LIFE ilhas barreira

REPORT

Monitoring the control of invasive mammals on Barreta Island

Faro | December | 2023

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Report of the Action D2 of the project Ilhas Barreira

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Reference

Nascimento T., Oliveira N., & Andrade J. 2023. Monitoring the control of invasive mammals on Barreta Island. Action D2 of the project Ilhas Barreira. Sociedade Portuguesa para o Estudo das Aves, Lisboa (unpublished report).

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Summary

Introduced mammals can pose serious threats to native seabird populations. On Deserta/Barreta Island in the Ria Formosa, south Portugal, the Audouin's gull (*Larus audouinii*) and Little tern (*Sternula albifrons*) are threatened by introduced cats and rats, through predation and disturbance in the breeding colonies.

To reduce the impact of these species on breeding birds and other native species, control measures were implemented on Barreta Island following the status assessment of the mammal species during an early phase of the LIFE Ilhas Barreira. By that time, the population size of cats was estimated at 7 individuals, while abundance of rodents was estimated at 0.23 photos taken by camera traps per 100 trapping nights. Trapping campaigns were set to completely remove cats from the island, through a Trap-Neuter-Return (TNR) program where cats were neutered and released in an existing cat colony in Faro. Regarding the invasive rats present on the island, the Brown rat (*Rattus norvegicus)* and the Black rat (*Rattus rattus*), Goodnature® traps were used to reduce the population size, mostly within and around seabird breeding colonies. Full eradication was not attempted due to the proximity to the coast and other islands, and the ease of rodents to enter the island.

During the cat control campaigns three adult cats were captured, with the first campaign in March 2021 and last in January 2022, and since then no more cats were detected or suspected to appear on the island. Several monitoring protocols were implemented in order to measure the success of the control measures, namely using camera traps, spotlighting transects, and track counts to detect cat footprints. All methodologies confirmed the absence of cats, but camera traps performed better on detecting cats when numbers were very small.

Following the cat control campaigns, 42 Goodnature traps were installed on the island to control rats in three main areas: the harbour, the Audouin's gull colonies, and the lagoon in the west part of the island. From February 2022 to June 2023, the traps were triggered 591 times, with the confirmed death of 54 rats (*Rattus* spp.) and the unintentional death of 71 Algerian mice (*Mus spretus*). Most of the triggers took place between September and February, following a reproduction peak of rats during fall. The effectiveness of the traps can be impacted by false triggers, and the scavenging of dead bodies by other species, contributing to inaccuracies in estimating the number of kills.

The number of rats caught in the camera traps remained low until July 2022, increasing in abundance from then on with a maximum recorded in March 2023. This increase was specially noted in the area of the boardwalk, which was also extensively used by cats before their removal. Goodnature traps performed well by keeping low the number of rats that use and settled around trap locations, but not acting as an effective barrier preventing rats to enter on the island and that move to sites where traps were not in place. To improve the desirable barrier effect, more traps were placed along the shore line of Barreta and under the boardwalk.

A regular monitoring of the control measures is important and should be included in the implementation of the biosecurity plan, especially to prevent the reintroduction of cats onto the island and the quick increment of the rat population. Those measures should follow an adaptive strategy.

Resumo

Os mamíferos introduzidos podem representar sérias ameaças às populações nativas de aves marinhas. Na ilha Deserta/Barreta, na Ria Formosa, sul de Portugal, a gaivota-de-audouin (*Larus audouinii*) e a chilreta (*Sternula albifrons*) estão ameaçadas por gatos e ratos introduzidos, através de predação e perturbação nas colónias de reprodução.

Para reduzir o impacto destas espécies nas aves reprodutoras e outras espécies autóctones, foram desenvolvidas e implementadas medidas de controlo na ilha da Barreta na sequência da avaliação do estado das espécies de mamíferos durante a fase inicial do LIFE Ilhas Barreira. Durante aquele período o tamanho da população de gatos era estimado em 7 indivíduos, enquanto a abundancia de roedores foi estimada em 0.23 fotos tiradas por armadilhas fotográficas a cada 100 noites de captura. Foram efetuadas campanhas de captura para remoção dos gatos na ilha, através de um programa Capturar – Esterilizar - Devolver (CED), onde os gatos foram castrados e libertados numa colónia de gatos existente em Faro. Relativamente a roedores invasores presentes na ilha, a ratazana-castanha (*Rattus norvegicus*) e o rato-preto (*Rattus rattus*), foram utilizadas armadilhas Goodnature® para controlar o tamanho da população, especialmente perto de colónias de reprodução de aves marinhas. A erradicação total não foi tentada devido à proximidade da costa e de outras ilhas, e consequentemente à facilidade de entrada de roedores na ilha.

Nas campanhas de controlo de gatos foram capturados três gatos adultos, tendo a primeira campanha sido iniciada em março 2021 e a última realizada em janeiro de 2022, e desde então não foram vistos nem há suspeita da presença de mais gatos na ilha. Vários protocolos de monitorização foram implementados para medir o sucesso das campanhas, nomeadamente através da utilização de armadilhas fotográficas, faroladas, e contagem de rastos para monitorizar pegadas de gatos na ilha. Todas as metodologias confirmaram a ausência de gatos, mas a armadilhagem fotográfica tiveram melhor desempenho na deteção de gatos quando a densidade era muito pequena.

Após as campanhas de controlo de gatos, foram instaladas 42 armadilhas Goodnature na ilha para controlar ratazanas (*Rattus* spp.) em três áreas principais: no cais de embarque, nas colónias de gaivotas de Audouin e na lagoa na parte oeste da ilha. De fevereiro de 2022 a junho de 2023, as armadilhas foram acionadas 591 vezes, sendo confirmada a morte de 54 ratazanas e a morte acidental de 71 ratinhos-das-hortas (*Mus spretus*). A maioria dos disparos ocorreu entre setembro e fevereiro, após o pico de reprodução de ratazanas durante o outono. A eficácia das armadilhas pode ser afetada por falsos disparos e pelo consumo de cadáveres por outras espécies, contribuindo para imprecisões na estimativa do número de mortes.

O número de ratazanas fotografadas nas armadilhas fotográficas permaneceu baixo até julho de 2022, aumentando em abundância a partir de então, com máximo registrado em março de 2023. Esse aumento foi notado especialmente na área do passadiço, que era também uma área bastante utilizada por gatos antes da sua remoção. As armadilhas Goodnature tiveram um bom desempenho, mantendo baixo o número de ratazanas que se movimentam e instalam em torno dos locais das armadilhas, mas não atuam como uma barreira eficaz que impeça a entrada de ratos na ilha e que se deslocam para locais onde as armadilhas não estão instaladas. Para melhorar o efeito de barreira desejável, mais armadilhas foram colocadas ao longo da costa norte da ilha e ao longo do passadiço.

A monitorização regular das medidas de controlo é importante e deve ser incluída na implementação do plano de biossegurança, especialmente para evitar a reintrodução de gatos na ilha e o rápido aumento da população de ratos. Essas medidas devem seguir uma estratégia adaptativa.

1 | Introduction

1.1 Background

Invasive mammals, such as rats, cats, and rabbits, have found their way to colonize many remote islands and coastlines. This introduction, often accidental due to human activities, has set off a chain reaction of ecological disturbances, resulting in great negative impacts on native populations and their habitats. Introduced mammals pose serious threats to the survival and breeding success of seabirds (Towns et.al. 2011) and land birds (Bonnaud et al. 2011) due to predation, graze on native vegetation and facilitate the dispersion of invasive plants (Harper & Bunburry, 2015; Wolf et al. 2018).

On Barreta Island, located in the Ria Formosa, South of Portugal mainland, data on abundance and seasonal fluctuations, of rodents and cats was collected at the beginning of LIFE Ilhas Barreira (LIFE18 NAT/PT/000927) under the action A3 - Gathering baseline information of introduced mammal species (see Nascimento et al., 2022).

On total seven cats were individually identified on the island. Their activity was higher between the restaurant and the boardwalk, with the exception of one cat that centered its activity on the lagoon on the western part of the island. From genetic analysis of feces, the cats of Barreta island fed on passerines, gulls (Laridae), little terns, rodents, reptiles, and food from anthropogenic origin (Morais, 2022).

Regarding rodents, a native species, the Algerian mouse (*Mus spretus*), and two invasive species, the Brown rat (*Rattus norvegicus*) and the Black rat (*Rattus rattus*) were present on the island (Nascimento et al., 2022). The Algerian mouse is highly abundant on Barreta Island, mainly after the reproduction peak period in August-September. Despite the high density values recorded, their diet does not pose a threat to the breeding birds present. On the other hand, rats (*Rattus* spp.) are less abundant but have a wide distribution, and may predate on bird eggs and chicks.

The presence of cats and rats on Barreta island may also cause the abandonment of breeding seabirds, especially of Audouin's Gull (*Larus audouinii*) and Little tern (*Sternula albifrons*), and increase mortality by predation (GalloOrsi 2003). The control of invasive mammals is thus essential to avoid its negative impacts on native species and threatened flora.

Here we report the implementation and the effectiveness of both cat removal and rat control developed under the Action C3 - Control of invasive mammals, through an intensive monitoring implemented under the Action D2 - Monitoring the control of invasive mammals. Overall, both tasks followed the previously designed Control Plan for Mammals on Barreta Island (Nascimento et al 2021).

1.2 Study area

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Ria Formosa is located in Faro, Algarve, south Portugal mainland, and is a complex coastal lagoon system which extend for over 60 km (Fig. 1), with 5 barrier Islands (Barreta/Deserta, Culatra, Armona, Tavira, and Cabanas).

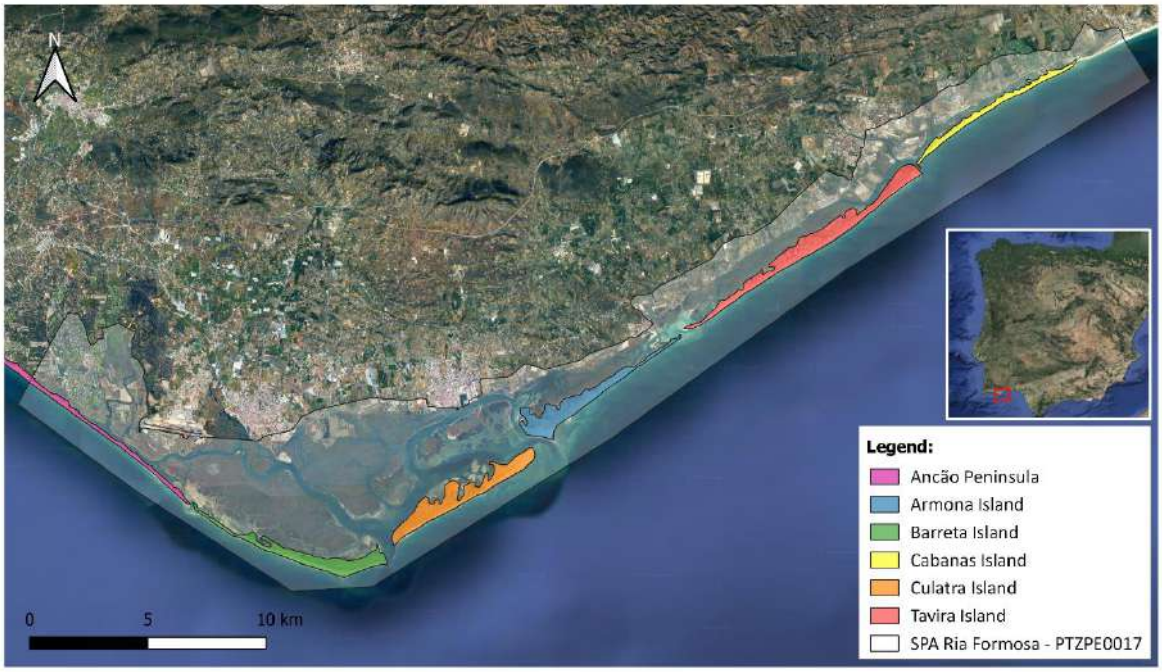

Figure 1 | Location of Ria Formosa SPA and the Barrier Islands on the Algarve coast including Barreta Island.

The Barrier Islands are a unique system that support priority habitats such as fixed dunes "grey dunes", essential for the stabilization of dune and protection of the shoreline, the presence of interesting floristic species with 14 Iberian endemism, and several bird species of conservation concern.

It is also home to two threatened breeding seabird species at national or global level: the Audouin's Gull, has a global conservation status of Vulnerable, and the Little tern, with the most important Portuguese breeding population located in Ria Formosa. The Barrier Islands also hold several other breeding birds, native reptiles and arthropods, having the surrounding sea grounds significant rich ichthyofauna, playing an important role as a fish nursery. By its natural values, Ria Formosa is classified as a Special Protection Area (SPA PTZPE0017), a Natural Park (designated under national legislation), and a Site of Community Importance (SCI PTCON0013). Main biodiversity threats are related to huge touristic pressure, especially during the summer months, bycatch and mortality in fishing gears, and the presence of invasive alien mammals (rats and cats) on the islands.

The Barreta island is one of the 5 sand islands of the Ria Formosa, with a length of 8.6 km and an area of approximately 3.2 km^2, being 150 m apart from the Ancão peninsula (to the west), and 700 m from Culatra island (to the east). The island is relatively close to the city of Faro, with a minimum distance of 4 km, although with several islets and salt marsh areas in between. The island has four

breeding seabirds: the Audouin's gull, the Little tern, the Yellow-legged gull (*Larus michahellis*), and the Lesser black-backed gull (*Larus fuscus*).

The island is inhabited by just one fisherman and the existing infrastructures are limited to three shelters and a restaurant (which operates all year round), all located in the eastern part of the island, and a boardwalk with around 1.7 km from the island harbour to Cape Santa Maria. Access to the dunes beyond the existing trails is prohibited, however it is a very regular behavior by visitors. The island can be visited throughout the year, with a greater influx of tourists during the summer.

2 | Methods

2.1 Cats

2.1.1 Control methods

Following the Control Plan for Mammals on Barreta Island (Nascimento et al., 2021), cats have been removed from Barreta Island through a Trap-Neuter-Release (TNR) program, by which cats were trapped, neutered, and then released.

Cat trapping has been carried out in areas where the highest activity was recorded: near the restaurant, along the boardwalk, and near the lagoon on the western section of the island (Fig. 2).

Figure 2 | Location of cat traps on Barreta island during cat trapping campaigns.

The location of the traps was adjusted throughout the campaigns to the activity areas of the remaining cats, through continuous monitoring of cat activity (Nascimento et al., 2021). Before each trapping campaign, lures have been placed in the capture areas to improve the likeness of a cat to be trapped. Lures consisted of wet cat food and/or canned fish.

Two campaigns to capture cats took place in 2021. One in March and one in September, both from the 25th to the 28th. The number of people involved per capture night varied between two and seven.

In 2022, another two capture campaigns were carried out from January 24th to 27th and in February from 21st to 24th. In January, four people were involved per capture night, and two in February.

These campaigns consisted of 4 capture nights in each month. Two to eight traps were placed near the lagoon on the northwest side of the island and along the wooden path. During the four days of each campaign, traps were only deployed in late evening, at 5:30pm and checked early in the morning at 7:30am.

No trapping occurred between March and September 2021 due to high temperatures, and large influx of tourists on the island.

Before each trapping campaign, the veterinary clinic was informed and was prepared to receive cats at any time. Cats were caught with live cage traps (76*30*32cm). These are humane and safe tool to capture cats without causing significant injuries and allow captured non-target animals to be released unharmed (Fig. 3).

Figure 3 | Captured cat (left) on Barreta Island and an example of a live-trap (right) used for capturing feral cats.

Trapped cats were delivered to the veterinary clinic as soon as possible, for assessment of general health and for neutering, which involved the removal of the ovaries and uterus, in case of a female cat, and the removal of both testicles, in case of a male cat. Until then, cats were kept closed in a transportation box in a dark room and fed regularly. To mitigate the impacts of cats on the island's fauna, captured cats were not returned to Barreta Island, but relocated to a cat colony in Ancão Peninsula, in Faro. Both relocation and neutering were coordinated by *Animais de Rua*. The process of release included a 3-week habituation stage, in which the cat was kept in a large trap in the colony and fed regularly. This allowed the cats to get used to feeding places, people, and other cats in the colony.

2.1.2 Control monitoring

It was essential to monitor cat densities and abundance fluctuations before and after the trapping campaigns to evaluate the degree of success of cat removal. Monitoring began after the first control campaign and involved the same methodologies used during the pre-control phase, which included spotlighting, transects to identify tracks and signs of presence, camera traps, and the recording of occasional sightings (Nascimento et al., 2022).

Spotlighting

In order to count cats and to identify hot spots of cat activity, one transect, covering two thirds of Barreta Island, was conducted every month from February 2020 to September 2022. This transect was 5.49 km long and was divided in four segments (Fig. 4). It was sampled by a team of two people at sunset or 30 min before the sunrise for three consecutive days, unless limited by the weather conditions. Data was recorded in the WVS Data Collection App[1].

[1] https://apkpure.com/wvs-data-collection-app/com.wvsdatacollection.android

An abundance index was calculated by the mean number of cat sightings per kilometer (Mitchell and Balogh, 2007), and used to compare before and after cat removal abundance index values.

Figure 4 | Transect with 5.49km length used during spotlighting surveys of cats on Barreta Island. The transect was divided in 4 segments.

Track counts

To monitor cat footprints, 56 stations 1*8 m placed 100m apart were marked on Barreta Island (Fig. 5). Stations were set in places with low vegetation and the sand was smoothed to better identify cat tracks on the following days. The presence of cat tracks was registered during three consecutive days every month from February 2020 to November 2021, and in January, April, and September of 2022.

A measure of 'imprintability' was taken in each station to account for variations in footprint detectability. The imprintability score was given by walking 10 steps along the station and record the value of each footprint on a scale from 0 to 3 (0 - no print visible; 1 - print barely visible; 2 – complete outline of print and some details of the sole visible; 3 - complete outline of print and all details of the sole visible) varying from 0 to 30. A station with a score of 0 to 5 – poor printing potential (1), 6 to 15 – reasonable (2), 16 to 25 – good (3), 26 to 30 – excellent (4). All stations with poor printing potential (1) were not used to calculate abundance indexes.

Two abundance indexes were calculated: the Allen index, given by the number of stations with cat tracks per transect per day, and the Catling index, given by the percentage of nights with tracks (Mitchell and Balogh, 2007).

Figure 5 | Location of track stations on Barreta Island.

Camera-traps

One grid of 22 camera-traps (PRIMOS Mug Shot Trial Camera Model 65064, 12MP and Bushnell CORE™ NO GLOW TRAIL CAMERA, 24MP) spaced 500*500 m was set on Barreta Island (Fig. 6). This grid covered near two thirds of the island in terms of length because the last third was a narrow sandy strip, which was assumed to have non-suitable habitat for cats. Cameras were installed 30 cm from a passageway used by cats, oriented so as to make an angle of 23° with the trail (Fleming et al., 2014), and set to take three photos one second apart upon triggered by a motion sensor.

Cameras were active from January 2020 to June 2023, with memory cards and batteries replaced once a month. All images were processed using Timelapse software. A collaboration with Microsoft was set in order to use MegaDetector algorithm to detect and filter out images with no animals or humans in, as frequently cameras were triggered by the movement of vegetation, producing an enormous amount of empty images. Cat photos were filtered in order to eliminate photos taken within 3 seconds of the previous recording.

Figure 6 | Location of the 22 camera traps set on the Barreta island, on a grid spaced 500*500 m.

2.2 Rodents

2.2.1 Control methods

Following the Control Plan developed to control rat population on Barreta Island (Nascimento et al., 2021), 42 Goodnature ® traps were used. Goodnature traps are auto-reset traps powered by compressed CO^2 gas that work by striking the skull of the rat killing it instantly (Fig. 7).

Figure 7 | Goodnature traps set on Barreta Island with no protection box (left) and a Goodnature trap set inside a protection box which was located near the harbour (right).

To safeguard the native Algerian mouse, the traps were not placed in the entire island, but only in areas where the presence of invasive rats has been confirmed, in potential entry zones and within and surrounding Audouin's gull colonies (see Nascimento et al., 2022). Also the bottom part of the trap has been installed vertically at a minimal height of 14 cm from the soil, so that mice cannot easily get inside the trap.

In total 42 traps have been set up, from which 11 of them near the harbour (G1-G11) on the eastern side of the Island, 15 next to the lagoon, on the western side on the island with an average distance of 50 meters (G28-G42) and 16 close to the Audouins' gull colonies in the centre of the island with an average distance of 100 meters (G12-G27) (Fig. 8).

Figure 8 | Location of the Goodnature traps, used for control rat population on Barreta Island.

2.2.2 Control monitoring

Goodnature traps

The CO^2 canisters had to be replaced after 24 strikes (and at least once a year if the maximum number of strikes is not reached), and lures refilled after three months. The installation of Goodnature ® traps for rat control was done in February 2022 with the exception of the traps placed closest to the harbour, that were installed in March with a protection box to prevent visitors to touch and get injured in the trap. The control period lasted until June 2023.

After deployment, each trap has been checked monthly for the number of trigger events and dead rodents around the trap counted.

For data analysis, traps were grouped by area, following the three areas, Harbour (G1-G11), Audouin's Gull colonies (G12-G27) and Lagoon (G28-G42).

Camera-traps

From the 22 camera-traps described in the section 2.1 (Fig. 6) images from rats (*Rattus* spp.) were used to compare rat abundance before, during and after the control phase. Cameras were active from January 2020 to June 2023. Rat photos were filtered in order to eliminate photos taken within 3 seconds of the previous recording. For comparison on the number of rat photos taken between areas with and without Goodnature traps a t-test was performed.

3 | Results

3.1 Cats

Seven individual cats have been previously identified on Barreta Island using camera traps from January 2020 to February 2021 (Nascimento et al., 2022). In the first campaign in March 2021, two cats were captured, one black pregnant female captured in the north part of the boardwalk, and one whitish male captured near the restaurant. On the second campaign, in September 2021, one grey male cat was captured in the northwest part of boardwalk. In another campaign in January 2022, the same grey cat was captured. This cat somehow found a way to come back to Barreta Island after been released in the Ancão peninsula in a cat colony. The return of the grey cat indicates that cats may enter by themselves on the island, although we assume a very low probability for this to happen. A fourth campaign was carried out in February 2022, with no cats captured. Since then no more signs of cats were registered, and no more capture campaigns were carried out.

To confirm the absence of cats and the success of eradication, the presence of cats on the island was monitored through three different methodologies: spotlighting, track counts, and camera traps. In the spotlighting survey the number of cat sightings reached a peak in February 2020, before the control measures, with an average of 0.30 cats per km (Table I). Cat sightings decreased during control, reaching zero in October 2021 (Table I).

From the track stations monitoring, a higher number of cat footprints was registered during 2020, decreasing during 2021 with a peak in September (Fig. 9). With the last cat captured in January, the following monitorings did not register the presence of cats. Both Catling and Allen indexes reflect a decrease in cat abundance during the control period and an absence of cats after it, proving the success of the control methods (Tab. II).

The images from camera traps registered a mean number of 45 cat photos per month before the control campaigns, with high peaks during the control phase (Fig. 10), probably related to the placement of bait points near the camera traps. After the grey cat captured in September no more cats were photographed until late November, when the grey cat returned to the island (Fig. 10). After its capture in January 2022 there were no more photographic records of cats on the island.

Table I | Monthly variation of the number of cat sightings, and average cat abundance per km, registered during spotlighting survey on Barreta island, before, during and after the cat control campaigns.

		Month	Nº of nights	Nº of cat sightings	Nº cats per km	Overall nº cats per km
2020	**Before control**	January	2	1	0.09	0.13
		February	3	5	0.30	
		May	2	1	0.09	
		June	3	2	0.12	
		July	3	1	0.06	
		September	3	1	0.06	
		October	3	3	0.18	
		November	1	1	0.18	
		December	3	1	0.06	
2021	**During control**	June	3	2	0.12	0.05
		July	3	1	0.06	
		September	3	1	0.06	
		October	3	0	0	
2022		January	3	0	0	
	After control	April	3	0	0	0
		September	3	0	0	

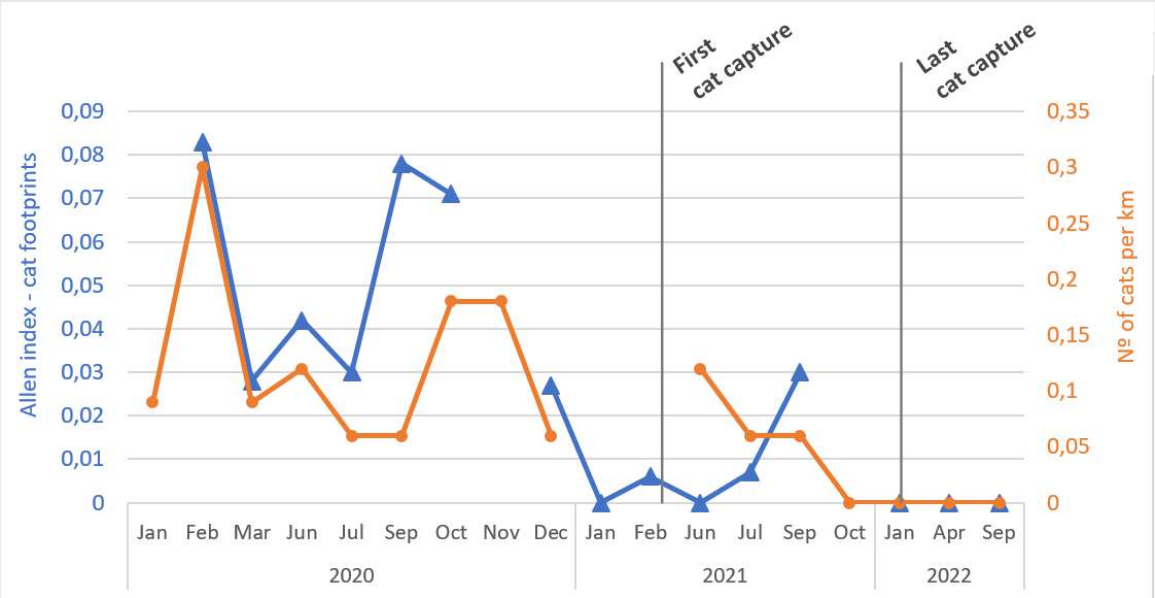

Figure 9 | Monthly variation of the Allen index of cat footprints registered during track surveys (in blue), and number of cats per km registered during spotlighting survey (in orange), on Barreta Island.

Table II | Monthly variation of cat footprints abundance given by the Catling and the Allen index, registered during track surveys on Barreta Island, before, during, and after the cat control campaigns.

		Month	Catling index value	Overall Catling index value	Allen index value	Overall Allen index value
2020	**Before control**	February	100	69.23	0.083	0.04
		May	50		0.028	
		June	100		0.042	
		July	100		0.030	
		September	100		0.078	
		October	66.67		0.071	
		December	66.67		0.027	
2021		January	0		0	
		February	33.33		0.006	
	During control	June	0	25.00	0	0.01
		July	33.33		0.007	
		September	66.67		0.030	
2022		January	0		0	
	After control	April	0	0	0	0
		September	0		0	

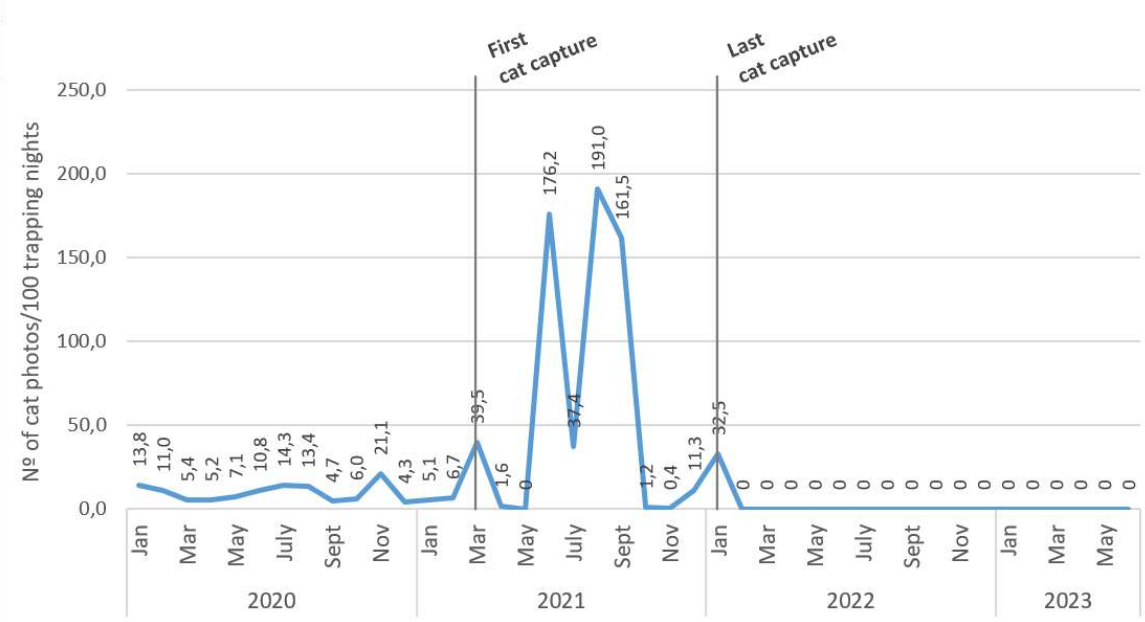

Figure 10 | Monthly variation of the number of images of cats per 100 trapping nights, taken from the camera-traps installed in Barreta Island, with emphasis on the period during cat control campaigns (March 2021 to January 2022).

3.2 Rodents

From February 2022 to June 2023 the 42 Goodnature traps were triggered 591 times. A total of 54 rats and 71 Algerian mouse were trapped, corresponding to 21% of total triggers. Of the dead rats, 29 were Brown rats, 10 Black rats, and 15 of unknown species due to body decomposition (Fig. 11). Taking into account that the number of the Algerian mouse was estimated to range from 800 to 5000 individuals in Barreta (Nascimento et al., 2022), and their average life expectancy is of 4 months, capturing a maximum of 71 mice in this period, represents between 1% to 9% of the total estimated population size.

During this period, it was also registered the unintentional death of 4 Eurasian magpies (*Pica pica*) and 3 House sparrows (*Passer domesticus*).

The highest number of triggers was recorded in the lagoon, followed by the area near Audouin's gull colonies, and lastly, the harbor (Fig. 12). A greater number of dead rats were found in the Audouin's colony area, while the largest number of mice was found in the harbour (Fig. 12). Given the scavenging behaviour by other animals, it is likely that the number of dead rats and mice is greatly underestimated. Camera-trap images confirmed that Eurasian magpies and Yellow-legged gulls were feeding on dead rats (Annex A), with scavenging by foxes (*Vulpes vulpes*) and Barn owls (*Tyto alba*) also being likely.

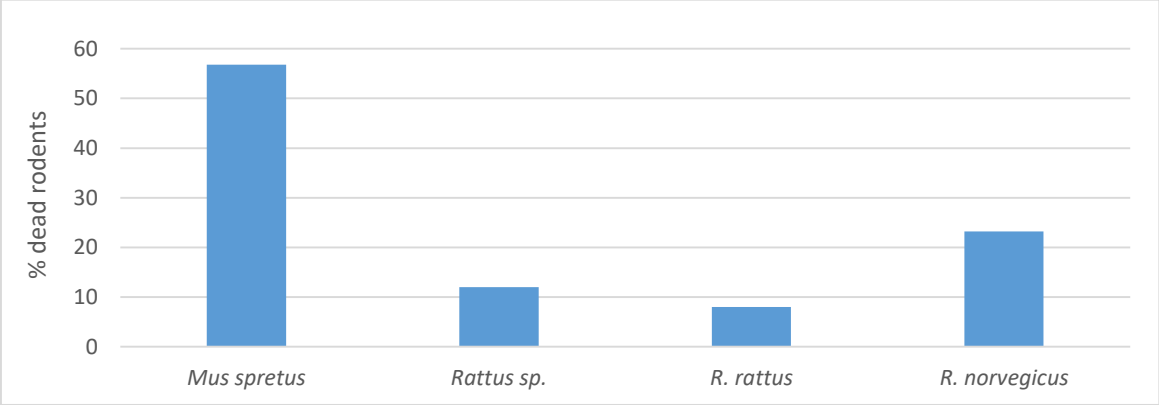

Figure 11 | Percentage of rodents found dead on the 42 Goodnature traps on Barreta Island, between February 2022 and June 2023.

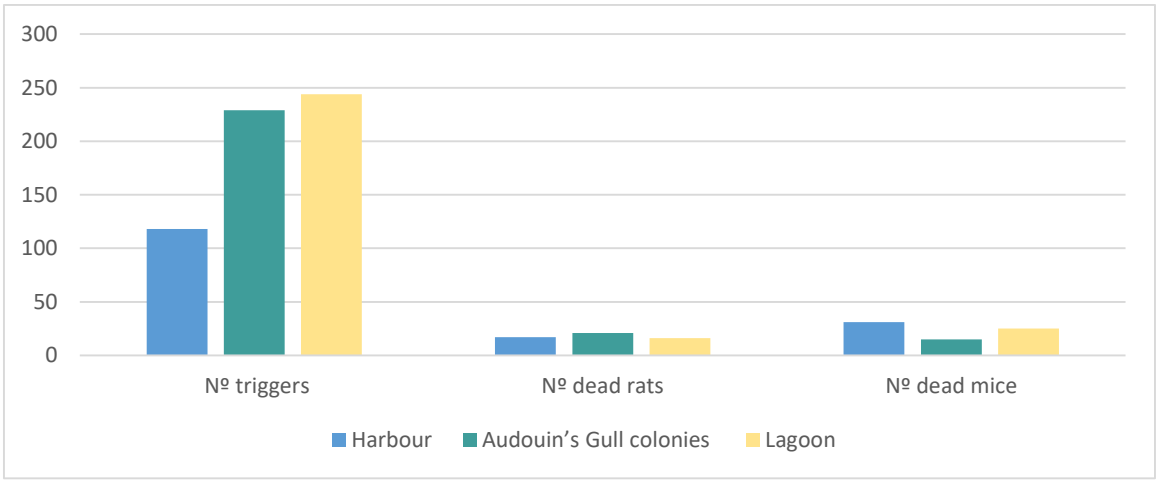

Figure 12 | Number of triggers and dead rats and mice found in the Goodnature traps located in the harbour, the Audouin's gull colonies, and in the lagoon in the western part of Barreta Island.

Most of the triggers took place between September 2022 and February 2023, with the most number of dead rats found in October 2022 and dead mice in January 2023 (Fig. 13). Although rats do not have a strict breeding season, being able to reproduce throughout the year, an increase in the abundance of rats from September 2022 onwards may be due to a reproduction peak during the fall. Rat images taken from camera traps remained at low levels from January 2020 to September 2021, with a peak in December 2021 in the final period of the cat control campaigns (Fig. 14). When the control of rats started in February 2022, the number of rats caught in the camera traps remained low until July 2022, increasing abundance from then on with a maximum recorded in March 2023 (Fig. 14).

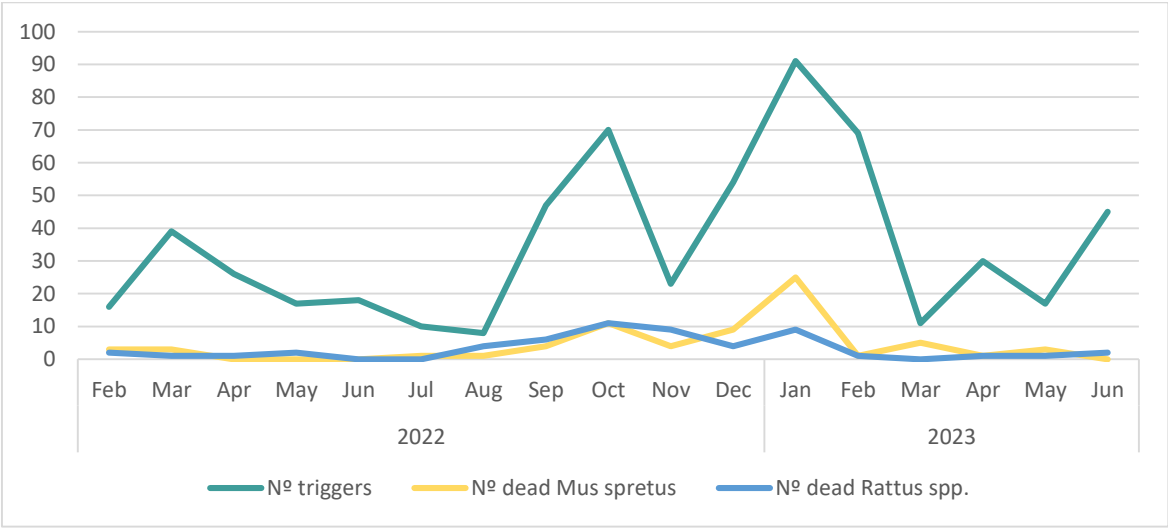

Figure 13 | Monthly variation of the number of triggers, dead rats, and dead mice found in the Goodnature traps installed on Barreta Island.

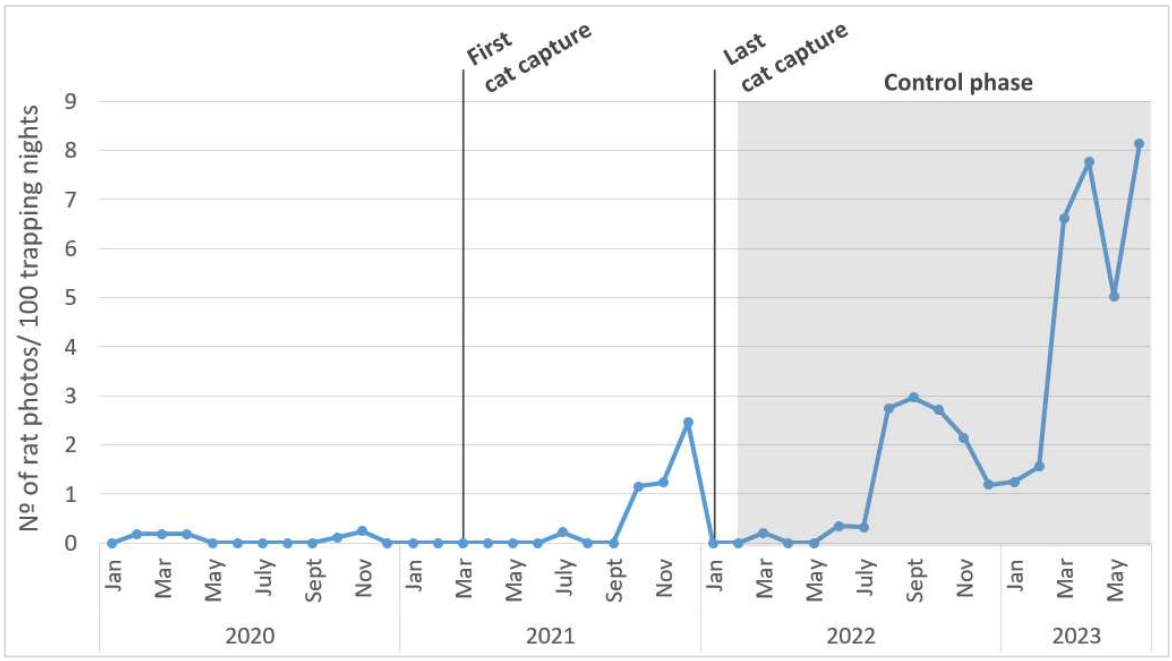

Figure 14 | Monthly variation of the number of images of rats *Rattus* spp. per 100 trapping nights, taken from the camera-traps installed on Barreta Island, with emphasis on the period during cat capture campaigns, and the period of the control of rats with Goodnature traps.

Most of the rat images recorded after the installation of Goodnature traps, were registered in three cameras set under the boardwalk (Fig. 15). The increase of rat images may be due to an increase of rat abundance, probably related to the reduction of predation by cats, or by a greater influx of rats to the island.

By analysing the difference in the number of rat images taken in each grid squares, with or without Goodnature traps, it was concluded that the number of rat photos taken is significantly higher in the grid squares that do not have Goodnature traps (M = 0.7 SD = 11.0), than the ones that have (M = 0.2 SD = 0.9), *t-test* = 2.2 *p* = 0.04.

With an apparent increase in rat abundance along the boardwalk, the Goodnature traps installed in the area registered high values of killed rats (Fig. 16), leading us to believe that they are being effective in controlling rats at a local scale (i.e. keeping low numbers the rats that use and settled around the location of the Goodnature traps), but not acting as an effective barrier preventing rats to enter on the island and move to sites where traps are not in place (Fig.17). In order to increase the effectiveness of the control and after the preparation of this report, 8 Goodnature traps were set under the boardwalk where higher concentrations of rats have been found. Future analysis is required in order to assess the effectiveness of this improvement. It was well noted that a periodic monitoring is needed, in order to implement an effective and adaptive strategy to keep rats in low numbers at the Audouin's Gull colonies.

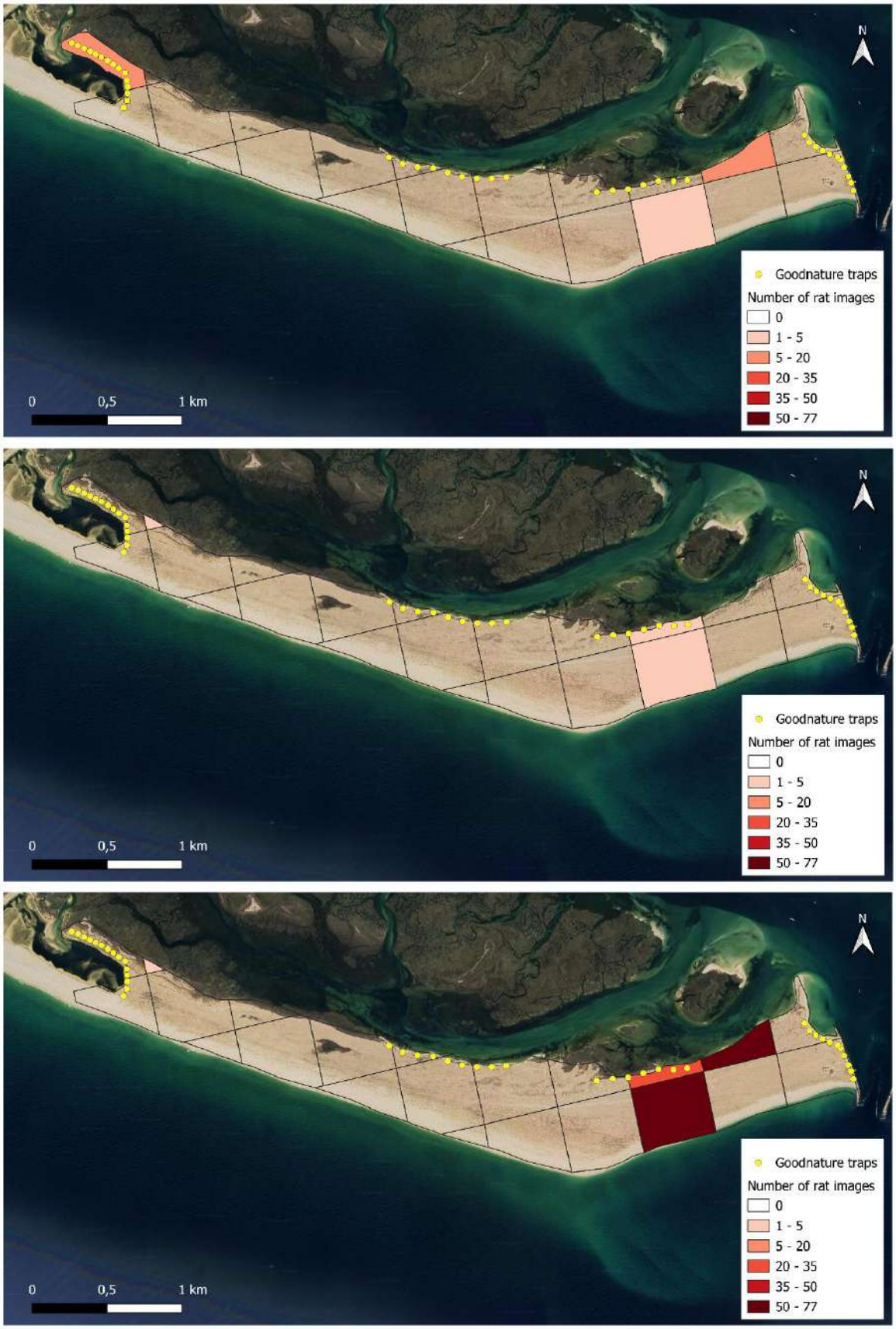

Figure 15 | Distribution map of rats photographed by 22 camera-traps installed inside each cell on Barreta Island, in a grid spaced 500*500 m apart. **Top** - before the beginning of control measures of cats and rats (January 2020 – March 2021); **Middle** - during the control of cats (March 2021 – January 2022); **Down** - during the control of rats (February 2022 – June 2023).

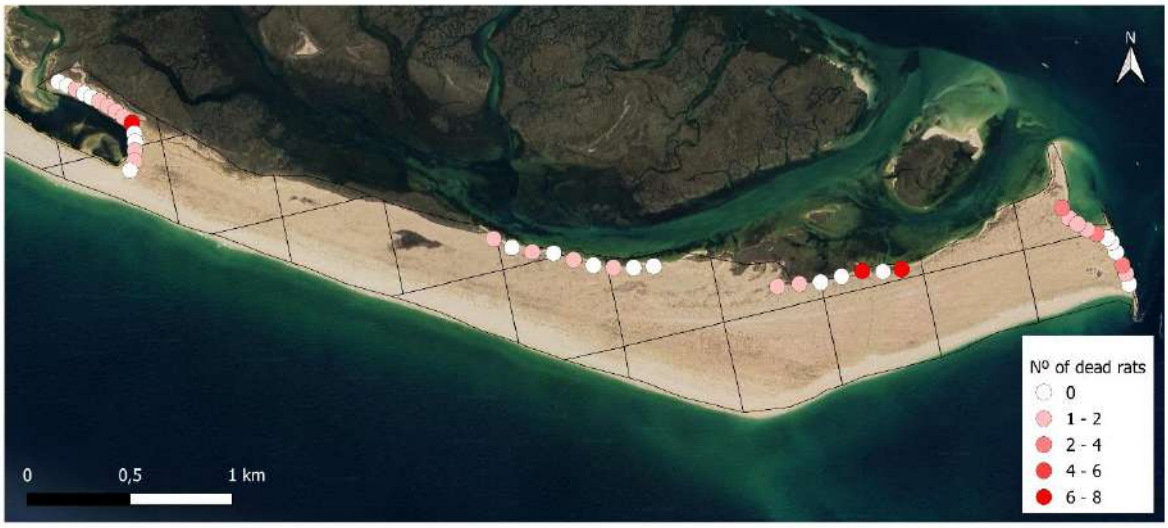

Figure 16 | Number of dead rats (*Rattus* spp.) recorded in each Goodnature trap, from February 2022 to June 2023.

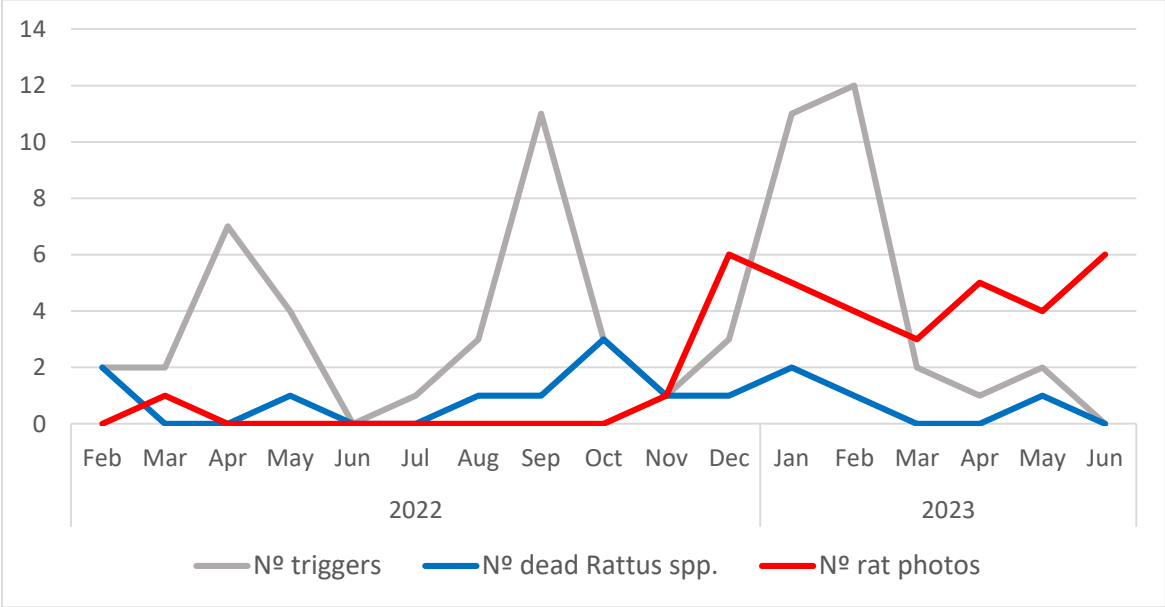

Figure 17 | Number of triggers and dead rats (*Rattus* spp.) recorded in 5 Goodnature traps and the number of rat photos registered in the CAT12N square (Fig. 6), from February 2022 to June 2023.

4 | Discussion

Careful planning, execution, and ongoing monitoring are essential to ensure the success of cat control campaigns. The absence of cat signs on Barreta Island, one and a half years after the last capture, is a primary indicator of the success of this intervention. A total of three cats, from the 7 adult cats identified in the beginning of the project (Nascimento et. al., 2022) were captured, neutered and released in a cat colony. The disappearance of the remaining four cats may be an indication of the island's unsuitability for its survival, which is also supported by the veterinary diagnosis of malnutrition in the cats that have been captured and sterilized. Also, two of these cats were used to eat leftovers in the restaurant being more or less friendly to humans, and it possible, although unlikely, that someone took any of these cat off the island. After being asked, none of the restaurant's regular workers said they took a cat with them.

Given the dietary preferences of the feral cats of Barreta (Morais, 2022) it is expected that the removal of cats from the island will reduce the impacts of predation on seabirds, land birds and other native species, and reduce disturbance and abandonment of Audouin's gull and Little tern colonies, although predation is likely to keep occurring due to the presence of natural predators on the island, such as birds of prey and foxes.

In terms of efficacy of the three methods used to monitor alterations in cat abundance before during and after the intervention, all methods performed well while number of cats was higher. However, spotlighting and track counts performed poor when number of cats was very small. Only camera traps detected cat activity during the last phase of the capture intervention (from October 2021 to January 2022), when only one cat was believed to be present on the island. Thus, we advise the use of camera traps in future cat removal to assess the effectiveness of the interventions. Camera traps should be put in place at least 1 year before the intervention start, in order to obtain accurate numbers of the cat population and yearly fluctuations.

Based on the analysis of automatic cameras, after the removal of cats from Barreta island, there was an increase in the species richness and in the relative abundance of some bird species (Almeida, 2023). The increase of the relative abundance of rodents registered on camera traps was also noted, which may be due to the reduction in predation and the change in behavior, foraging patterns, and habitat use by rodents, as well as a higher influx of rats to the island. This increase was specially noted in the area of the boardwalk, which was also extensively used by cats, and people, and is in a close proximity to islets that can serve as a source population of rat incursion.

The installation of Goodnature traps on Barreta island can be a valuable tool for rodent control in certain areas, especially after cat removal, although its effectiveness is limited by the ease of rats reaching the island and their high abundance throughout the Ria Formosa. Due to the increase in rats near the boardwalk, 8 traps were installed in the area during the preparation of this report, in order to increase the effectiveness of the control around the Audouin's Gull's colonies closest to

areas with the greatest abundance of rats (Fig. 18). This improvement aimed to reduce 1) the number of rats that enter on the island from the shore line near the breeding colonies and 2) the number of rats that have already been established under the boardwalk that crosses the island. Also, with the recent changes and increase in size in Audouin's gull colonies, a better control of rats and reduction of their impacts is expected to be achieved with the new trap layout. Thus, periodic monitoring is needed in order to secure an effective and adaptive strategy to keep rats in low numbers.

Figure 18 | Location of the Goodnature traps used for control rat population and the location of the Audouin's gull colonies on Barreta Island. A higher number of traps were placed in the boardwalk area where the greatest abundance of rats was recorded.

The effectiveness of Goodnature traps can also be impacted by adverse weather conditions, with false triggers contributing to inaccuracies in estimating the number of kills. Also, even with regular monitoring, the number of killed rats may be underestimated given the scavenging of dead bodies by other species registered on Barreta island. In our case, we recorded active scavenging of dead bodies by Eurasian magpies and Yellow-legged gulls. Especial care should also be kept to the amount of unintentional captures of non-target species. Even with the design of the traps built to specifically target rodents, they can be triggered by non-target species, such as passerines, causing their death. In the case of Barreta island the capture of non-target species is more worrying due to the presence of a native rodent species, which triggers the traps and are often killed. At the moment this undesirable side effect is unavoidable without compromising rat control, although efforts were made to reduce impacts on the Algerian mouse population, such as placing traps at a higher height and with greater spacing between them. More, the 71 mice captured by Goodnature traps from February 2022 to June 2023 represent only 1 to 9 % of the Barreta population, which may not pose a serious threat to this population. While passerines were captured in even fewer numbers, 4 Eurasian magpies and 3 House sparrows, representing a negligible portion of the local populations (Equipa Atlas 2022).

A regular monitoring of the control measures is of greatly importance and should be included in the implementation of the biosecurity measures, especially to prevent the reintroduction of cats onto the island, and to evaluate the suitability of trap locations for rodent control. The monitoring of entry points and the enforcement of strict regulations can minimize the risk of reintroduction. It is also

recommended that the feral cat populations located in the surrounding areas, namely in Ancão Peninsula, should be closely monitored and managed in order to prevent future entries on Barreta Island.

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Annex

Annex A – Images of interactions of animals with the Goodnature traps, including rats, Eurasian magpies, Yellow-legged gulls, and Barn owls.


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