, itself a threatened species. The adaptation of this bird to different ecosystems and predation pressure will be crucial for its long- term survival. This preliminary study was a first step to better understand the Raso lark ecology and this possible adaptation to this new environment.

2. Aims of the project

Thus, we wanted to continue and deepen this first preliminary study with very interesting and worrying results on the impact of potential predators and/or competitors of Raso larks. In this project, we sought to assess and understand the possible predation risk of the critically endangered Raso lark in the Desertas islands, using principally artificial nest experiments. Our aims were to (*i*) identify the different potential predators present in these different ecosystems (e.g. mammals, birds, reptiles); (*ii*) estimated more precisely the presence of introduced rodents, on the different areas with bait trapping; (*iii*) assessed the relative impact of predator species on experimental nest survival compared to the original Raso island ecosystem. For that, we studied on the tree desert islands with the particular and unique possibility to compare their different ecological situations.

3. Materials & Methods

a. Study sites

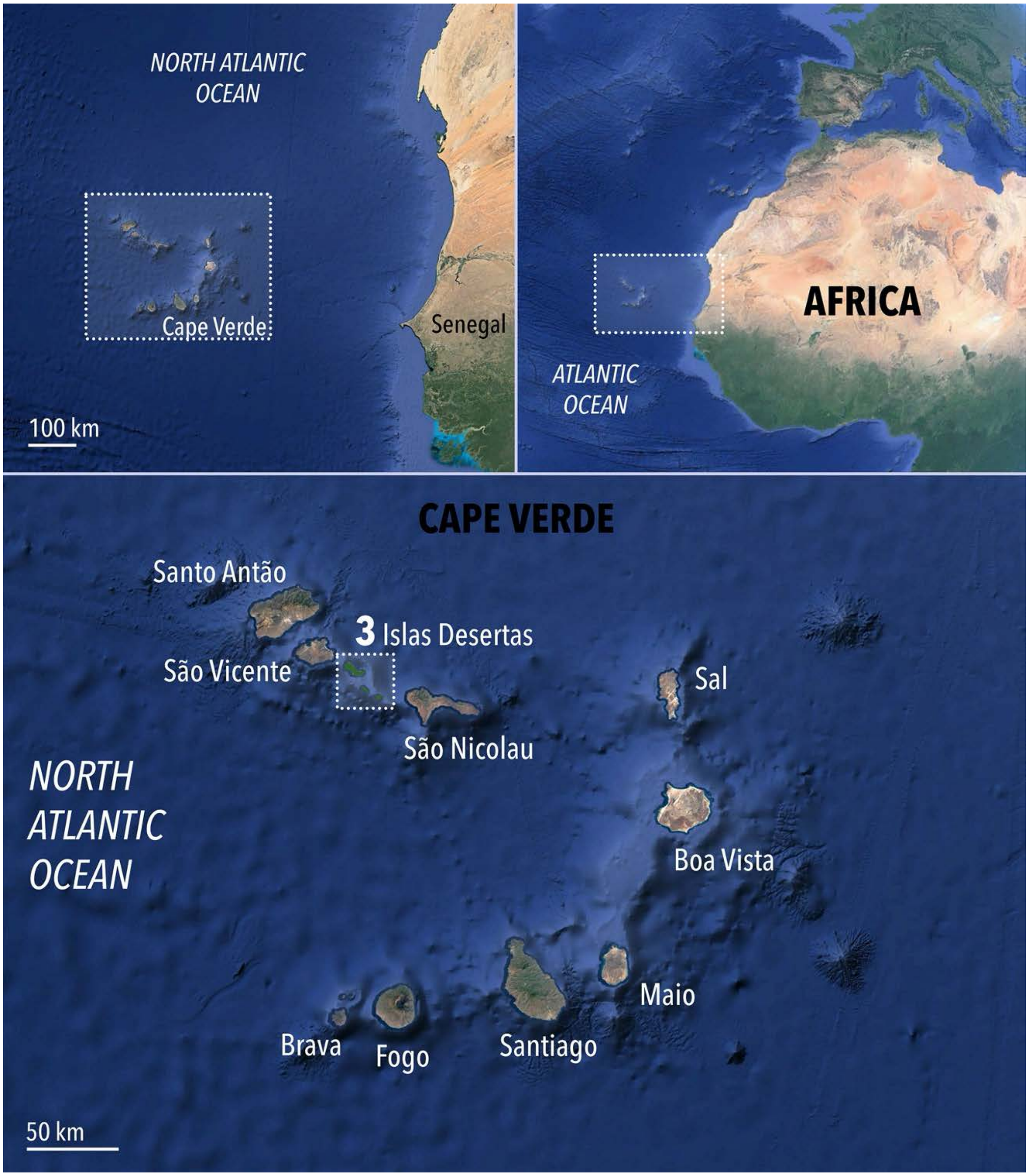

Fig. 1. Map of Cape Verde showing the localization of the main islands and the study area; 3 Islas Desertas.

Cabo Verde is an archipelago of ten islands and eight islands located in the eastern Atlantic Ocean approximately 500 km from the coast of Senegal, West Africa (16° 00' N, 24° 00' W). These islands occur in two groups – the Barlavento, or Windward Islands in the north, and Sotavento, or Leeward Islands in the south. Size varies dramatically between islands, of which Santiago (São Tiago - 991 km2) is the largest and Santa Luzia (35 km^2) among the smallest islands. Total land area for the archipelago is 4,564 km^2 (Fig. 1).

The Cabo Verde government has established a system of Marine Protected Areas within the framework of the "West Africa Regional Marine and Coastal Conservation" program (PRCM). The adjacent marine area, the island of Santa Luzia, and the islands of Branco (3 km^2) and Raso (7 km^2) are designated Marine Reserves (CBD, Third National Report - Cabo Verde). This marine protected area (MPA), which is also known as Desertas MPA, is exceptionally important for nature conservation, both at a national and an international level (Fig. 2).

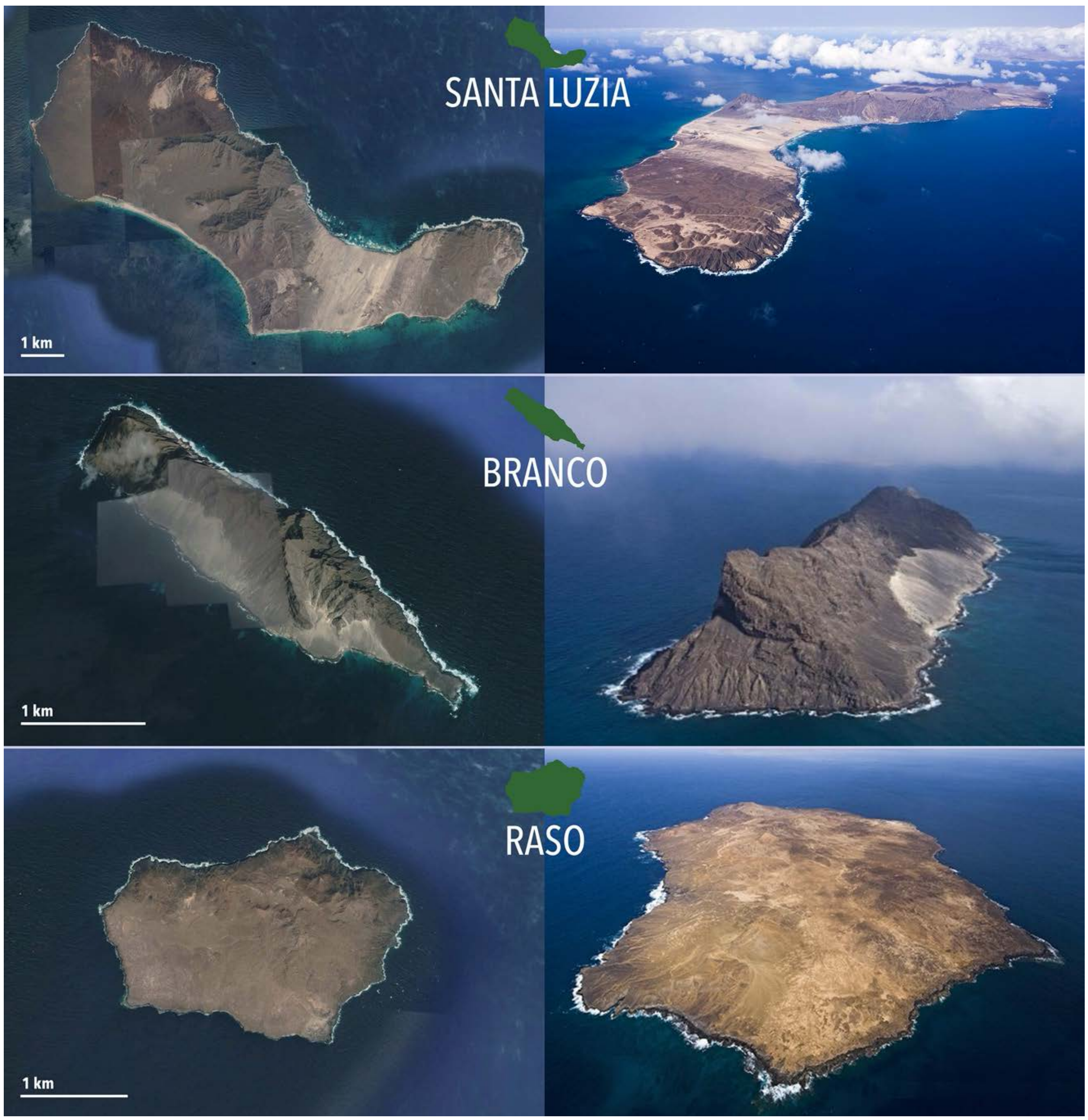

Fig. 2. Aerial pictures of the 3 Islas Desertas; Santa Luzia, Branco and Raso.

Our study took place on the Desertas Islands, composed of Santa Luzia Island and the Branco and Raso islands, located on the northwest alignment of the Cabo Verde

Archipelago (16 480 N, 24 470 W and 16 360 N, 24 340 W; Fig. 2), flanked by the islands of São Vicente to the West and São Nicolau to the East. The three islands have a total of 43.3 km2 of land area and present quite low elevations compared to the other islands of the archipelago. This group of islands is located at the border of the North African arid and semi-arid climatic regions, presenting a climate defined as being dry tropical Sahelian, predominantly represented by flat, very arid lowlands (Fig. 2), followed by very arid medium elevation areas, then beaches, dunes, and sandy areas, streams, and floodplains. By means of the low elevation, the annual precipitation is among the lowest in Cabo Verde, which should be the primary limiting factor of the distribution of terrestrial biodiversity in the islands, leading to a low diversity of plant and insects in the area, mainly on Raso [24].

Santa Luzia island presents a land area of approximately 35 km^2 and has the highest elevation of the group, reaching 397 m. This island is very arid, yet there are more humid zones close to the river line, with hills, rocky plains, and sand dunes being the main landscapes. **Branco** island is the smallest of the group with a land area of approximately 3 km^2. Mountainous (2 km^2) and medium-elevation (1 km^2) arid areas dominate the island's landscape [25]. The island is of difficult access due to the roughness of the sea, lack of safe natural ports, and steepness (there is only a minor area of plane ground of about 400 x 200 m). **Raso** island has a land area less than 6 km^2 and, in contrast with Branco, is almost flat in all its extent. This island is fundamentally characterized by plains and low-altitude arid zones (Fig. 2) with patches of grassy vegetation.

b. The Critically Endangered Raso lark (*Alauda razae*)

Raso and Santa Luzia are Priority Key Biodiversity Areas documented in the CEPF hotspot profile for the Mediterranean Basin, because they are highly threatened and biodiversity-rich (potentially so in the case of Santa Luzia) islands, with several endemic and highly threatened taxa. In particular, the marine protected area (MPA) holds the entire world population of the Critically Endangered Raso Lark (*Alauda razae*) and is therefore listed by the Alliance for Zero Extinction.

The Raso lark is a small, heavy-billed lark with a max body length of 18 cm. Thick-based heavy bill, particularly in males, imparts an upturned appearance. Body plumage heavily streaked with buff and black, short erectile crest (Fig. 3). It is heavily streaked on the breast and has paler underparts. The Raso Lark is sexually dimorphic in size and structure. Donald et al. [26] identified clear differences in feeding behaviour between male and female Raso Larks with males spending a higher proportion of their time digging for food and females a higher proportion of their time feeding on the surface.

Previous authors (e.g. [27-29]) have suggested that the population fluctuates in response to rainfall and that long-term desertification is a major threat. This is supported by the observation that birds are largely confined to small areas of green vegetation on the island's flat plain (4 km2) and that breeding only seems to take place after rain (a common strategy in African larks), which falls largely in August to October [27-28].

Fig. 3. The Critically Endangered Raso lark on Santa Luzia (photo by S. Caut).

The nests are built on the ground under the mallow *Abutilon pannosum* or under the Simple leaved Bean-caper *Zygophyllum simplex*, or occasionally in clumps of grass Poaceae [30]. Clutch size varies between one and three eggs [31-32] with greyish white background and dark brown markings, heavily concentrated at the wider end. The incubation is undertaken entirely by the female and appears to last 12–13 days [31-32] and the female incubates in periods of around ten minutes, followed by feeding breaks of around the same length, during which the male often accompanies her. Although data are scant, it appears that the young may remain in the nest for up to 15 days after hatching [30].

In historical times Raso Lark´s were distributed more widely throughout Cabo Verde, including Santa Luzia, São Vicente and Santo Antão [33]. All these islands, except Santo Antão, are separated by shallow seas and were probably intermittently connected during the last glaciations [34]. The arrival of human settlers on the island and the mammals that accompanied them was a likely cause of the loss of the Raso Lark from all islands except Raso, the largest island never to have been inhabited by people or mammals [35]. Confined to a single island and with a population that fluctuates greatly and is often below 100 individuals, a reason why the species is classified as Critically Endangered. The possibility of a lark re-introduction to Santa Luzia was first considered around 2008 when the Raso population had increased from its 2004 low point to around 200 birds [22]. However, an important limitation was the possibility that the cats on Santa Luzia would predate on the larks soon after their release there. Therefore, a cat eradication campaign was implemented with a first translocation in mind to around April 2018 (37 individuals in 2018 and 33 in 2019), when cat numbers were reduced by approximately 50%, to a density under two per square kilometer [35]. Early indications are encouraging with the released birds breeding, and their annual survival is not substantially worse than that of larks on the source island, Raso [22], with even encouraging natural exchanges of individual between Raso and Santa Luzia.

Thus, the history of Desertas Islands represents a unique and exceptional study case of the Raso lark species. Each of the three islands have different scenario in respect to the Raso lark population; (*1*) **Raso** island = Historical Presence; (*2*) **Santa luzia** island = Recent Translocation (in disturbed environment); and (*3*) **Branco** island = Absent. A comparison of these 3 scenarios is a unique possibility to better study the ecology of this bird, its adaptation to a new environment but also those of the potential predators.

c. Fauna of Desertas Islands

These differences between very close islands which also have hold very varied animal and plant populations. In our case, the fauna present and therefore the potential predators or competitors for the Raso lark are very different and could strongly influence its dynamics, survival and adaptation, adding significant interest to our comparison of scenarios in the three islands (Tab. 1).

GROUPE	SPECIES	SANTA LUZIA	BRANCO	RASO
Seabirds	*Bulweria bulwerii*		X	X
Seabirds	*Calonectris edwardsii*		X	X
Seabirds	*Oceanodroma jabejabe castro*	X	X	X
Seabirds	*Pelagodroma marina*		X	
Seabirds	*Sula leucogaster*			X
Seabirds	*Phaethon aethereus*			X
Seabirds	*Puffinus boydi*		X	X
T. Birds	*Alauda razae*	Translocation in 2018		X
T. Birds	*Ammomanes cinctura*	X		
T. Birds	*Corvus ruficollis*	X		X
T. Birds	*Falco tinnunculus neglectus*	X		X
T. Birds	*Pandion haliaetus*	X		X
T. Birds	*Passer iagoensis*	X		X
T. Birds	*Tyto alba detorta*	X		
T. Reptiles	*Chioninia coctei*	Extinct	Extinct	Extinct
T. Reptiles	*Chiononia stangeri*	X	X	X
T. Reptiles	*Hemidactylus bouvieri Rasoensis*	No recorded since 2012		No recorded since 2012
T. Reptiles	*Tarentola gigas brancoensis*		X	
T. Reptiles	*Tarentola gigas gigas*			X
T. Reptiles	*Tarentola raziana*	X	X	X
Mammals	*Félis catus*	Eradicated in 2020		
Mammals	*Rattus sp.*		Probably no	Probably no
Mammals	*Mus musculus*	X	Probably no	Probably no

Tab. 1. Principal vertebrates found in Desertas Island (X = Present, [23, 36]).

Santa Luzia island is the largest uninhabited island of Cabo Verde and of the three islands in the marine protected area, the one most impacted by anthropogenic influence and the most degraded (i.e. past impact of grazing cattle and goats, past production of hay, fishing communities used regularly the island, tourism visit, ect). As a result of all anthropogenic activities, the island has introduced species. The most important was the domestic cat, which had a significant impact on the local community [37-39]. Faced with these results, a recent eradication project has probably extirped all the population since 2020. There is also a small population of mice *Mus musculus* Linnaeus on the whole island and more abundant in the south [23]. Fortunately, there does not seem to be the presence of rats on the island even in areas associated with the fishermen camps and areas most used for boat landings [23]. Four species of terrestrial reptiles are present (Table 1). In addition, there were historical reports of a Giant Wall Gecko subspecies *Chioninia coctei*, which is now estimated extinct. As compared to Raso and Branco islands, Santa Luzia supports low numbers of breeding seabirds, although it is likely that extensive colonies existed in the past [27]. Santa Luzia island is also a refuge for six species of terrestrial bird species [35]. Until recently, the Raso Lark was not present on the island despite the presence of patches of grassy vegetation which was the observed preferred habitat of the Raso lark on the island of Raso [26, 27, 40]. However, in 2018 a translocation project of Raso lark in Santa Luzia started to restore the only population currently present on Raso [22]. The community of invertebrates present in Santa Luzia is very poorly known but holds some species of interest such as the *Chilades evorae* [41] or recently reported orb spider *Argiope sector* [42].

Branco island is the most inaccessible of the three islands, but holds important seabird colonies. The existent knowledge about the Branco seabird populations is scarce and depends on occasional opportunistic visits and some rare expeditions to the island. Nevertheless, five seabird species breed on the island and hold important colonies at least of Cabo Verde shearwater and Bulwer's Petrel. It is the only island of the MPA where breeds the elusive White-faced Storm-petrel and is the second largest colony of this species in the country [27]. Tree species of reptiles were found in this extrem habitat, with the presence of the particular subspecies of gecko, *Tarentola gigas brancoensis*. Finally, the difficulty to access the island was also a protection for these insular populations to the introduction of mammals as rodents or cat. To evaluate possible threats, mice traps were deployed in the main landing area to detect the possible presence of these animals and no animals were detected in 2014 [43]. Even if this protocol was very localized, it seems to signify absence of rodents in this island.

Raso island is better known for its endemic Raso lark, an important terrestrial bird that is classified as Globally Threatened, but it also holds the better known and well-studied seabird colonies in the reserve. The most important colony of Cabo Verde Shearwater in the world lies in Raso, and important colonies of other five species also breed. For reptiles, Raso have the same diversity as Branco, but with this subspecies of gecko, *Tarentola gigas gigas*. To our knowledge, there is no presence of rodent noted, even if there still more investigation is necessary.

d. Three unique study scenarios

In summary, we have 3 Desertas islands with 3 different scenarios for the Raso lark and 3 potential different species interactions. The comparison of this unique possibility was the basis of our project. This combination of situations make it possible to understand some ecological adaptations or species interactions both for our principal species (Raso lark) and also for these potential predators and/or competitors (Fig. 4).

Fig. 4. Principal potential predators and/or competitors of Raso lark in the Desertas islands.

The study of the different combinations of situation could make it possible to answer some ecological features: What is the impact of mice on Raso lark (Santa Luzia *vs* Raso)? How do naive Raso lark adapt to this new competitor, predator (Santa Luzia *vs* Raso)? What is the predation rate of giant geckos on Raso lark nests (Raso)? Is it more important than that of mice (Santa Luzia *vs* Raso)? Do Terrestrial birds predators (*Corvus sp*. and/or *Falco sp*., [23]) have more impact on the Raso lark depending to the time presence (Santa luzia *vs* Raso)? Will the gecko have the same impact on artificial nests in an ecosystem with or without the presence of Raso lark (Branco *vs* Raso) ... The questions are multiple and will allow an innovative approach using the synergy of these 3 islands. To best answer all these questions, it is necessary to set up the same protocols on the 3 islands (Fig. 5).

The experiment was conducted on these 3 Desertas islands between the 29 October to 7 November 2024 (3 nights and 2 days for each); Raso Island (29 October to 1 November); Branco Island (1 to 4 November); and Santa Luzia Island (4 to 7 November).

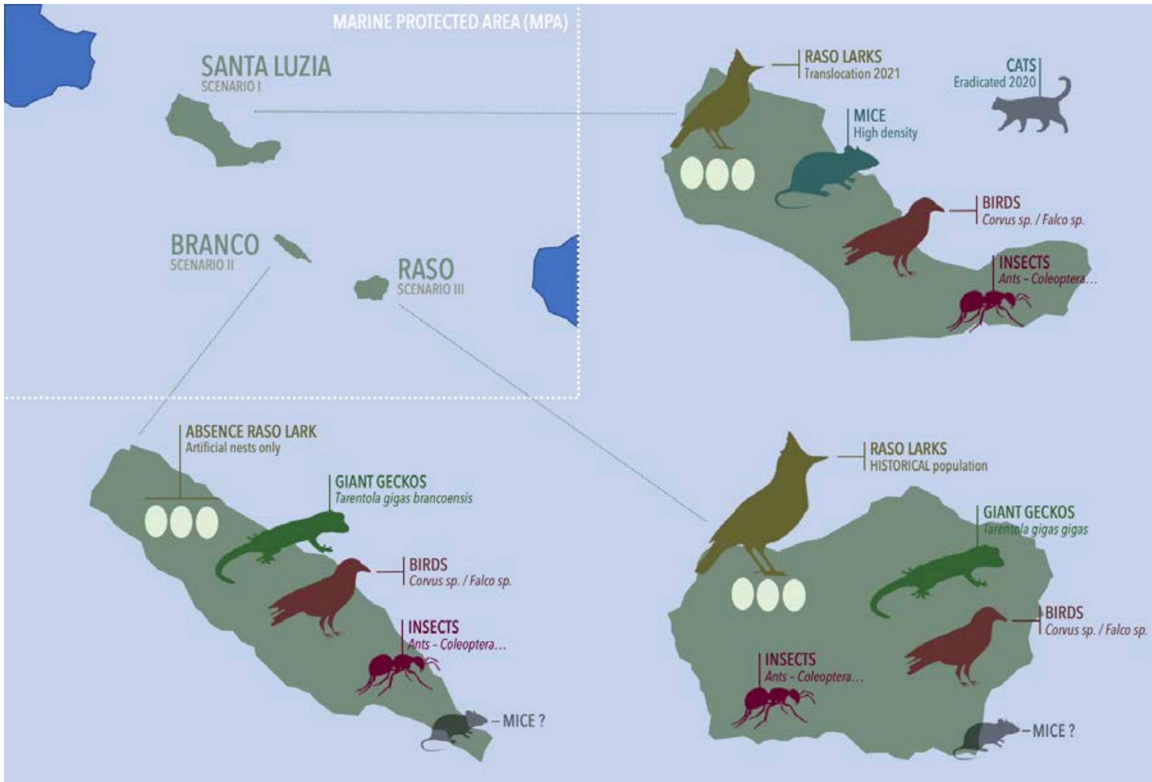

Fig. 5. The 3 different scenarios (I, II and III) in each Desertas islands depending on the Raso lark situations; (1) Santa luzia: Recent translocation of Raso lark (new environment) / Presence of Introduced mammals (= predators and/or competitors) / Presence of Terrestrial Birds (e.g. corvus = predators) / Absence of Giant gecko (= predators); (2) Branco: Absence of Raso lark / Absence of Introduced mammals (*to be checked*) / Absence of Terrestrial Birds (*to be checked*) / Presence of Giant gecko (*Tarentola gigas brancoensis*); (3) Raso: Historical presence of Raso lark / Absence of Introduced mammals (*to be checked*) / Presence of Terrestrial Birds (e.g. corvus = predators) / Presence of Giant gecko (*Tarentola gigas gigas*).

e. Protocols

(i) Vertebrates (Birds and Reptiles)

We will characterize the animal communities of each island during our field trip (especially potential predators and/or competitors of Raso lark). We will establish different line transects across each island and during our different displacements to search and identified seabirds, terrestrials' birds, Reptiles. These transects were chosen to cover the maximum surface of the island and were used for most of our surveys to reduce our impact on the island.

(ii) Rodents trapping

An understanding of the population ecology of rodents is necessary to help decide conservation strategies and their possible impact in the Desertas islands ecosystem, (especially on the Raso lark species). The First activity of the project was to identify potential sites for mammals trapping. It was therefore necessary to observe the different species in each island and the sites of greater density (e.g., Raso lark presence and translocation area, bird nesting sites, the presence of reptiles). Secondly, a trapping protocol was defined to maximize the probability to catch introduced mammals. We estimated the population size using rodent traps (20 x 13 x 13 cm3) baited with peanut butter. Trap stations were set every 10 m along the line transects. For logistic reasons, we used only 20 traps which we moved between different trapping area defined. Traps were set for one or two consecutive nights for each line transect. Traps were opened in the late afternoon and were checked and close each morning.

We collected general information for each trap: whether or not it sprung, the presence of bait, and captures of rodents and nontarget species. We calculated an index of abundance (IA) taking into account the number of corrected trap-nights [44] IA = 100 x captures/(TU - S/2); TU = P x N, where P is the number of trapping nights, N is the number of traps, S is the total of traps sprung by any causes, TU is the number of trap nights, and TU - S/2 is the number of corrected trap nights.

Captured individuals were killed to collect tissue samples for future laboratory analysis (e.g., muscle, liver). We recorded the sex, general health status, and sexual maturity of killed rodents, together with various biometric parameters (length of body, tail, right foot and right ear, total weight, and weight without viscera).

(iii) Artificial bird-nest predation experiment

An artificial bird-nest predation experiment was conducted at the same different sites of rodent trapping. The study was conducted during the start of the likely reproduction period for the Raso Lark in the area (e.g., November, [30]).

Fig. 6. Picture of one of artificial bird-nests containing two Raso lark artificial small eggs and one large hen egg, type T^1 (photo by S. Caut).

Artificial nests were placed on the ground, directly in the vegetation, inspired by previous observation of the Raso Lark nests (e.g., artificial nest in our preliminary study [23], Fig. 6). Each artificial nest contained different eggs. Different egg sizes were selected to represent size categories of bird eggs (mean ± SD of length x width in mm taken from 10 eggs): Large, using hen eggs (*Gallus gallus*, 53 x 42 mm); Small, using weighted plastic eggs (30 x 20 mm) and quail eggs (*Coturnix japonica* 33 x 26 mm) more like Raso lark eggs (e.g., Skylark *Alauda arvensis* 23 x 17 mm). With these, 3 different types of artificial nests are made; (T^1) nest with one hen egg and two plastic eggs (the same used in preliminary study [23]); (T^2) nest with one hen egg and two quail eggs; and (T^3) nest with only two quail eggs (more similar of Raso Lark nest). Moreover, camera trap was added in the T^3 artificial nests to try to identify more precisely the potential predator (n = 10). These nests are associated with camera traps. We therefore placed these nests on the ground and less covered by vegetation to avoid accidental triggering due to the movement of plants in the wind and to allow a better view for the camera. The cameras have been set to trigger photos and videos at the slightest movements (Fig. 7).

Fig. 7. Picture of one of artificial bird-nest containing two small eggs (type T^3) with a camera trap (photo by S. Caut).

To minimize the possibility of human scent affecting egg predation, the eggs were handled with care after rubbing our hands in vegetation and leaf litter. Artificial nests were randomly placed in preferred nesting vegetation under the mallow *Abutilon pannosum* or under the Simple leaved Bean-caper *Zygophyllum simplex*. To limit that rodent trapping will interfere with the artificial nest experiment, we placed nest in the same area but at least 20 meters outside rodent transects.

Each nest was checked twice a day, at sunrise and sunset, to distinguish nocturnal from diurnal predation events during the rodent trapping experiment. If one of the egg types was pierced, nibbled, or had disappeared, the nest was considered to be depredated [45]. When possible, egg fragments were used to identify the likely predators: tooth marks were clues of rodent predation and perforation suggested bird predation.

4. Results & discussion

a. Introduced mammal predators

These islands have history and geographic locations that may have favored the possible invasion and establishment of many introduced mammals over time. In particular, the most widespread mammals found on the oceanic islands, cats and rodents, that have been shown to be present in the majority of island with human interactions [4]. Their study shows that mammal introduction is often accidentally through fishing boats that regularly visit the islands or through the farmers that once inhabited the island.

Our rodent trapping confirmed the presence of mouse (*Mus musculus*) only on the Santa Luzia Island (Fig. 8). In this study, we have concentrated our observations and our protocols in the South site and which post-translocation observations had taken place in 2018 and 2019 [22] and where the mice abundance was twice of the north and Center site [23]. However, the mouse density was very low with only 3 mice captured on 60 PN (IA = 7.5%). For comparison, we captured compared to 2021 with 31 mice captured on 40 PN in the same southern area (IA = 80.5%, Fig. 8). We observed that the rodents were in reproductive phase, with males that had very developed testicles and the unique female had 7 embryos in her body. The weight and size of the individuals (Total length = 14.9 ± 0.7 cm; Eviscerated weight= 11.8 ± 1.3 gr., n = 3) were very similar as those of 2021 (Total length = 14.8 ± 1.4 cm; Eviscerated weight = 11.3 ± 0.4 gr., n = 14) which were also greater in the southern area than in the rest of the island.

Currently there is very little monitoring on the Santa Luzia mice population. Rodrigues et al. [46] found a wide distribution but low abundance (maximum abundance index was 0.06 and 0.067 catches/trap/night) which seemed to be particularly associated with fishing camps and areas mostly used for landing boats. Geraldes and Melo [47], studied mice abundance during one year (2013-2014) and found a high abundance on the island with a maximum density during the dry period (March to July). Caut and Jowers [23] observed a significantly different mice abundance in the south than in the north or the center with an abundance twice as high. The mice population of the south seem to be very different with IA about 80% associated with a different body condition (Fig. 8). It is very difficult to compare densities in rodents from one study to another. Fluctuations of density could be explained by different ways. For example, resource availability plays a key role in the reproductive cycle of mice. Thus, from one year to another or from one month to another the densities could vary enormously. In general, the rainy season increases resource levels which aid to the start of the reproduction cycle of rodents. However, during the rainy season, the opposite effect can also take place when water flows down the hills can reduce mice density to a minimum (Geraldes P, Pers comm). Accordingly, we observed significantly less erosion in the south of the island. Our explanation for the high densities of mice in 2021 would be the recent eradication of cats from the island [22]. Although the exact dates of the introduction of cats remains partially unknown, it is likely that they were introduced at least twice (1950, 1996) through shepherds who lived on the island. Therefore, this population became well adapted to the environment in a relatively short period of time, with an estimation of circa 200 cats being eradicated (Geraldes P, pers Comm). Where mice co-occur with other introduced mammals, their density is suppressed. Meso-predator release is an issue which needs consideration. This process predicts that once superpredators are suppressed a burst of mesopredators may follow which leads their shared prey to extinction [48]. The removal of a top predator allows a lower trophic level predator to increase in numbers due to release from predatory pressure. Many studies have shown that cats predate on mice on Santa Luzia [38,39,49], where they are the only mammal species available to cats. Mice are an important prey species for cats on the island, both in the dry an in the rainy period ([39], about 50% of prey in scat). Thus. the removal of cats could possibly lead to an increase in mice numbers through a decrease in predation pressure. From an ecosystem point of view, all the trophic relationship could be modified directly or indirectly by changes in predation competition. No other rodent species were trapped. So, fortunately, no rat capture was made during our mission, which seems very surprising given the ability of rats to disperse and adapt to oceanic islands. This absence confirms the previous rat monitoring program, following the stranding in October 2012, of a cargo vessel, the Terry Tres on the Southern shore of the Santa Luzia island.

However, faced with this high density of mice on Santa Luzia, local associations have set up numerous traps across the island for several years, without there being a real structured eradication program (Queiruga A, Pers comm). These trapping campaigns, which have worked well, could be another explanation for this very low density of mice. It would be interesting in the future to monitor the evolution of this population in relation to the possible evolution of Raso lark to see if there is truly an impact. Indeed, we observed many individuals of the Razo Lark during our stays (morning and evening) on Santa Luzia. Given the fact that we could not carry out a precise identification of each individual, in particular by the colour ring marking, it remains difficult to give a precise estimation of numbers. Nevertheless, on each trip, we observed at least 2-3 different couples. Their presence confirmed the good choice of this site for our study for rodent trapping and the artificial nests experiment. Although no nests were observed during the mission on Santa Luzia, the Razo lark were in the courtship phase, active in pairs, especially during the morning. The only estimate we have of the Raso lark population on Santa Luzia at this time of year would be around 450 individuals, even if the protocols used contain a lot of bias (Queiruga A, Pers comm).

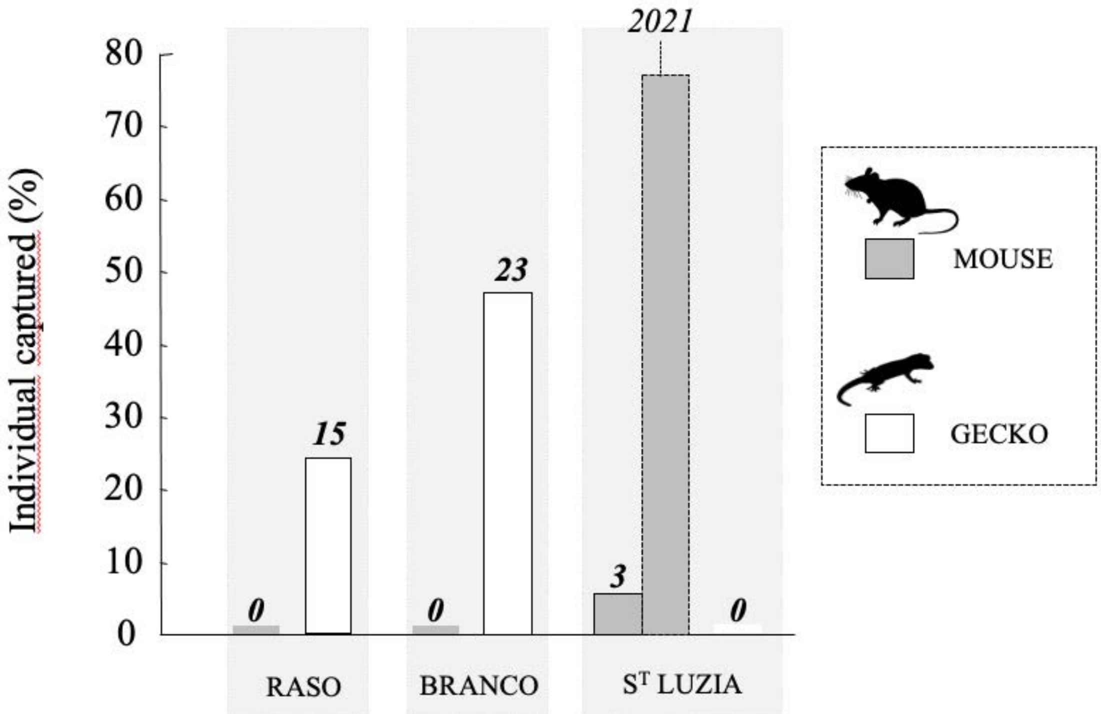

Fig. 8. Captures of mice (*Mus musculus*) and Gecko (*Tarentola gigas*) during the study in the Desertas islands (Raso, Branco and Santa Luzia). Bars represent the percentage of corrected trap-nights containing at least one individual. The number of total individuals is marked in italics above each bar (see text for correction factor). Result of 2021 study was represented for comparison.

On the other two islands (Raso and Branco), we did not capture any rodents and we observed no possible traces of their presence (Fig. 8). This absence can be explained by the poverty of available resources and the more marked hardness of these ecosystems. It is not excluded that there could have been episodes of rodent presence on these islands, knowing that fishermen also use them to make temporary camps during their fishing season, but much less than Santa Luzia. To our knowledge, no monitoring exists on the presence of rodents on these islands. Despite the extraordinary adaptability of rodents and their presence in more than 90% of oceanic islands, these two islands remain untouched. This is a huge opportunity, especially for the gecko *Tarentola gigas* and the Raso lark population on Raso Island, which would likely suffer greatly from direct predation by rodents (e.g., juveniles, eggs.). Finally, the use of rodent traps allowed us to capture numerous geckos and thus verify their presence on both islands. During 60 PN, we captured 15 geckos and 23 geckos on Branco and Raso respectively (Figs. 8-9). These non-invasive traps could be used in the future to study this specie density.

Regarding the Raso lark populations on Branco and Raso, this was our first visit to these islands. On Branco, the Raso lark has never been observed and we confirm these observations. However, the island is located between Raso (its original distribution area) and Santa Luzia where individuals have been translocated. Natural exchanges of individuals have been observed between these two islands [22], one might have thought that Branco being in the middle, it could host some. Probably, the ecosystem is not adequate. For Raso island, the population is really important especially in the southern part of the island. The estimates made in 2024 on the island are between 900-1000 individuals (Biosfera, pers. Comm.). The population correspond to the high level know [22]. These results are rather very encouraging.

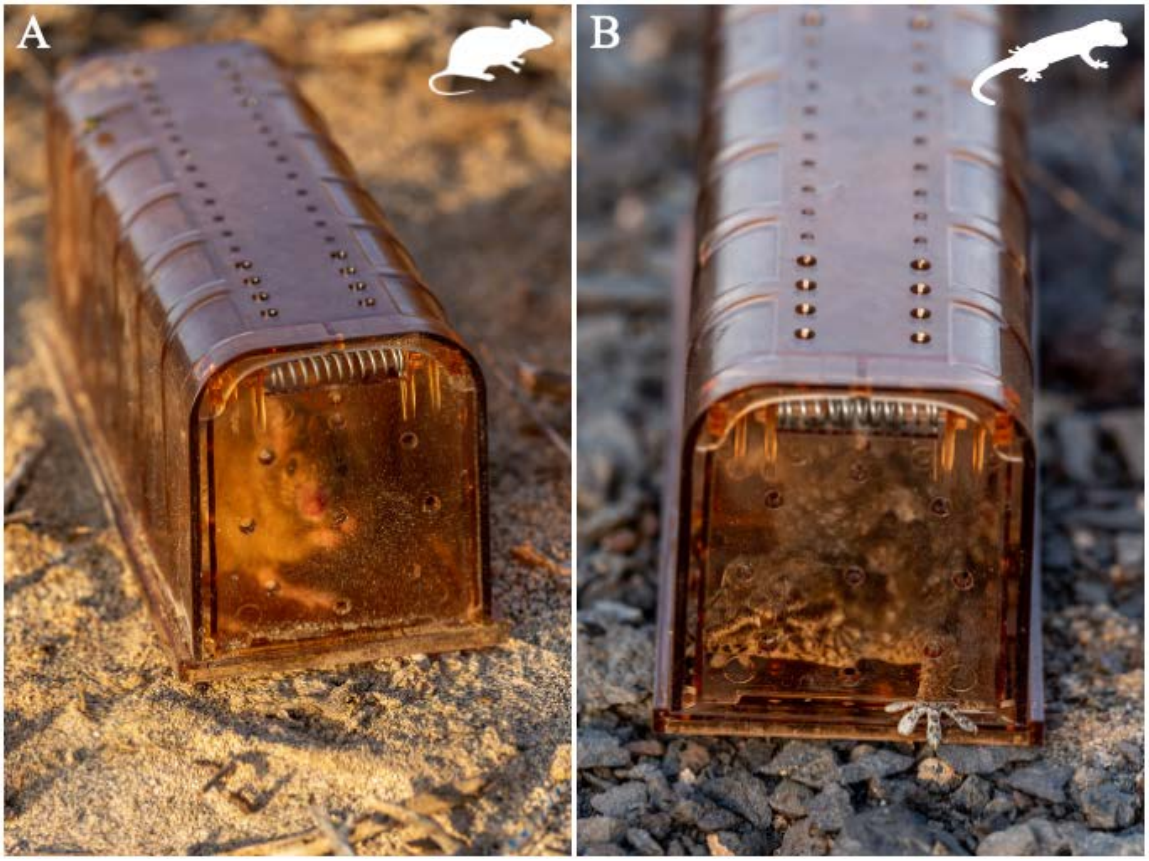

Fig. 9. Pictures of captured; (A) Mouse (*Mus musculus*) and (B) Gecko (*Tarentola gigas*) in the rodent trap (photo by S. Caut).

b. Predation on artificial nests

Despite the absence of terrestrial mammals and the paucity of avian predators, an extraordinarily high proportion of Raso lark nests have been observed to fail on Raso, their original ecosystem. For example, Castell [31] observed that four nests contained fragments of unhatched eggshells and Donald and Brooke [30] estimated in two years sampling an overall survival rate of eggs from laying to hatching at just 5% on Raso. Of the different potential nest predators on Raso, only the Cape Verde giant gecko (*Tarentola gigas*), endemic to Raso and the neighbouring island of Branco, was common [40]. This species is thought to feed on broken seabird eggs and possibly also seabird chicks [50] and it is certainly large enough to predate a lark nest. This gecko species has been present on Raso much longer than Raso Lark [51]. Notably, the Giant gecko (*Tarentola gigas*) is absent from Santa Luzia, perhaps allowing higher nest survival rates but other potential predators are present (*Mus musculus*) as well as other avian predation. Because the Raso lark is totally naive to this new environment and predators, it is unknown how the population might be affected in years to come.

In our preliminary artificial bird nest experiment on Santa luzia in 2021 (Caut and Jowers [23]), we found two different types of depredation. Firstly, the diurnal predation, with 100% of nest predated. In each time, the real chicken egg was pierced and sometimes several meters from the nest (Fig. 10). This signature is typical of an avian predator (e.g. Brown-necked Raven *Corvus ruficollis* or Neglected Kestrel *Falco tinnunculus neglectus*). Of the potential avian predators in Santa Luzia, only the Brown-necked Raven *Corvus ruficollis* or Neglected Kestrel *Falco tinnunculus neglectus* were likely to predate eggs. Both species breed in small numbers (one to three pairs of each) on Santa Luzia but are probably well established in the island. We observed a group of tree individuals of Brown-necked Raven in the south. They actively searched on the ground in the morning and in the evening in the bushes. Those were most likely responsible for this depredation. Corvids are well known to be a major predator of birds' nests [52-54]. This species has already been mentioned to have a possible impact on Lark's nests on Razo, where they are also in small groups [22,31]. Similarly, Neglected Kestrel can be a major predator, but more on juveniles and adults than eggs. During the translocation programs, several predation events were observed on adult larks (e.g. kestrels killed at least six of the 12 birds released on the first two days, [22]. Although kestrels also occur on Razo, the fact that the Santa Luzia kestrels had chicks in the nest and the larks' lack of familiarity with their new environment may have contributed to the predation. However, researchers hypothesized that these predation events were favored by the presence of the black protruding antennae of the tags. The populations of these two predator birds still remain quite low on the Santa Luzia island (e.g. with observed two Neglected Kestrel and five Brown-necked Raven in total during our mission). Our results on Santa Luzia Island are very different in 2024. We observe a virtual absence of diurnal predation due to birds (T^1 and T^2 = 0%), whereas it was 100% in 2021 (T^1, Fig. 10 and Tab. 2). There is a small predation for T^3 nests.

	RASO			BRANCO			ST LUZIA			
	T^1	T^2	T^3	T^1	T^2	T^3	T^1	T^2	T^3	*T^1 2021*
DIURNAL	100	-	65	-	-	-	-	-	5	*100*
NOCTURNAL	-	-	20	-	7	3	-	-	-	*60*

Tab. 2. Percentage of artificial nest predated (Type T^1, T^2, T^3 , and T^1 in 2021 study for comparison) during the night (nocturnal) or the day (diurnal) on the tree Desertas islands (Raso, Branco and Santa Luzia).

However, these results must be taken with caution due to the use of camera traps, it is likely that birds detect the nests more easily. Indeed, crows observe movements on the island, especially those of researchers. They then come curiously to the area to search and observe during many hours. Even though we took the greatest possible precaution by starting very early in the morning before their activities, camera traps can also attract their attention. These are probably the reasons that explain the very high diurnal predation on Raso island (T^1 = 100% and T^3 + 100%, Tab. 2). This island has almost no vegetation and the crow population is very active and curious. These different reasons could explain the high predation rate observed (e.g. with observed one Neglected Kestrel and five Brown-necked Raven in total during our mission in Raso). Different scientific monitoring protocols on different species have been implemented in the past. All the researchers' testimonies indicate problems with crows, which detect any markings or tracking equipment and come to search or destroy them. On Branco, we did not have this problem, because crows are rare and very inactive, explaining the total absence of predation of eggs (Tab. 2). Indeed, the possibility of predation of bird nests on Branco is very limited. There are no Raso lark individual and the most represented nesting birds are more aggressive and build their nests in burrows (e.g. *Puffinus boydi*).

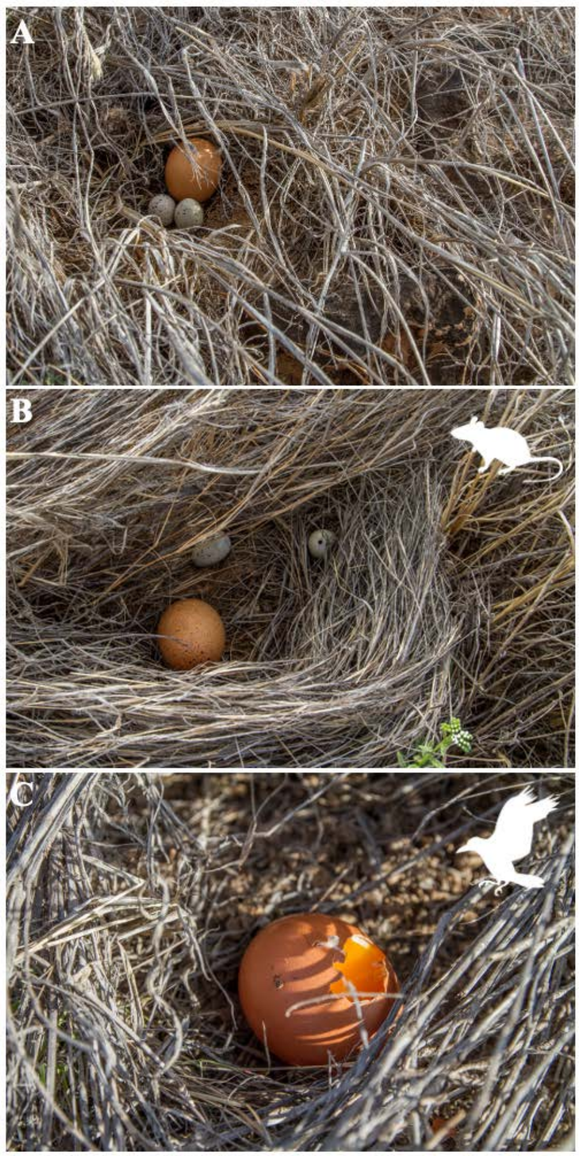

Fig. 10. Picture of one of artificial bird-nests containing two Raso lark artificial small eggs and one large hen egg, type T^1 (photo by S. Caut).

Secondly, the second type of depredation observed in 2021 occurred during the night. It corresponded to a movement of small eggs up to 50 cm from the nest (Fig. 10B). This depredation was observed in more than 60% in the south (Tab. 2). We attributed this depredation to mice which are nocturnal in Raso. In addition, the results were directly related to the mice trapping capture results [23]. Captures in the south was twice higher for both the IA parameter and the nest count depredated at night (Fig. 8 and Tab. 2).

Unfortunately, or rather fortunately, we captured very few mice in 2024. This low density may explain the absence of predator nests on Santa Luzia at night. This result is very interesting and shows the possible impact of this introduced rodent population. However, it remains very difficult to know if its impact is direct, via the consumption of eggs. The only photo and video triggers made by the mice (n = 7, Tab. 3) show that the mice have no interest in the eggs. They quickly pass in front of them without taking the time to stop or smell them (Fig. 11D). Mice are omnivorous and can impact a range of taxa including plants, invertebrates and birds [9,55]. Eggs represent a potential resource for mice, if their size is small and their shell strength is weak enough to break. In our preliminary study (2021), we have used plastic eggs that were much more resistant than real eggs, a reason behind mice moved them, possibly through an attempt to break them. We did not observe any traces of teeth or displacements on the real chicken eggs, probably too heavy and resistant for mice. n our study, we used real eggs, smaller than chicken eggs, along with quail eggs. Perhaps these eggs are still too big? Indeed, we were able to observe and measure the size of a Raso lark egg on the only nest discovered during our mission. It is even smaller than those of quails (length 21 mm x width 14 mm, Fig. 12).

	RASO		BRANCO		ST LUZIA	
	DIURNAL	NOCTURNAL	DIURNAL	NOCTURNAL	DIURNAL	NOCTURNAL
Alauda razae	16	-	-	-	12	-
Corvus ruficollis	34	-	-	97	5	-
Puffinus boydi	-	-	-	-	-	-
Passer iagoensis	1	-	-	-	-	-
Tarentola gigas	-	6	-	4	-	-
Chiononia stangeri	-	-	-	-	1	-
Mus musculus	-	-	-	-	-	7

Tab. 3. Number of camera trap pictures for the different species observed at night or during the day on the desert islands (Raso, Branco and Santa Luzia). For each island, a total of 3 nights and 2 days.

In a review, Angel et al. [55] analyzed the data on the impact of mice on native plants, invertebrates, terrestrial birds and seabirds. When considering these impacts on the island ecosystems, they highlighted that mice predation on seabird eggs and chicks was recorded from islands when mice are the only introduced mammal. On islands where mice are one of a number of introduced mammals, the effects of dominance, competition and predation by larger species may render them less of a threat to native vertebrates. Angel et al. [55] predicted that where mice are or become the only introduced mammal, on temperate or tropical islands, nest predation is likely to occur during times of severe food-stress, such as winter seasons or dry monsoons. Unfortunately, there have been no studies on the impact of mice on the biodiversity of Santa Luzia and this is an important point for future research.

Fig. 11. Camera trap pictures of different species on the artificial nests T[3] (represented by a dotted white circle); A = *Alauda razae*, B = *Corvus ruficollis*, C = *Passer iagoensis*, D = *Mus musculus*, E = *Puffinus boyd*i and F = *Tarentola gigas*.

Fig. 12. Picture of a veritable Raso lark nest with one egg observed on Raso island (photo by S. Caut).

Regarding nocturnal predation by geckos, we have the same observations as for mice. While the density is much higher (Fig. 8, Tab. 3), the photos and videos taken by the camera traps show individuals passing in front of the eggs without any interest (Fig. 11F). Again, it is possible that the size of the eggs is still too large, but if they were interested, we would expect them to at least try to consume them. So, the role of gecko predation on Raso lark nests remains to be more determined. To our knowledge, direct predation has never been observed.

c. Conclusions

Translocating a portion of a threatened population to a new locality is a common practice for conservation purposes [56,57] and is the most obvious measure in the case of the Razo lark. However, effective post-release monitoring of bird translocations is vital for improving overall translocation success [57]. In their original ecosystem, free of mammal predation in Raso island, this species has already suffered significant predation, particularly at the level of nests possibly by the Giant gecko. What about his survival on Santa Luzia? One might think at first that the absence of its most important predator could increase this nest success. But things are not so simple as the presence of avian predators and a new mammalian predator could have a more harmful impact.

The percentage of nests depredated on Santa Luzia in 2021 were very high and less than three times lower for mice (25 to 60%) than for native crows (0-100%, [23]). Duron et al. [20] found the same result for rats in New Caledonia rainforest. The native crow's impact on native bird nests may be much higher than the impact of invasive rodents. Further studies on real bird nests may be needed to corroborate this result. However, both corvids and rodents use distinctive cues to find nests and eggs, corvids being visual predators and rodents being olfactory predators (e.g., [52]). Even if we took great care by choosing schedules without activity, we cannot exclude the possibility that avian predators may have followed us checking experimental nests, thereby finding the nests more easily than without a human presence.

In our study in 2024, on this same island of Santa Luzia, we paid much more attention to the problem of experimentation with the presence of crows, and the results are very different. Diurnal predation by crows is very low (5%), but not negligible. Indeed, our experiment lasted only 2 days and the hatching time in this species is estimated to be 15 days [40]. So, during the entire incubation period, the predation rate can have a significant impact. On contrary, the impact of mice remains to be defined. The density in 2024 was really very low to learn more. Monitoring the mouse population with that of the Raso lark is necessary. The same is true for geckos on Raso. The Raso lark population does not seem to be really impacted by this reptile. Our results with artificial nests coupled with camera traps seems to go in this direction with an absence of direct predation. It would be very interesting for these two potential predators to continue to study the possibility of direct predation through egg consumption, particularly through other more specific experiments or in more controlled environments. However, what is clear is that predation by birds, particularly crows, can play an important role and seems to be the most important.

Another possible limitation to our results is that artificial nests do not necessarily reflect predation percentages for real nests. Their use has been criticized [17,18] and highlight results of predation percentages need to be considered with caution. For example, artificial nests may not be recognized as real nests by predators, in part because of the absence of parents protecting their nest and thus giving away its location [20]. In our first study in 2021, the use of plastic egg for small eggs could limited the olfactive attraction and make it more difficult to assess predation by the absence of direct consumption by mice. So, in 2024, we used commercial quail eggs (*Coturnix japonica*) to limit this artifact and also decreased the egg size. These modifications did not reveal a greater predation, rather the opposite. Furthermore, we have not observed any signs of direct predation by other species such as insects (an insect inventory is underway to confirm our observations).

Our study focuses on egg predation, but it does not allow to study the effect on the following stages (chicks or adults) which can also be very interesting for the survival of the species. The predation of chicks by avian bird predators are well known and noted by the Razo Lark in Santa Luzia. But mice predation on seabird species after hatching receiving increased attention [55], particularly on Gough Island, South Atlantic, UK Overseas Territory [58] where seabird chicks (Atlantic Petrel *Pterodroma incerta* and Tristan Albatross *Diomedea dabbenea*) are susceptible to predation by mice. The Razo lark is a very small species, adult brood the nest for 13 days and juveniles do not leave the nest for more than 15 days (Brooke et al. 2020). Therefore, the one month period remains critical for the survival. Angel, Wanless & Cooper [55] also identified potential competition between mice and birds for food (eg. invertebrates). The Razo lark, typically 18–22 g, shows dietary similar to other skylarh (e.g. *A. arvensis*); while invertebrates are delivered to nestlings, the diet of nonbreeding birds is principally vegetal material, including seeds, from the plains of Razo [30].

The invasion of ecosystems by exotic species is currently viewed as one of the most important sources of biodiversity loss. The largest part of this loss occurs on islands, where indigenous species have often evolved in the absence of strong competition, herbivory, parasitism or predation. As a result, introduced species thrive in those optimal insular ecosystems affecting their plant food, competitors or prey. As islands are characterised by a high rate of endemism, the impacted populations often correspond to local subspecies or even unique species. One of the most important taxa concerning biological invasions on islands are mammals. A small number of mammal species is responsible for most of the damage of invaded insular ecosystems: rats, cats, mice and a few others. The situation of introduced mammals on Raso is not very clear. Few studies have focused on the presence of introduced mammals that are sometimes very difficult to capture or observe. Currently, we have observed a low density of mice on Raso, but its evolution should be monitored regularly over time. Three years ago, the density was very worrying. According to our results, the islands of Branco and Raso do not seem to be invaded by rodents, but as a precaution, monitoring could also be important. Their impact could be catastrophic on the very valuable island species as the Raso lark (*Alauda razae*) or the Raso giant gecko (*Tarentola gigas*).

This artificial experiment is a first step to study the nest success in Desertas islands. There is insufficient evidence at this time to confidently state whether or not the Razo Lark will be able to cope with mice or gecko predation. Razo Larks, like Sky Larks, compensate in part for high nest losses by rapid re-laying after nest failure. Brooke et al. [22] observed one pair building a new nest the day following the loss of their previous nest. Ground nesting birds experience high nest predation, especially those that breed in shrub and grassland habitats [59]. A study on lark species adaptation to predation examined two species which can produce three clutches per season as an evolved adaptation to predation pressure to increase chances of successful fledging [60]. This study showed that nest lost was not as 'disastrous' as compared to loss of the incubating female. Mice or geckos would not be expected to predate on incubating females but may predate on eggs and young chicks. To resolve these issues satisfactorily, the evolution of the mice population after cat eradication and its predation upon Razo Larks should be monitored and evaluated in Santa Luzia. The same is true for the predation pressure exerted by avian predators, specifically at the level of eggs for crows and juveniles and adults for kestrels. In addition, the possibility of standardizing studies on islands (Razo, Santa Luzia and Braco) with tree different scenarios, could be a major asset for a better understanding of predator-prey relationship and adaptation in their environment.

One of the difficulties of conservation biology is the general lack of experimental approaches. Because it is often unethical, or simply because this discipline deals with small and/or fragile populations, experiments on these populations are not always feasible. As a result, knowledge of population dynamics, when not dealing with caged invertebrate populations in the laboratory, is often derived from theoretical studies, with notable exceptions such as those based on some isolated populations on islands. However, one aspect that is often lacking is the interspecific dimension: in the above cases, it is quite exceptional to take in addition of two interacting populations, yet direct and indirect "complex" interspecific relationships can be major ecological forces in some communities.

However, there is an enormous set of ecological events that can be considered large-scale natural experiments: voluntary (e.g. translocation) or unintentional (e.g. biological invasions) species introductions. Several aspects make biological introductions an interesting tool for the study of interspecific interactions: they are diverse in nature, involve many different organisms and occur in contrasting ecosystems. Biological introductions are often a very rich source of information for understanding the functioning of ecosystems, because they come from introductions that are generally relatively well documented. Moreover, in many cases (especially biological invasions or translocations), the new ecosystem is an island, with all the advantages that island ecosystems provide for basic research: closed ecosystems, of limited size and relatively large food webs. simple and non-redundant. In the same way that the physiology of an individual can be better understood during a disease, the dysfunction of an ecosystem can help to gain knowledge about its normal functioning. In this regard, the changes generated by the simple modifications of species introductions and their subsequent spread provide many types of information. Thus, biological introductions represent simple experiments in adding species to a new food web. Such experiments can benefit from controls and replicas in the case of archipelagos (e.g. Desertas islands). Similarly, species deletions can be studied in large-scale experiments that are all the more accessible to population or community biologists, because they can be designed by them: the control or eradication of the species exotic (e.g. the cat on Santa Luzia). With this new tool for adding and removing species in relatively simple island ecosystems, one can gain more knowledge about basic processes such as colonization, dispersal, spatial spread, as well as population dynamics in interaction. This approach represents one of the important bases of this project. The unique possibility of the situation of the 3 desert islands with a combination of different scenarios is a major tool for better understanding the interspecific relationships between the Raso lark in its environment.

5. Acknowlegment

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7. PICTURES OF RASO ISLAND

PICTURES OF BRANCO ISLAND

PICTURE OF SANTA LUZIA ISLAND


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