Rat and lagomorph eradication on two large islands of central Mediterranean: differences in island morphology and consequences on methods, problems and targets

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Abstract Montecristo and Pianosa islands, although approximately equal in surface area (c. 1,000 ha), differ greatly in substrate, human presence, vegetation and altitude (650 m vs. 30 m asl, respectively). The former island hosts one of the largest yelkouan shearwater (*Puffinus yelkouan*) populations in Italy, the latter a depleted remnant of once numerous Scopoli's shearwaters (*Calonectris diomedea*). Two consecutive EU-funded LIFE projects have been designed to protect these seabird populations. On Montecristo, rough and inaccessible, aerial delivery of toxic baits in January-February 2012 eradicated black rats (*Rattus rattus*) and feral rabbits (*Oryctolagus cuniculus*) (originally a non-target species), with no permanent consequences on a local, ancient population of wild goats (*Capra hircus*). Eradication on Pianosa, currently underway (started January 2017), is being performed by ground baiting, delivered by 4,750 dispensers placed on a 50 m × 50 m grid throughout the island. The latter operation is included in a multi-species eradication aimed at several other target species, among which was the brown hare (*Lepus europaeus*), apparently introduced around 1840. Genetic analyses on the first trapped hares showed that this was the last uncontaminated and viable population of *L. europaeus* subsp. *meridiei* in existence. Whether of natural origin or introduced, the commencement of eradication of this population has instead created the awareness of a taxon otherwise unavailable for conservation elsewhere. While both projects address the same conservation issues (protection of shearwater colonies and restoration of natural communities), they differ greatly regarding economic cost, public perception, effort needed to maintain results in the long term and effects on non-target species. In the present paper, specific attention has been paid to the comparison between bait delivering techniques, results obtained, the array of problems originating from the complex regulatory framework and reactions by the general public.

Keywords *Capra hircus, Lepus europaeus meridiei*, Montecristo, *Oryctolagus cuniculus,* Pianosa, *Rattus rattus,* Tuscan Archipelago

INTRODUCTION

We present here two eradications of invasive mammals carried out on Mediterranean islands, directly concerning black rat (*Rattus rattus*), but also affecting two species of lagomorphs (feral rabbit (*Oryctolagus cuniculus*) and brown hare (*Lepus europaeus*)) and the wild goat (*Capra hircus*) (Table 1). These actions are part of a comprehensive recovery programme of nesting areas of seabirds in the Italian islands (Capizzi, et al., 2016). The two islands concerned, Montecristo and Pianosa, belong to the Tuscan Archipelago National Park and are almost equal in size but very different in morphology, vegetation, fauna and human presence. These differences influenced the eradication approaches.

Montecristo is a 1,080 ha island located in the central northern Mediterranean Sea, in an intermediate position between Corsica and the Italian Peninsula (Fig. 1), with a rugged topography and a maximum altitude of 650 m. It is uninhabited, and access is strictly limited. There are very few trails and no roads. As a consequence, the only realistic method to eradicate rats was the aerial distribution of bait. The main conservation target here was the yelkouan shearwater (*Puffinus yelkouan*), with 400–750 breeding pairs whose reproductive success was heavily affected by predation on eggs and chicks by the black rat (Baccetti, et al., 2009). A population of feral rabbits was also present. Given the bait distribution technique chosen, the eradication of this species was considered possible, although unlikely, and was not declared as a project target. The species considered at risk of unwanted mortality (Table 1) by direct consumption of baits (<http://www.montecristo2010.it>) were mainly the yellow-legged gull (*Larus michahellis*) and Montecristo wild goat. The latter was introduced on the island in pre-Roman times from founders that were still at a very early stage of domestication (or just tamed). The species' historical origin, together with its current uniqueness in the western Mediterranean, motivated its role as a flagship species and led to the founding of Montecristo State Nature Reserve in the early 1970s. The cultural/historical value of this peculiar population makes it deserving of appropriate conservation efforts (Gotti, et al., 2014).

Pianosa is a 1,040 ha island, that is entirely flat (< 30 m altitude), 30 km NW of Montecristo (Fig. 1) with a

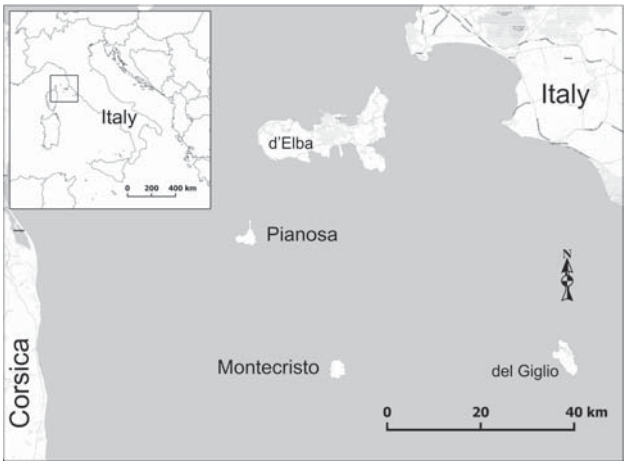


Fig. 1 Location of Montecristo and Pianosa islands.

small village and some scattered (and usually abandoned) settlements. It was occupied as a prison until 1998, making it inaccessible even for researchers during that time. Currently it is permanently inhabited by 20–30 detainees with two–three guards and it is open to guided tours with a daily limitation of 330 visitors. The extensive road network is maintained in reasonably good condition; vegetation is relatively accessible, especially on formerly cultivated areas (roughly half of the island). The main conservation target is Scopoli's shearwater (*Calonectris diomedea*), threatened by black rat predation on eggs and chicks (Table 1), consisting of 30–50 nesting pairs on Pianosa and 150–250 on La Scola, a satellite islet located 240 m to the east of Pianosa (Capizzi, et al., 2016). Rats were removed from La Scola, only 1.6 ha in size, in 2001; however, the short distance from the main island allows periodical rat incursions (three in the period 2001–2011, by single individuals), which till now have been successfully eliminated (Capizzi, et al., 2016) by a set of bait stations permanently installed and refilled when necessary.

Black rat eradication on Pianosa is part of a multi-species eradication programme aimed at the restoration of the native animal community <(http://www.restoconlife.eu/en>), which originally included the removal of the brown hare (*Lepus europaeus*). The house mouse (*Mus musculus*) is widespread on the island and is not an explicit eradication target of the project (Table 1), due to the spacing of the bait stations chosen for an island of the size of Pianosa and for the primary target species. The existence of permanent settlements, the presence of tourists during the summer and the occurrence of several non-target species, together with legal constraints on distribution methods, forced the choice of a ground-based eradication. Diurnal raptors, owls, yellow-legged gulls and hooded crows (*Corvus cornix*) and finally some domestic cats (*Felis catus*) are among the non-target species potentially threatened by the operation (Table 1). For non-domesticated feral cats living in the wild another specific eradication action has been conducted.

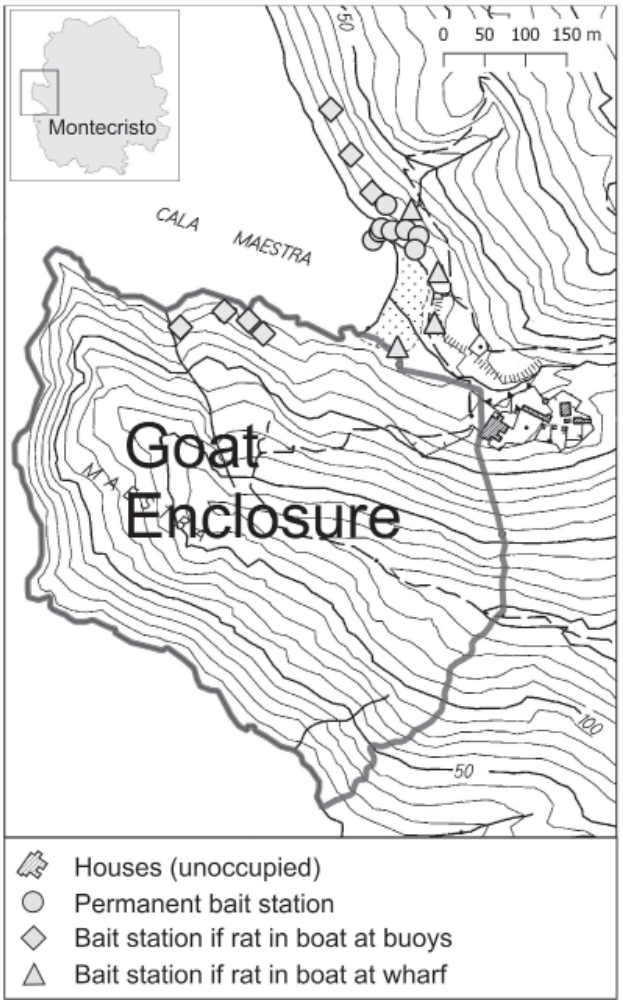


Fig. 2 Location of the goat enclosure, houses, and bait stations involved in the Montecristo biosecurity plan.

METHODS AND RESULTS

Rodent eradications

On Montecristo the first aerial baiting was conducted on 8 and 9 January 2012, with a pellet density of 10 kg/ha on the ground. The baits consisted of 2 g cereal (Brocum®, 0.005% brodifacoum as active ingredient, produced by Colkim Ltd).

A 30 ha area was excluded from the aerial drop (Fig. 2). This included unoccupied human dwellings, and an enclosure of about 25 ha, where 44 wild goats (at least 24% of the population size, assessed through direct counts, the rest having remained free) were kept to ensure survival of the population. This area was treated either by bait stations in the goat enclosure hand-broadcast of pellets outside the goat enclosure. Wax blocks (Solo Blocs®, 0.005% brodifacoum as the active ingredient, produced by Bell Ltd) were installed in the bait-stations.

The aerial distribution was originally planned along parallel transects, 50 m apart, to obtain a roughly complete overlap between parallel transects. However, the pilot had difficulties flying along such predefined routes without veering significantly from the flight line, as the geographic positioning system (GPS) based guidance system malfunctioned and caused frequent interruptions of the baiting. We changed our plans and opted in favour of baiting along two different sets of 100 m wide parallel flight lines, at right angles to each other. This would allow a greater tolerance for the helicopter's distance from the scheduled flight-lines and smaller areas without overlap. We then covered the coast and endeavoured to cover obvious gaps (Fig. 3). The second distribution of baits was initially expected to occur two weeks later, but the exceptionally dry weather that allowed pellets to persist on the ground in good shape and adequate amounts, made it unnecessary for a much longer time. The second baiting was done 45 days after the first delivery, covering 110 ha only, corresponding to the most critical areas: the coastline, a buffer zone around the excluded areas and an area where the first distribution appeared to have been less than optimal. The bait density was lower than in the first

Table 1 Species involved in the Montecristo and Pianosa rat eradication projects. Among non-target species, strong negative impacts on local populations have been recorded on Montecristo for the breeding pair of *Corvus corax* (with permanent reoccupation of the site in 2015–2016) and on Pianosa for *Tyto alba*.

Island	Conservation target species	Invasive species	Invasive non target species	Non target species
Montecristo	*Puffinus yelkouan*	*Rattus rattus*	*Oryctolagus cuniculus*	*Larus michahellis, Capra hircus, Corvus corax*
Pianosa	*Calonectris diomedea*	*Rattus rattus*	*Mus musculus*	*Larus michahellis, Corvus cornix,* owls, diurnal raptors

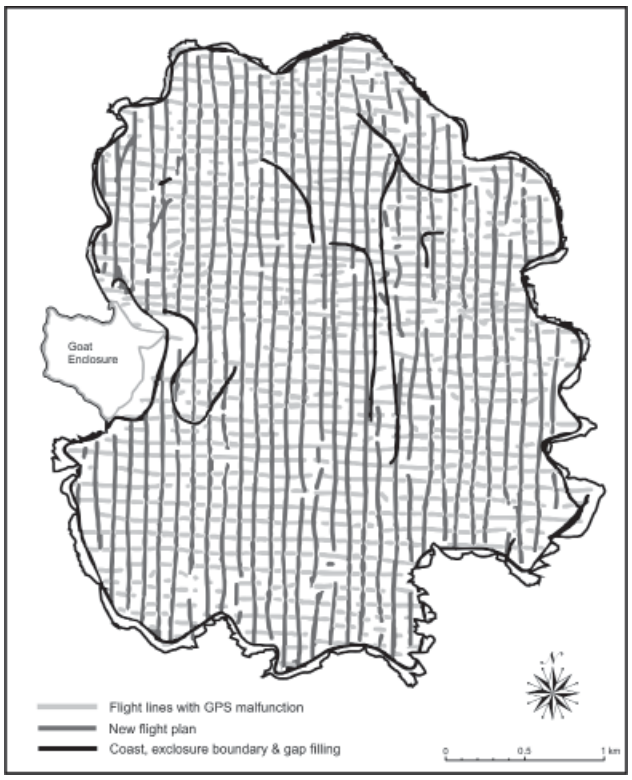
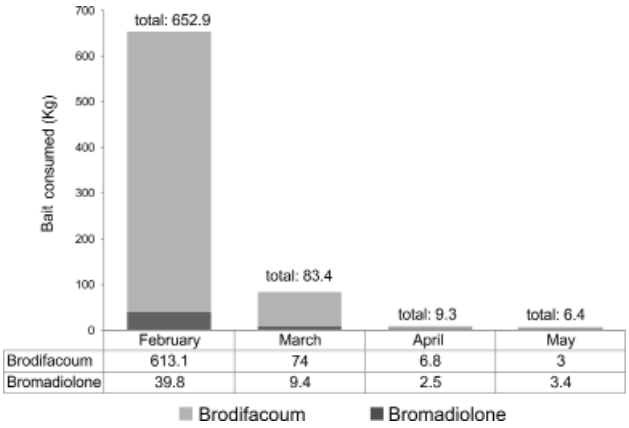


Fig. 3 Helicopter flight lines during the first bait drop.

distribution, i.e. 4 kg/ha on the ground. The eradication was successful, as the last sign of rats was detected 15 days after the first distribution (Sposimo, 2014). The cost of the whole operation, excluding preliminary analyses, planning and devices for protection of goats, was €226,800 (US $280,000).

On Pianosa Island, the eradication took place via ground-baiting with second generation anticoagulants inside bait-stations, placed at the nodes of a 50 m × 50 m grid covering the entire island. Bait density was doubled along the coastline and in urban areas, in consideration of locally higher rat densities. Approximately 4,750 bait-stations were deployed in January 2017, then checked and refilled monthly until May 2017. The percentage of consumed baits and/or any sign of rats were recorded. Bait stations were retrieved in October 2017. The bait consisted of wax-blocs with brodifacoum (Solo Blocs®, 200 or 20 g), except in the area occupied by human settlements where it was replaced by wax-blocks with 0.005% bromadiolone (Notrac Blox®, 225 or 28 g, produced by Bell Ltd) during the first and second baiting events, to reduce the risk of secondary poisoning of domestic animals (Buckle & Smith, 2015).

Rates of bait consumption are detailed in Fig. 4. After the initial and very high rate of bait consumption, the rate decreased by one order of magnitude during each of the two successive sessions; low and steady final values were assumed to be mainly due to house mice and invertebrates. In May, only one credible sign of black rat was found across the entire island, but the success of the eradication has to be confirmed by the implementation of monitoring activities that are still ongoing; the presence of house mouse was detected in nine bait-stations, suggesting that eradication of this species, as expected, is unlikely. This result would be consistent with other evidence of house mice being more difficult to eradicate than *Rattus* species (MacKay, et al., 2007), because of smaller home-range size that allows the survival of some individuals in bait-free areas between 50 m spacing of stations. The cost of the eradication, excluding preliminary analyses and planning, was €477,600 (US $590,351).



	February	March	April	May
Brodifacoum	613.1	74	6.8	3
Bromadiolone	39.8	9.4	2.5	3.4

Fig. 4 Bait consumption on Pianosa during the first four sessions.

Lagomorphs

Feral rabbit: the aerial delivery of rat bait took place on Montecristo during mid-winter, when feral rabbits appear to be in the most critical annual phase and when local decreases in the population had been observed. Nevertheless, the presence of a 25 ha fenced area where the bait distribution had been implemented with bait-stations inaccessible to rabbits, and the lack of any specific effort to cull surviving rabbits (Murphy, et al., 2010), made the eradication of this species quite unlikely. Nonetheless, rabbits do seem to have been eradicated, probably due to the rabbit-permeable fencing of the goat enclosure and unusually long duration of pellets outside it, because of the dry weather. After the bait delivery of February 2012 there was just a single observation of rabbits (an adult with young) in April 2014. Traps were immediately set in the observation area without any result. The lack of any further finding of individuals or sign more than three years later makes it unlikely that any survivors might still be present on the island. Despite the lack of any specific monitoring, rabbits would not have escaped detection in the surroundings of the fenced gardens, where full time employed wardens are present, or along the transects regularly covered for goat counts.

Brown hare: the Pianosa multi-species eradication programme originally included netting and shooting brown hares, which had likely been introduced on the island for hunting purposes as early as 1840. Tissue and blood samples obtained from 35 individuals netted at the beginning of the operation, or shot with hunter-dog teams, were collected and genetically analysed, leading to the unpredicted result that the Pianosa brown hare population represented the last uncontaminated and viable population of *Lepus europaeus meridiei*, a subspecies once distributed in central and northern Italy, believed to be extinct due to genotype contamination with exotic hares massively imported in Italy for hunting (Mengoni, et al., 2018). Pianosa's insular status, habitats, and past restricted access due to the prison have resulted in maintaining a viable and representative stock of high conservation value. The number of individuals captured and culled in early 2016 had no consequence on the population size after one to two breeding seasons.

Biosecurity

Reinvasion risk varies greatly between the two islands, because of the different human presence and accessibility (Russell, et al., 2008b). On Montecristo an incoming rat would likely follow a single pathway covering the small area of the wharf and buoys. After the eradication, a biosecurity interception system was set up consisting of 15 bait stations placed all around the entry point at the landing

bay. We experimentally tested the effectiveness of this system in December 2016, releasing 14 black rats, all adult males, equipped with VHF transmitters. Animals were released on the pier individually, over 19 hours, simulating a reinvasion event. Each bait station was armed with a lethal snap-trap. Individuals were tracked for 65 hours. Twelve individuals were intercepted by a bait station, the majority (10) within 20 m from the release point, while one disappeared shortly after release (and is suspected of dying from hypothermia after having been observed swimming) and the last one escaped the interception system to hide in a stone wall 100 m inland from the wharf. The average time between release and capture was 3.4 h, which is very short if compared with the results of similar experiments on brown rats (Russell, et al., 2008a). The biosecurity system was modified after these results and organised in three sub-systems (Fig. 2): one permanently active (eight bait-stations), concentrated in the vicinity of the wharf, and two more to be activated in case of potentially rat-infested boats docking at the wharf or buoys. A plan for contingency response has been set-up as well.

Biosecurity measures to be implemented in Pianosa, beginning in October 2017, are directed both towards ferries, to reduce the presence of rodents on board, and towards the implementation of an island-based interception system, roughly following Montecristo's scheme. In the likely case of an unsuccessful mouse eradication, the land system will require a more frequent bait replenishment, together with a permanent mouse-control strategy in the harbour area.

Effects on conservation targets

The effects of the Montecristo eradication on its conservation target species are shown in Table 2, where a dramatic increase in breeding success of yelkouan shearwater has taken place since the year of the bait delivery (2012), whereas breeding performance of Scopoli's shearwater on Pianosa has constantly remained poor. Evidence of new breeding sites, including nest boxes, being occupied by yelkouan shearwaters on Montecristo since 2012 is available, but an increase of nest density or population size remains to be quantified as of yet. A number of benefits were recorded on non-target avian species, such as minor increases of breeding scops owl (*Otus scops*) and European nightjar (*Caprimulgus europaeus*), and an obvious increase of sedentary and alien chukar partridges (*Alectoris chukar*).

Effects on non-target species

Thorough searches for gull and goat corpses were repeatedly carried out on Montecristo from one to four months after bait delivery, where gull casualties were recorded for at least a four month period. On Pianosa, the operators who checked bait-stations every month collected all corpses they found. Standardised counts were performed on both islands to assess any negative effects on non-target populations. Deaths recorded on Montecristo only occurred for two species, the wild goat (n=35) and yellow-legged gull (n=891), while the local pair of common raven (*Corvus corax*) was no longer observed, indicating presumed extirpation. Ravens permanently reoccupied the site only in 2015–16. Annual monitoring of the Montecristo goat population by distance sampling methods showed a temporal decrease of approximately 30–40% in the summer following the aerial treatment, while counts performed in all subsequent years attested to a fast recovery of the population to the pre-eradication level. On the contrary, yellow-legged gulls dropped from 1,036–1,833 breeding pairs in the two years before baits were delivered to 591 in 2012, 292 in 2013, with a steady, slight increase in all following years, up to 499 in 2017.

On Pianosa the impact of rodenticide indirectly consumed by native predators was more diverse, more concentrated in time, but less thoroughly recorded: findings of fresh corpses ceased around mid-March 2017 and included nocturnal raptors of two species (eight individuals), diurnal raptors of three species (seven individuals) and at least three hooded crows; no gulls were affected. Effects on native populations at Pianosa seem to be limited to the expected extirpation of breeding barn owls (*Tyto alba*).

Table 2 Breeding success of the two conservation target species on Montecristo (black rats eradicated 2012) and Pianosa (treated 2017, first rat free season still in progress).

	Montecristo target: *Puffinus yelkouan*		**Pianosa target: *Calonectris diomedea***	
Year	No. nests	Reprod. success	No. nests	Reprod. success
2010	18	0.06	-	-
2011	-	-	-	-
2012	19	0.96	6	0.17
2013	28	0.93	-	-
2014	27	0.78	16	0.19
2015	26	0.80	19	0.16
2016	35	0.80	17	0.12

DISCUSSION

Black rats have been successfully eradicated on Montecristo and Pianosa seems to be on a similar trajectory, thanks to two projects performed with radically different techniques.

In order to maintain these achievements – and investments – in the long term, different efforts are needed. Biosecurity measures are relatively simple for Montecristo, as long as the current management of access is allowed. A field test has shown that currently adopted measures are adequate, suggesting minor adjustments enabling a slight reduction of effort needed for their maintenance.

Reinvasion risk is significantly higher for Pianosa, this island being affected by a permanent, yet currently moderate, flow of supplies and visitors, that could strongly increase in the near future due to already planned restoration of many buildings. This, together with the probable survival of the house mouse, results in the need for more complex and costly (due to bait consumption by mice) biosecurity measures. Risks for native species and the insular ecosystem deriving from a house mouse increase following black rat eradication was considered to be low, due to the presence of several species of specialised or generalist predators of rodents (three breeding species of owls and one of snake).

The unexpected disappearance of rabbits from Montecristo can likely be related to timing of the operations, that coincided with seasonal lows of the population, and to random factors such as a very unusual and prolonged drought for the season (January–April rainfall of 34.6 mm in 2012, vs. an average of 112.1 mm in the same period for the previous five years), which allowed longer bait persistence and possibly impacted rabbits more strongly. Similarly, unexpected results for different reasons were obtained in the case of the Pianosa brown hare, representing a taxon believed to be extinct and, thus, deserving appropriate management in future.

Effects on conservation target species were, and are expected to be, very positive. Although this is easily understandable – and already evident for Montecristo

yelkouan shearwaters, based on the resulting local population size and productivity – in the case of Pianosa, for Scopoli's shearwaters a full evaluation should include: i) the huge potential for breeding sites, most of them currently unused by the depleted breeding stock; and ii) the effortless maintenance of permanently rat-free conditions on adjacent La Scola islet, where a large Scopoli's shearwater colony is already present. Moreover, since Pianosa is almost devoid of burrowing seabirds at present, but has suitable breeding sites, its value in the future attraction of species that are currently absent (e.g. yelkouan shearwaters from nearby Montecristo and Mediterranean storm petrel [*Hydrobates pelagicus melitensis*]) might even exceed its importance for Scopoli's shearwater.

Consequences on non-target species have varied greatly, depending on bait deployment methods, geo-morphological features and faunal composition of the two islands. Non-target mortality of Montecristo goats did not prevent the recovery of the population to its initial level in a few years and, after the aerial treatments, the widespread presence of goats did not limit the availability of baits for rats. The presence of the large enclosure to protect some goats and prevent population extirpation has to be considered as a prudent measure to ensure the long-term persistence of this valuable population. However, it posed a risk to the success of the rat eradication and demanded an alternative approach (bait delivery inside bait-stations).

The higher mortality of diurnal and nocturnal raptors observed on Pianosa (and probably underestimated) can be attributed to several factors: 1) their greater abundance, 2) the presence of house mice that are preyed upon by small-sized raptors that do not feed ordinarily on rats, and 3) possibly also the delivery of poison through bait stations, that may allow rodents to consume a much higher amount of poison than during an aerial distribution. The most striking difference between the casualties of the two projects was the massive impact of the aerial treatment on the yellow-legged gulls, compared to the absence of any effect on this species in the bait station-based operation. Losses could have been minimised with an aerial delivery planned earlier in the season, when fewer birds are on the breeding sites. Nevertheless, even these losses – of a human-dependent and super-abundant species – are negligible compared to the benefits achieved. A slightly earlier seasonal planning, however, has to be recommended in consideration of possible public reactions to the issue of gull mortality, which was a population decrease lasting more than one year following the operation's conclusion. Losses of barn owls on Pianosa, and their probable (albeit possibly only temporary) extirpation, represent possibly the highest biological cost of the programme.

Both projects triggered negative reactions from the public, particularly harsh towards the Montecristo eradication. Evidently, aerial baiting was perceived as a more threatening method by non-experts. Thus, projects planning to use this technique should employ greater communication efforts at different levels. The strategy for communicating with the public, structured as in many other LIFE projects (e.g. via a dedicated website) was clearly ineffective, despite the projects being on islands lacking human populations which should have restricted the potential audience. People from nearby towns on the coast or from nearby Elba Island were often unresponsive to any outreach efforts and usually exploited debated topics in favour of other agendas, such as anti-Park personal positions, or criticising the 'waste' of money (Baccetti, et al., 2016). Ambiguity of national regulations in force during the Montecristo eradication led to legal actions being taken against project managers, but were finally positively concluded for the defendants. Currently, the EU Biocide Regulation 528/2012 clarifies the situation, but the possibility to carry out aerial baiting remains undefined, depending on specific authorisations issued by nationally competent authorities.

Aerial baiting has allowed the black rat to be eradicated from an island primarily relevant for Mediterranean seabird conservation that could not be otherwise treated with traditional ground-based methods. Tangible drawbacks are not larger than those observed during a comparable operation implemented by a bait station distribution, while the economic cost was certainly lower. Nevertheless, at present, the opportunity to carry out similar operations is extremely uncertain in Italy, as well as across the rest of the EU.

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