Black rat eradication on Italian islands: planning forward by looking backward

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Abstract Since 1999, the black rat (*Rattus rattus*) has been eradicated from 14 Italian islands, and eradication is ongoing on a further five islands. Most projects were funded by the European Union (EU) Life Programme. Over the years, eradication techniques have been improved and adapted to different situations, including aerial bait distribution on islands with large inaccessible areas, which otherwise would have relied on a manual bait distribution. A priority list of eradications on islands, which was compiled ten years ago, has been met to a large extent, as rats have been successfully eradicated from many islands of great importance to breeding seabirds. Despite some cases of re-invasion occurring in early projects, advances in biosecurity measures have allowed for eradications on islands where this was previously considered unfeasible due to a high risk of re-invasion. This paper reports on black rat eradication work performed on Italian Mediterranean islands with small villages. We show biodiversity benefits of these programmes, but also qualitatively address socio-economic and health impacts on local communities. Eradication projects have faced new obstacles, due to recent changes in legislation which complicated the application of rodenticides and made it very difficult to get permission for aerial distribution of bait on some of the priority islands.

Keywords: biosecurity, cost-effectiveness, invasive alien species, *Rattus rattus*, reinvasion, shearwaters

INTRODUCTION

In recent years, a growing awareness about the importance of the threat posed by alien species on native ecosystems has driven an increasing number of interventions aimed at eliminating or mitigating their impacts. Much of the effort to restore native ecosystems has been directed towards islands, which represent ideal environments for implementing eradication actions, because the impact of alien species may be especially important (e.g. Manne, et al., 1999; Baillie, et al., 2004), and their natural isolation helps to maintain the benefits achieved.

On Italian islands, measures to eradicate rats have had great success. Since the late 1990s, rats have been eradicated, or locally controlled on many islands (Capizzi, et al., 2016), with the EU Life programme providing important financial support, making it possible to achieve significant conservation objectives.

Rat eradications were carried out over the years on islands with different characteristics, and experience built up in selecting context-sensitive materials, techniques and strategies. Indeed, activities were carried out on islands small and large, uninhabited or with small residential areas, flat or with very rough terrain and with significant differences in the presence of non-target species.

Although there have been successes over the years, some mistakes have also been made. In our opinion, a critical review encompassing the activities so far carried out, along with the results achieved, can help to effectively plan future eradications.

In this paper, we review the rat eradication actions carried out in past years as well as those currently implemented, highlighting the progress, problems and constraints experienced so far, and analyse the strengths and weaknesses of the solutions adopted. Our aim is to show that a review of past experiences can have a positive influence on planning for future eradication attempts.

Evolution of techniques and targets

Priority list

Since resources for conservation actions are limited, priority setting is considered a key aspect in defining conservation strategies (Hughey, et al., 2003; Joseph, et al., 2009), including those involving invasive alien species management (e.g. Gallardo & Aldridge, 2013). Capizzi, et al. (2010) established a priority list of islands for rat eradication on Italian islands, considering the optimal allocation of available resources. This prioritisation considered the number of shearwater pairs and the monetary costs of rat eradication on each island, as well as the risk of reinvasion. To date, all the islands in the top five (and seven in the top ten) were included in eradication projects performed or still ongoing (Table 1). Furthermore, recent advances in biosecurity measures have allowed the carrying out or planning of eradications on islands that were previously not included on the priority list because of a high risk of reinvasion, such as Linosa (eradication ongoing) and Ventotene (eradication ongoing).

Island size

Since our eradication projects began, the number of rat free islands has increased considerably. This was possible due to increased experience and confirmation that these interventions bring substantial benefits to birds (see below).

The first eradications in 1999–2000 were carried out on islands of a few hectares (Table 2), but since 2005 rats have been eradicated from islands with an area of over 100 hectares (Zannone, Giannutri, Molara). Since 2012, islands with over 1,000 hectares have also been attempted (success declared in 2014 for Montecristo, ongoing actions on Tavolara and Pianosa).

Field techniques

Bait delivery

In the first eradication programmes, rodenticide baits were placed inside bait stations, at a relatively high density (about 10 stations/ha). In subsequent eradications, involving islands larger than 100 ha (i.e. Giannutri and Zannone, between 2005 and 2006), bait station density was reduced to an average of 4/ha. On Zannone, given its relatively rough terrain, bait distribution, in some inaccessible areas, was carried out by hand-broadcasting from a helicopter, using rodenticide bait blocks, which were secured inside biodegradable dispensers (sections

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Table 1 List of islands prioritised for rat eradication (from Capizzi, et al., 2010) and status of eradication interventions. Crosses indicate the presence of the two shearwater species on the various islands.

		Scopoli's shearwater (*Calonectris diomedea*)	Yelkouan shearwater (*Puffinus yelkouan*)	
1	Tavolara	X	X	Eradication planned in 2017
2	Palmarola	X	X	Eradication planned in 2018
3	Montecristo	X	X	Eradication in 2012
4	Pianosa Group (La Scola and Pianosa)	X		Eradication in La Scola (2000), and Pianosa (2017)
5	Giannutri	X	X	Eradication in 2005
6	Santa Maria Group (14 islands)	X	X	No action
7	Molara		X	Eradication in 2009
8	Zannone	X	X	Eradication in 2006
9	Spargi	X	X	No action
10	Soffi Group (four islands)	X		No action

of bamboo trunk). On larger, mainly inaccessible islands, aerial distribution was carried out on the whole island. Bait, in the form of pellets, was distributed using helicopters, with an automated distributor (bucket) purchased in 2008 and used by all projects since then.

Optimisation of active ingredients

In the first eradication projects (e.g. those in 1999–2000 on small islands), both bromadiolone and brodifacoum were used, regardless of the presence of non-target animals. In subsequent years, on larger (> 100 ha) islands (i.e. Giannutri, Zannone and Molara), we relied solely on brodifacoum, which was judged, on the basis of published data, to be the most effective and the most used active ingredient (e.g. Howald, et al., 2007; Buckle & Eason, 2015). However, when dealing with inhabited islands with pets (e.g. Linosa and Ventotene, where eradication is ongoing) and livestock (Pianosa, Tavolara), we chose to perform a two-stage bait distribution, with a different active ingredient. In the first phase (first two distributions), when rat populations were still at a high level, a bait containing an active ingredient less toxic for non-target species was used (e.g. bromadiolone or difenacoum, e.g. Capizzi & Santini, 2007; Buckle & Eason, 2015), thereby reducing the risks of secondary poisoning for animals that could eat dead or dying rats. The use of brodifacoum was limited to the last two applications (second phase), when the population of rats was expected to have been decimated by previous baiting campaigns, and therefore the risk of a poisoned rat (or mouse) being eaten by a non-target species was much lower.

Biosecurity issues

Rat reinvasion following an eradication programme is a real threat (Russell & Clout, 2005; Russell & Clout, 2007), wasting a great deal of time and monetary effort. In recent years, rats have reinvaded some of the islands where they had been previously eradicated (Table 3). Reinvasion occurred as rats swam from neighbouring islands or the mainland (maximum distance of reinvaded islands: 320 m, average distance: 218.6 ± 102.7 m). In the case of Molara, the hypothesis of an unsuccessful eradication was not supported by evidence, as genetic analyses have shown that the reinvading rats were different from the eradicated ones (Ragionieri, et al., 2013). The distance of Molara from other neighbouring islands and the mainland (1,400 m), plus the simultaneous appearance of rabbits, suggests that they have been transported by boat. However, recent progress in the understanding of biosecurity measures, i.e. a better understanding of rat swimming abilities as well as of effective quarantine measures (Russell, et al., 2008; Oppel, et al., 2011), allowed us to plan and complete eradication programmes on islands where there is a boat service and on islands with small villages. Therefore, in 2016, rat eradication was achieved on Linosa, which has a small village of about 500 people, and has just started (January 2018) on Ventotene, which has about 700 residents. If the Ventotene rat eradication is successful, it will be the largest inhabited island in the Mediterranean cleared of rats.

Ecological and socio-economic benefits

Benefits for shearwaters

The detrimental impact of rats on nesting shearwaters has been well documented on several islands, both oceanic and Mediterranean. In the Mediterranean, observed population declines of burrowing seabirds such as Scopoli's shearwater (*Calonectris diomedea*), yelkouan shearwater (*Puffinus yelkouan*), Balearic shearwater (*P. mauretanicus*) and storm petrel (*Hydrobates pelagicus*) was mainly attributed to alien predators, especially rats (e.g. Penloup, et al., 1997; Martin, et al., 2000; Igual, et al., 2006; Baccetti, et al., 2009). Detailed surveys on Italian islands (for survey methods see Baccetti, et al., 2009) corroborated the evidence, showing a large difference in terms of breeding success between islands with or without rats; the latter included both islands where rats had never been present and where they had been eradicated (Capizzi, et al., 2016, Fig. 1). Pooled data from both Scopoli's shearwater and yelkouan shearwater indicated that breeding pairs on islands without rats had much higher breeding success (0.78±0.17, n=15) than those breeding on islands with rats (0.14±0.25, n=11). Rat removal also affected the size of shearwater colonies. At La Scola, ten years after rat eradication, the colony of Scopoli's shearwater increased from 60–100 pairs in 2001 to 150–250 pairs in 2010. At Zannone, after rat eradication (2007) there was an increase in the Scopoli's shearwater colony from 27 pairs in 2007 to 80 pairs in 2016.

The completed rat eradications have rendered over 1,500 ha rat-free, and ongoing or planned projects will likely increase this surface area to 4,500 ha (Fig. 2). Currently,

Table 2 Summary table showing the Italian islands where rat eradication was completed in the period 1999–2017, and those where the intervention is scheduled in coming months, with details on the islands, the interventions and project details. Success (i.e. successful eradication) was established two years after the last sign of rats.

Year	Island	Region	Area (ha)	Distance (m)	Active ingredient	Bait method	Responsible (funding)	Outcome
1999	Isolotto di Porto Ercole	Tuscany	6.5	320	Bromadiolone, brodifacoum	bait station	National Park	successful, reinvaded
1999	Isola dei Topi	Tuscany	1.3	300	Bromadiolone, brodifacoum	bait station	National Park	successful, reinvaded
1999	Peraiola	Tuscany	1	30	Bromadiolone, brodifacoum	bait station	National Park	successful
1999	Palmaiola	Tuscany	7.2	2,950	Bromadiolone, brodifacoum	bait station	National Park	successful
1999	Gemini Alta	Tuscany	1.9	48	Bromadiolone, brodifacoum	bait station	National Park	successful, reinvaded
1999	Gemini Bassa	Tuscany	1.6	120	Bromadiolone, brodifacoum	bait station	National Park	successful, reinvaded
2001	La Scola	Tuscany	1.6	242	Bromadiolone, brodifacoum	bait station	National Park	successful, new incursions (3) promptly eradicated
2006	Giannutri	Tuscany	239.4	11,471	Brodifacoum	bait station	National Park	successful
2007	Zannone	Latium	104.7	5,700	Brodifacoum	bait station	Circeo National Park	successful
2008	Molara	Sardinia	347.9	1,400	Brodifacoum	aerial	MPA	successful, reinvaded in 2010
2008	Proratora	Sardinia	4.5	200	Brodifacoum	bait station	MPA	successful, immediately reinvaded, eradicated 2010, reinvaded in 2010
2010	Isola Piana	Sardinia	13.6	551	Brodifacoum	bait station	MPA	successful
2010	Isola dei Cavalli	Sardinia	2.2	300	Brodifacoum	bait station	MPA	successful, new incursions (2) promptly eradicated
2012	Montecristo	Tuscany	1071	29,410	Brodifacoum	aerial	National Park	successful
2016–2017	Linosa	Sicily	545.1	43,000	Difenacoum & brodifacoum	bait station	Sicily Region (LIFE)	to be confirmed
2017	Pianosa	Tuscany	1026	13,300	Bromadiolone & brodifacoum	bait station	National Park	to be confirmed
2017	Tavolara	Sardinia	602.0	1,150	Brodifacoum	aerial	Municipality of Olbia (LIFE)	started in autumn 2017
2018	Palmarola	Latium	125.1	7,300	Brodifacoum	bait station	Latium Region (LIFE)	started in January 2018
2018	Ventotene	Latium	143.6	43,000	Bromadiolone & brodifacoum	bait station	Latium Region (LIFE)	started in January 2018

Distance = from mainland or other islands in metres. National Park = National Park of Tuscan Archipelago (LIFE). MPA = Marine Protected Area of Tavolara – Punta Coda Cavallo

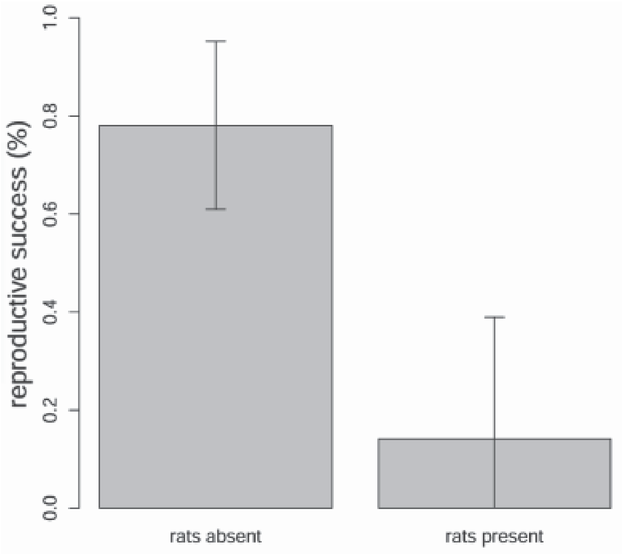

Fig. 1 Boxplot showing mean and standard deviation of breeding success (in terms of percent chick survival) of both shearwater species on Italian islands with (n=11) and without (n=15) rats.

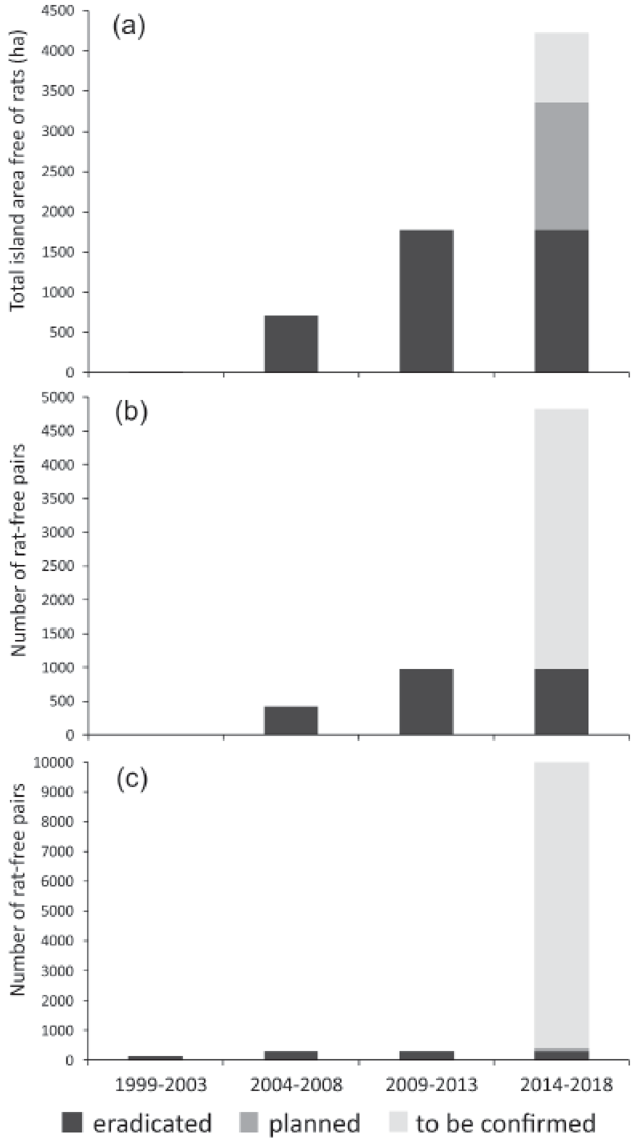

Fig. 2 Results of rat eradications on Italian islands in terms of pest free area and native species recovery since 1999 in five-year intervals a) total island surface area (ha) freed of rats, b) number of pairs of yelkouan shearwater (*Puffinus yelkouan*) and of c) Scopoli's shearwater (*Calonectris diomedea*) released from rat predation. The graphs also include eradications where the outcome is still to be confirmed, as well as those planned in the coming months.

15% of the Italian population of shearwater pairs (both *Calonectris diomedea* and *Puffinus yelkouan* computed as the geometric mean of minimum and maximum estimates, data from Baccetti, et al., 2009, updated when necessary) have been released from rat predation (Fig. 3). Increased benefits to the Italian population will occur with ongoing and planned eradications (i.e. Linosa for Scopoli's shearwater and Tavolara for yelkouan shearwater).

Socioeconomic and public health issues

Islands where rats have been eradicated are uninhabited or host just a few houses. Recently, the possibility of conducting rat eradication programmes on islands with small villages (Linosa, 500 residents, and Ventotene, 700) also provides significant socio-economic and health benefits for residents and tourists (see below). As an example, in Ventotene (120 ha, 700 inhabitants, rat eradication funded within Life PonDerat project), we ran a preliminary survey (performed through interviews to residents, which is still ongoing) to estimate the economic benefits when removing rats. First, in terms of prevented management costs, we estimated the current yearly quantity of rodenticides used to protect crops from rat damage at about 100 kg, corresponding to a yearly overall cost of about €5000. Also, the municipality runs its own pest control activities in public areas, hiring the service of a pest control company at an annual cost of about €3000. Second, rat eradication brings biodiversity benefits. As bait is generally used improperly, by using the most toxic active ingredients (usually brodifacoum) and by distributing baits indiscriminately, the risk to non-target species is apparent. Eradication would reduce these non-target effects. Third, direct damage costs are prevented because a certain amount of crop damage still occurs despite the current use of rodenticides which would also be prevented if rats were eradicated.

Lastly, rat eradication brings health benefits. For example, we recorded a 15.5% prevalence of *Leishmania infantum* in *Rattus rattus* from Montecristo, an island far from the mainland without carnivores (except the sporadic presence of dogs), leading us to identify rats as possible reservoirs and vectors of this protozoan (Zanet, et al., 2014). On inhabited islands (e.g. Ventotene and Linosa), it is likely that rat removal will bring health benefits by reducing the impact of rodent borne diseases, although social costs associated with rodent-borne diseases are difficult to quantify (e.g. World Bank, 2010). On Ventotene, the challenge is to obtain an overall estimate of the benefits of eradication, both ecological and socio-economic (García-Llorente, et al., 2008).

Therefore, the associated economic benefits should also be considered when evaluating the cost-effectiveness of these conservation efforts, as they may confer an added value that can help with public acceptance of this type of project.

Impact on non-target species

Conservationists, researchers and land managers can look pragmatically at the possible loss of individual non-target species, by comparing them with the increased benefits to native species and ecosystems (e.g. Ogden & Gilbert, 2009; Capizzi, et al., 2010; Gillespie & Bennett,

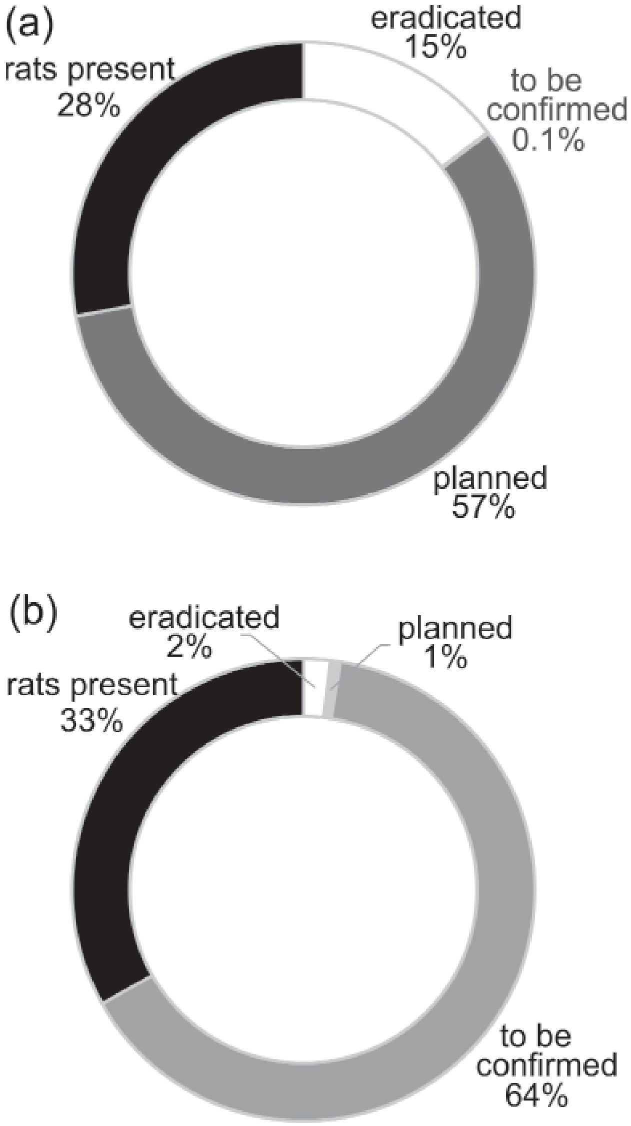

Fig. 3 Percentage of the Italian population of yelkouan shearwater (a) and Scopoli's shearwater (b) nesting pairs released from rat predation.

2017). However, minimal impacts on non-target species are often crucial to the acceptance of the project by the general public and are a significant factor in obtaining authorisation from public authorities. Indeed, much of the concerns of the public and public authorities were around the impact on non-target species, which has been demonstrated to be almost negligible (Capizzi, et al., 2016). In a few cases, the actual non-target impact involved species that, following rat removal, would have become extinct anyway, i.e. a few pairs of nocturnal raptors (barn owl, *Tyto alba*). We did not observe any impact on other rat predators, such as snakes (green whip snake, *Hierophis viridiflavus* and the asp viper, *Vipera aspis*), or birds of prey (kestrel, *Falco tinnunculus* and peregrine falcon, *Falco peregrinus*).

In most cases, populations of lizards (both *Podarcis sicula* and *P. muralis*) and native geckos have increased since rat eradication. The populations of wild or feral ungulates (mouflons and goats, in most cases alien species themselves) did not experience significant impacts, despite some losses of goats on Montecristo. Finally, no impact on pets (dogs and cats), poultry or livestock has been recorded so far.

Unsolved problems and lessons learnt

Authorisation and legal aspects

Limitations resulting from the application of EU Biocide Regulation 528/2012 represent a major obstacle to running eradication programmes, even though this Regulation explicitly accommodates a derogation on the use of rodenticides (Article 43), including aspects relating to the protection of the environment. Italian authorities interpreted the European regulation on biocides to mean that they should only be distributed inside bait stations, thus implicitly forbidding aerial distribution. This has led to legal disputes during the eradication on Montecristo, which were resolved but will cause problems for many eradications to come. For instance, the derogation for aerial distribution on Tavolara (which hosts the largest colony of *Puffinus yelkouan* in the world) was only obtained more than one year after the original request, thereby risking the loss of funding and compromising the outcome of the project.

Dealing with stakeholders

It is well known that communication and information aspects are very important in projects involving the suppression or removal of invasive species to favour native species or ecosystems (e.g. Larson, et al., 2011; Adriaens, et al., 2015). In the case of island communities, the main issue is that, if not properly communicated, actions may be perceived as an intrusion by outsiders. On-site meetings with island inhabitants do not always receive good feedback. In our experience, ensuring a constant presence in the area and establishing positive relationships with locals are paramount to raising public awareness on relevant conservation topics, as well as gaining project acceptance. Public approval is indeed a key factor for rat eradication success on islands (Epanchin-Niell, et al., 2010).

It is also vital to establish a constructive dialogue with port authorities and ship owners, to allow boats and harbours to be monitored, so that rats cannot be transported with the possibility of them being distributed across the island. This is especially important on islands served by regular ship visits, such as those hosting small villages (e.g. projects ongoing on Linosa and Ventotene).

Learning from failures

As mentioned above, the analysis of recolonisations following eradications has allowed us to conclude that islands closely neighbouring other rat-inhabited islands present a high risk of re-invasion after a successful eradication operation. The case of La Scola Island is representative, with three reinvasions in about fifteen years. The eradication of rats from the nearby (320 m) island of Pianosa will solve the problem permanently. Rat eradication on Molara represents a different case of reinvasion. The island was reinvaded a few months after an apparently successful rat eradication, but invading rats were genetically different from the eradicated rats (Ragionieri, et al., 2013). We strongly suspect that this recolonisation event represents a case of sabotage, possibly caused by the hostility of some people towards the project: the simultaneous appearance of rabbits on the island corroborated this hypothesis. This confirms the importance of properly addressing community opinions (Genovesi & Bertolino, 2001) and trying to highlight critical issues that may otherwise compromise the outcome of the project. To avoid the voluntary release of rats on rat-free islands, it is crucial to implement long term biosecurity and provide the necessary human resources for continuous awareness-raising.

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