Fifteen Years of Rat Eradication on Italian Islands

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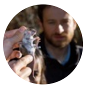

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Chapter 10
Fifteen Years of Rat Eradication on Italian Islands

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Background

Island ecosystems are especially prone to the negative consequences of alien species introductions (e.g. Manne et al. 1999; Baillie et al. 2004). Rats are known to be among the worst invaders of island ecosystems, being responsible for a variety of impacts, ranging from predation upon seabirds at all life stages including eggs, nestlings and adults (Jones et al. 2008), and of a large range of other vertebrate (i.e. mammals and reptiles, e.g. see Harris 2009; Whitaker 1978), invertebrate (St. Clair 2011; Towns et al. 2009) and plant taxa (Palmer and Pons 2001), and also affecting also ecosystem functions (Towns et al. 2006). Global evidence, including from Mediterranean islands (Traveset et al. 2009), where the observed population decline of burrowing seabirds (i.e. Cory's shearwater *Calonectris diomedea*, Yelkouan shearwater *Puffinus yelkouan*, Balearic shearwater *Puffinus mauretanicus*, storm petrel *Hydrobates pelagicus*) was mainly attributed to alien predators, especially rats (e.g. Thibault 1995; Penloup et al. 1997; Martin et al. 2000; Igual et al. 2006; Baccetti et al. 2009; Ruffino et al. 2009).

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Due to their high reproductive potential and opportunism in exploiting a wide range of food sources (Macdonald and Fenn 1994; Varnham 2010), as well as to the lack of predators, competitors, parasites and diseases, rats have spread with great success on island ecosystems all over the world. The black rat (*Rattus rattus*) spread throughout the western Mediterranean basin about 2000 years ago (Ruffino et al. 2009), although recent studies highlighted that current population may have originated from a single recent colonization event (Colangelo et al. 2015). However, the black rat is perhaps the most widespread mammal on Mediterranean islands (Amori 1993; Sarà 1998). In Italy, for example, it is present on about 80 % of the islands, being absent only on small or very isolated ones (Baccetti et al. 2009).

When feasible, eradication is judged as the ideal tool to manage invasive species (e.g. Myers et al. 2000; Veitch et al. 2011). Bomford and O'Brien (1995) defined eradication as "the complete and permanent removal of all wild populations from a defined area by a time-limited campaign" (p. 249). They also listed six criteria to be met for a successful eradication campaign, three of them being essential: (1) rate of removal exceeds rate of increase; (2) immigration prevented and (3) all reproductive animals must be at risk.

With regard to the second criterion, natural isolation makes islands ideal places for implementing eradication programmes, and in last decades considerable efforts have been made in order to eradicate rats (mostly brown, black and pacific rat) from islands all over the world (e.g. Howald et al. 2007; Genovesi and Carnevali 2011; Capizzi et al. 2014). In order to eliminate or mitigate the detrimental impacts of the black rat on native ecosystems in Italy, several restoration projects were implemented over the last 15 years on Italian islands. Although multiple rodent species may be present on Mediterranean islands (e.g. house mouse *Mus musculus* and brown rat *Rattus norvegicus*) and an eradication programme have sometimes been carried out against these species (e.g. see for *R. norvegicus* V. Di Dio, unpubl. data, for *M. musculus* Baccetti and Sposimo, unpubl. data), the focus of this chapter is on the black rat, as it is believed to be the most detrimental to seabirds more widespread (Amori 1993; Sarà 1998). Over the last 15 years, a large amount of data were collected focusing on aspects of rat ecology, impacts of rat predation on native species (i.e. seabirds), the monetary costs of implementing rat eradication or control and the impact of these projects on non-target species. In this chapter, we summarize the most applicable results, highlighting future research and management priorities in an attempt to fill the knowledge gap about several aspects of rat presence, impact and management on Mediterranean islands. Despite the wide distribution and long presence of black rats, detailed information on their ecology and their impacts on island ecosystems have been, until recently, largely unavailable for Mediterranean islands. Furthermore, the outcome of rat eradication projects—both positive and negative—can provide valuable lessons for future projects.

Field Techniques for Rat Eradication

Since 2000, rat eradication has been carried out on 14 islands (Fig. 10.1), using two different techniques, bait stations or broadcast (hand or aerial), either exclusively or in combination with each other (Table 10.1). The first technique consisted in of securing extruded bait blocks inside bait stations (Thomas and Taylor 2002), i.e. plastic boxes fixed to a shrub, tree or other substratum, with the dual purpose of protecting bait from environmental conditions and from consumption by non-target animals (e.g. mouflons, wild goats, rabbits, seagulls, ravens). The second technique was the aerial distribution of pelleted bait by helicopter (Broome et al. 2014). Pelleted bait rapidly degraded after exposure to moisture and rain. Hand broadcast of pellets as secondary method was used only on limited sectors of islands to reinforce application of the other methods.

The first rat eradication projects (Perfetti et al. 2001) were carried out using bait stations, at an approximate density of about 10 bait stations/ha (distance apart of about 30 m), which has limited utility to small islands. Bait formulations included durable extruded bait blocks containing Brodifacoum or Bromadiolone as active ingredients (concentration: 50 ppm; trade names: Solo® Blox, Notrac® Blox, Bell Laboratories).

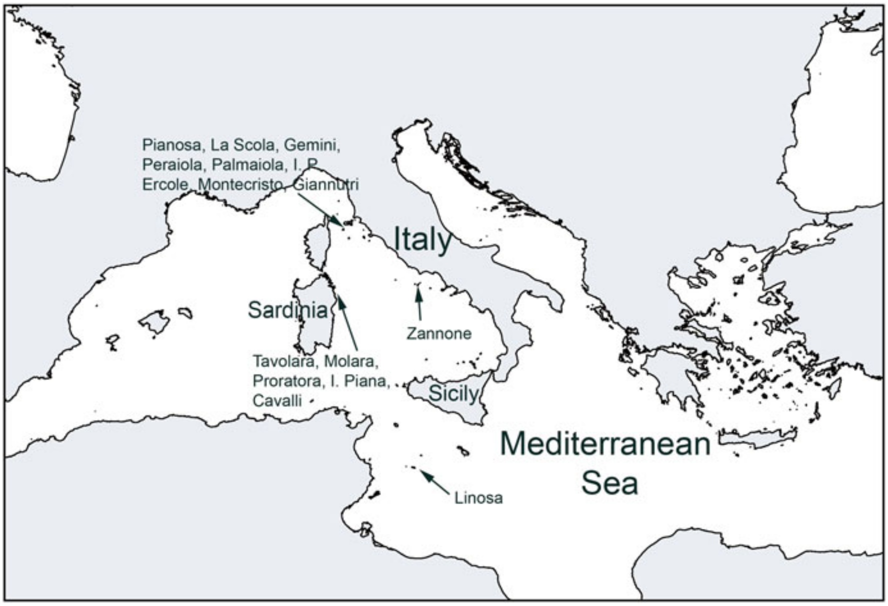


Fig. 10.1 Map showing the geographic position of the islands mentioned in the text

Table 10.1 Italian islands where rat eradication was carried out from 1999 to 2012

Year	Island	Region	Area (ha)	Distance from mainland or other islands	Active ingredient	Bait distribution	Responsible (funding)	Outcome
1999	Isolotto di Porto Ercole	Tuscany	6.5	320	Bromadiolone, brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful, reinvaded
1999	Isola dei Topi	Tuscany	1.3	300	Bromadiolone, Brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful, reinvaded
1999	Peraiola	Tuscany	1	30	Bromadiolone, Brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful
1999	Palmaiola	Tuscany	7.2	2950	Bromadiolone, Brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful
1999	Gemini Alta	Tuscany	1.9	48	Bromadiolone, Brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful, reinvaded
1999	Gemini Bassa	Tuscany	1.6	120	Bromadiolone, Brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful, reinvaded
2001	La Scola	Tuscany	1.6	242	Bromadiolone, Brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful, new incursions (3) promptly eradicated
2006	Giannutri	Tuscany	239.4	11,471	Brodifacoum	Bait station	National Park of Tuscan Archipelago (LIFE)	Successful
2007	Zannone	Latium	104.7	5700	Brodifacoum	Bait station	Circeo National Park	Successful
2008	Molara	Sardinia	347.9	1400	Brodifacoum	Aerial	Marine Protected Area of Tavolara—Punta Coda Cavallo	Successful, reinvaded in 2010
2008	Proratora	Sardinia	4.5	200	Brodifacoum	Bait station	Marine Protected Area of Tavolara—Punta Coda Cavallo	Successful, immediately reinvaded, eradicated 2010, reinvaded in 2010
2010	Isola Piana	Sardinia	13.6	551	Brodifacoum	Bait station	Marine Protected Area of Tavolara—Punta Coda Cavallo	Successful
2010	Isola dei Cavalli	Sardinia	2.2	300	Brodifacoum	Bait station	Marine Protected Area of Tavolara—Punta Coda Cavallo	Successful, new incursions (2) promptly eradicated
2012	Montecristo	Tuscany	1071.7	29,410	Brodifacoum	Aerial	National Park of Tuscan Archipelago (LIFE)	To be confirmed

The active ingredient, the bait administration method and the final outcome are, respectively, indicated in the last three columns

By the mid-2000s (2006–2007) projects aimed at eradicating rats from much larger islands were a focus on conservation efforts (i.e. Giannutri and Zannone, respectively, 239 and 104 ha: see Sposimo et al. 2008; Francescato et al. 2010). In these projects, a more precise calibration of bait station density and bait application rates were facilitated by specific studies on rat relative abundance in different habitat types. Extruded blocks containing Brodifacoum (concentration: 50 ppm; trade name: Solo® Blox) was used exclusively by securing in bait stations to prevent the removal of the bait. Bait station placement was four per hectare (distance apart of 50 m), and each station monitored for bait uptake during each visit. Overall, bait was applied on four different occasions, using a pulsed baiting technique (Dubock 1984; Buckle 1994). On the largest island (Giannutri, size ha 239; about 950 bait stations), we set out bait at rate of ~2.4 kg per ha, followed after 15 days by a second administration of about 2.4 kg per ha, with a third and a fourth administration of 1.2 kg per ha each. The total amount of bait administrated was 7.2 kg. Not unexpectedly, not all bait was exclusively consumed by rodents, but also by invertebrates and snails. Residual bait in the stations was replaced at each pulse event.

On the larger, more rugged islands of Molara (2008: Sposimo et al. 2012) and Montecristo (2012: Sposimo 2014) with foot inaccessible areas, such as steep areas or cliffs, bait was delivered by broadcast buckets suspended under a helicopter, and bait stations were used sporadically.

Two applications by aerial broadcast of pellets containing 50 ppm Brodifacoum were spread from buckets suspended under helicopters guided by a GPS-based control system on two islands, at intervals of 20 days (Molara) or 1 month (Montecristo, where the second distribution was carried out on only 10 % of the island surface). The use of helicopters increased efficiency of the eradication, and reduced the financial costs of the eradications facilitating the support for these projects. For example, the use of bait stations on Montecristo would be impractical, unsafe and improbable because of the steep terrain (up to 650 m a.s.l.) and size (over 1000 ha) of the island.

What to Do When Eradication Is Not Feasible?

Eradication of rats from islands is an ideal option to protect breeding seabird species; however, it is not always feasible (Bomford and O'Brien 1995; Myers et al. 2000). Eradication feasibility is often limited by its high costs (due to the relevant amount of materials and labour), and either the risk of reinvasion or the hazard from the rodenticide to native species. When eradication is not feasible, an alternative strategy of controlling rodents should be put into practice in order to mitigate the impact of rats on breeding seabird species (Corbi et al. 2005; Igual et al. 2006; Pascal et al. 2008; Baccetti et al. 2009).

Local control is initially easier and less expensive to implement on annual basis with respect to eradication, but it has to be implemented every year to give results with increasing costs over time. Therefore, in the long term it is not cost-effective (e.g. Capizzi et al. 2006; Pascal et al. 2008). However, results at several Italian islands

(Zannone, Ponza, Pianosa, Molara, Tavolara, Linosa) showed that the seabirds' reproductive success was actually improved by undertaking rat control in the surroundings of the colonies (Corbi et al. 2005; Igual et al. 2006; Baccetti et al. 2009).

A hypothetical example of an evaluation of the two alternatives is given in Fig. 10.2. Monetary costs (in €) of eradication and control, in relation, respectively, to island size and the number of seabird colonies to be protected, are shown in

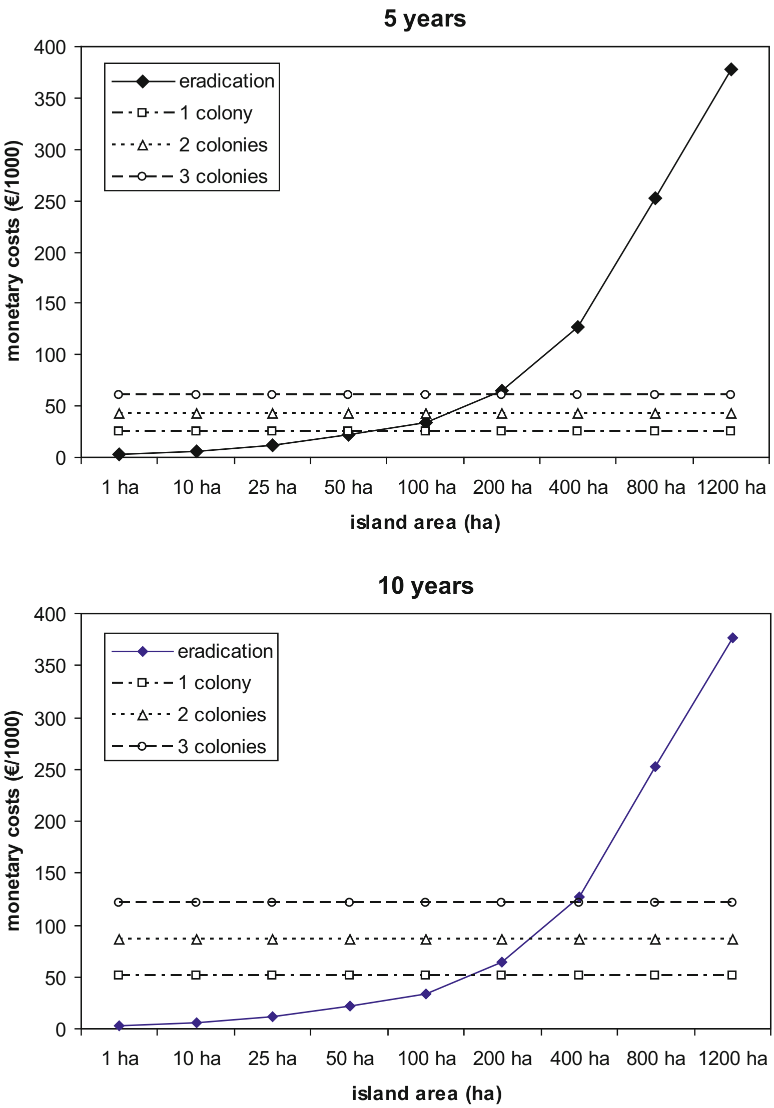


Fig. 10.2 Comparison of monetary costs to be sustained for eradicating rats from islands of different size and those necessary for controlling rats around seabird breeding colonies. We assessed three different scenarios, depending on whether the island is reinvaded by rats after 5, 10 or 20 years

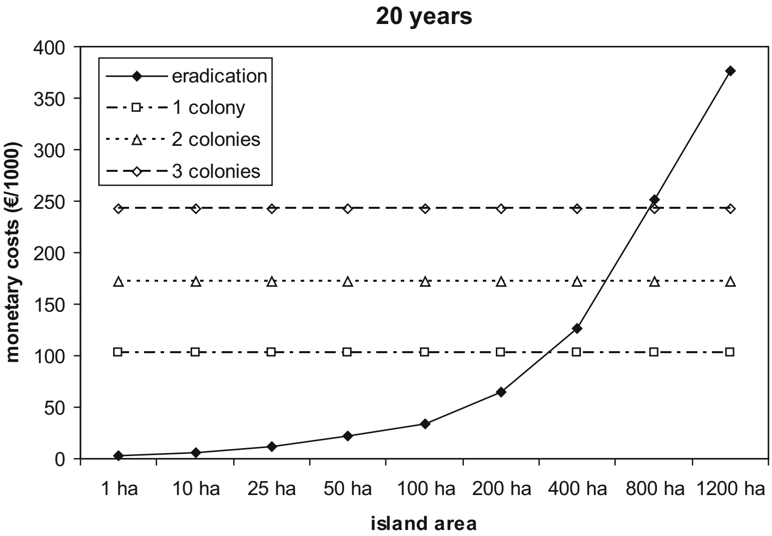


Fig. 10.2 (continued)

Fig. 10.2a, b and c, where the respective costs of a rat eradication are compared with the estimated costs of control for 5, 10 and 20 years, respectively. As shown in the graphics, the equilibrium point is achieved at different areas depending on the number of colonies and from the years before reinvasion. For example, for islands at high risk of reinvasion (i.e. assuming benefits lasting for only 5 years) the equilibrium point between eradication and local control is achieved at 50, 100 and 200 ha in the presence of one, two or three bird colonies, respectively. Conversely, when reinvasion is not likely and/or may be effectively prevented (benefits lasting 20 years or more), eradication is always the most appropriate and cost-effective option for islands from 400 ha (one colony) to 800 ha (three colonies).

However, in this example monetary costs for eradication are estimated assuming the use of bait stations, which is often impractical or even unfeasible on large islands, where aerial baiting is a more cost-effective method. Furthermore, the analysis does not take into account benefits to other components impacted by rats, such as other vertebrates, invertebrates, plants and ecosystem functions, as well as benefits to local human population derived from rat removal (Bell 2011; Oppel et al. 2011).

Studies on Rat Ecology

Seasonal Abundance

Conducting studies on the ecology of the black rat is required to fill the lack of knowledge with regard to this species, as well as informing about more effective control strategies (Ringler et al. 2014).

Patterns of seasonal rat abundance were studied on four islands by snap-trapping. Rat traps (Bell T-Rex®) were placed inside bait stations, in order to avoid injuries to non-target animals or humans. We adopted a transect-like trap arrangement of ten traps, spaced 10 m apart. On each island, four trapping sessions (spring, summer, autumn and winter) were carried out, with the exception of Molara, where only two sessions (spring and autumn) were conducted. Each trapping session lasted five nights. To maximize trapping success, traps were pre-baited for two nights, with traps not set. Trappings were undertaken on the various islands in different years:

Linosa, four sessions from July 2013 to May 2014
Molara, two sessions in March and September 2008
Montecristo, four sessions from March 2010 to February 2011
Tavolara, three sessions in September 2009, April 2010, December 2013

Results highlighted the different population patterns between islands and between years.

As shown in Fig. 10.3, at Montecristo and Linosa the population remained rather stable throughout the sampling year, while at Tavolara and Molara different seasonal patterns were recorded. However, a new trapping session in 2014 at Tavolara showed a very different scenario, with a much lower overall capture rate, stable throughout the year. This suggests the presence of inter-islands and inter-annual differences in the patterns of rat abundance.

Reproductive Period

Rats sampled (above) were evaluated for age and reproductive status and compared with seasons and islands, also recording contrasting patterns (Fig. 10.4). At Tavolara, the higher proportion of juveniles was in early winter, suggesting that reproduction occurred mainly during autumn. At Linosa, the highest proportion of juveniles occurred in autumn, with peak of reproduction in late summer, but juveniles were present throughout the year. In Molara, we recorded juveniles in both spring and autumn, indicating reproduction occurred in both winter and summer. Finally, our data suggest that in Montecristo reproduction occurred mainly in spring and was interrupted in the period from November to March, in Tavolara between late summer and autumn. It is very difficult to explain these differences between islands, and it is possible that they might be better understood by collecting long term both population and climate data. However, these findings indicate that population data are always needed before undertaking an island eradication project.

Rat Density

On Ponza Island (Capizzi et al. in prep.), we estimated the rat density in the surroundings of a shearwater colony (Cory's shearwater *Calonectris diomedea*) in October 2009 and January 2010. The two seasons were chosen according to the

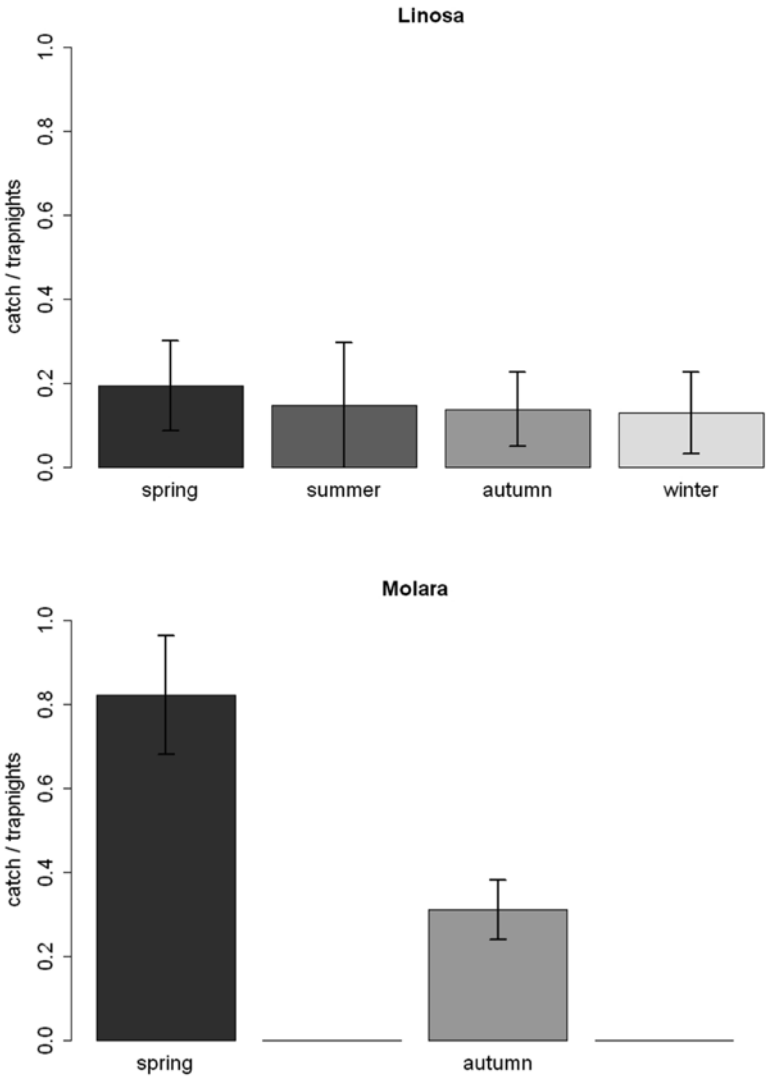


Fig. 10.3 Trapping success recorded during live-trapping sessions carried out on four Italian islands before rat eradication

usual timing of eradication programmes, which are typically performed in autumn or early winter. Overall, 48 Sherman traps arranged to form a 4×12 rectangular grid, with traps spaced 15 m apart. To overcome neophobia, at the beginning of each capture session two nights of pre-baiting (traps baited but with shutter locked) followed by five and four night trapping, respectively. Rats were marked by cutting a few tufts of hair on the right thigh of individuals captured. For the data analysis, Noremark software and the Join hypergeometric Estimator (JHE) for closed population were used, then assuming that the assumptions for a closed population were

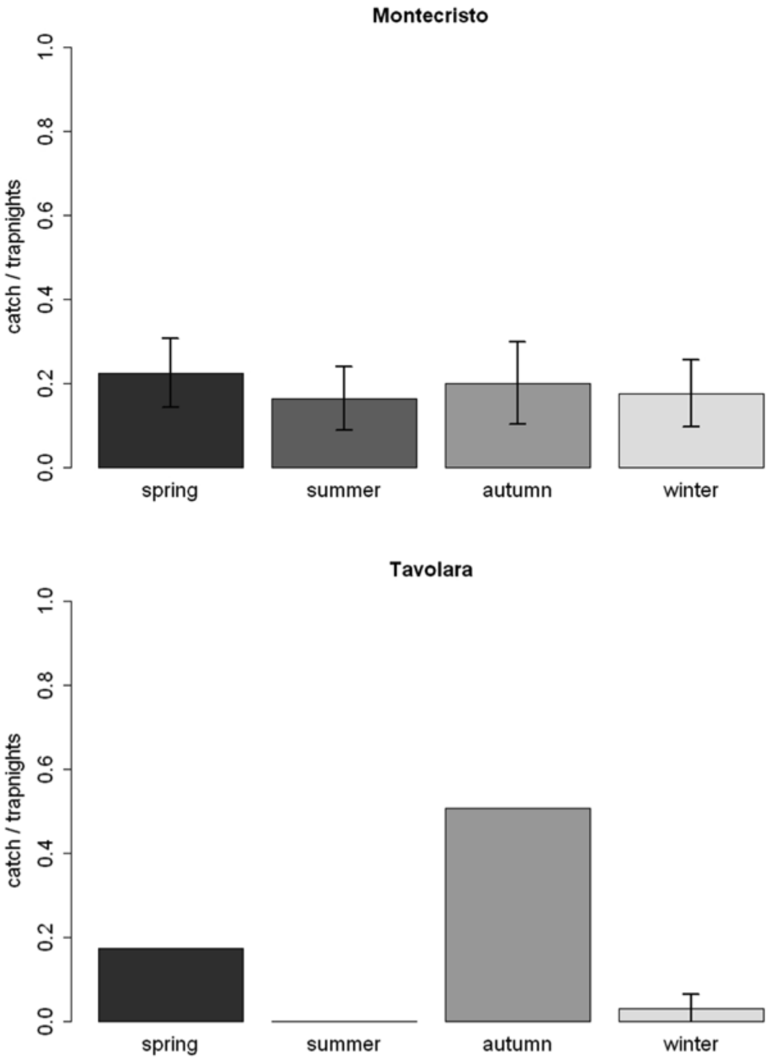


Fig. 10.3 (continued)

met. Density was estimated using an area 48 traps placed by the method of the MCP (Minimum Convex Polygon) with a buffer of around 15 m per side. For statistical tests, SPSS (version 12.0) was used.

In autumn, using the estimator JHE, the estimated population for the study area was 59 individuals with a minimum of 46 and a maximum of 78, for a confidence interval of 95 %. The estimated density for the study area (MCP traps + buffer = 34,465.5 m^2) is 17.1 individuals/ha with a minimum density of 13.3 rats per hectare and a maximum density of 22.6. The corresponding Minimum Number

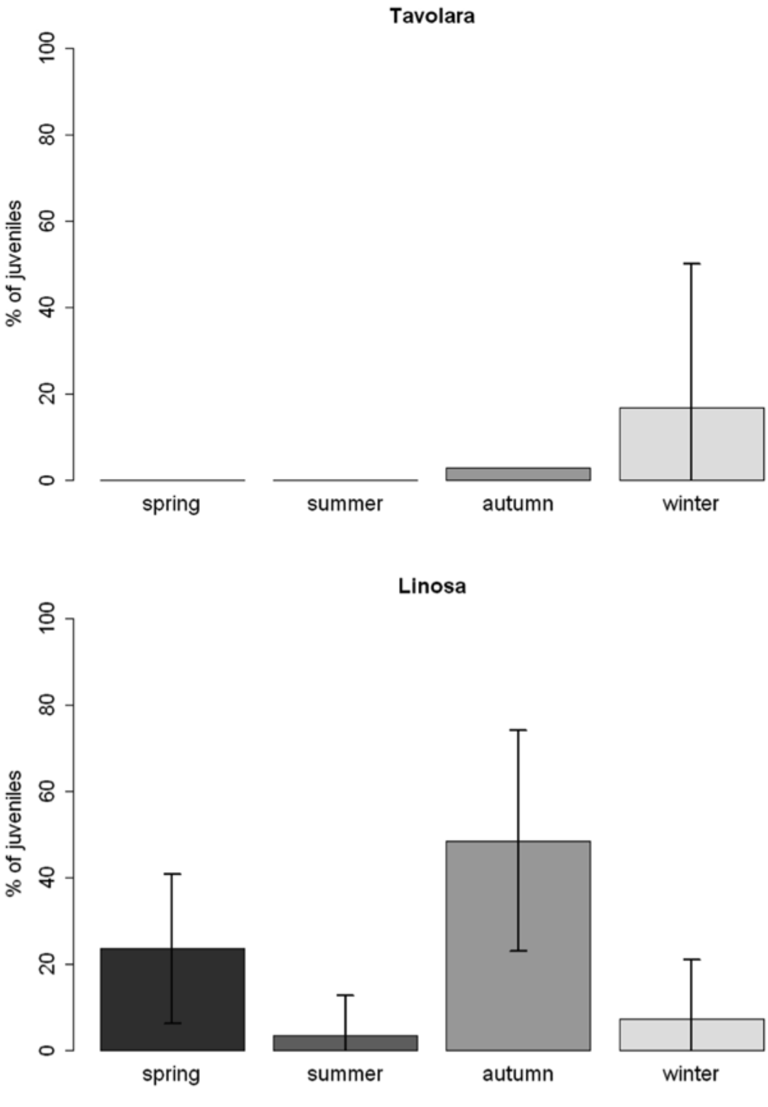
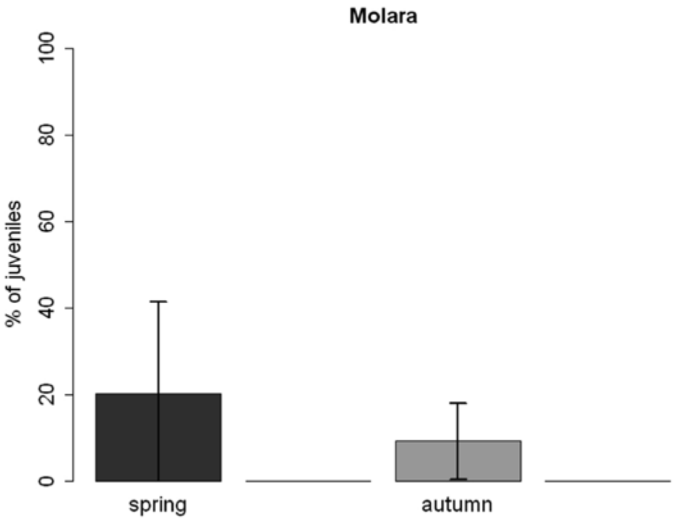


Fig. 10.4 Percentage of juveniles recorded during live-trapping sessions carried out on four Italian islands before rat eradication. For each island, the estimated reproductive period is also indicated

Alive (i.e. the number of rats actually captured) was of 39 rats within the study area, corresponding to a density of 11.3 ind/ha. Sex ratio was of 0.62, i.e. strongly skewed towards females.

In winter, the estimated population by JHE was 34 individuals with a minimum of 15 and a maximum of 180, for a confidence interval of 95 %. The estimated density for the study area (MCP traps + buffer = 34,465.5 m^2) is 9.7 ind/ha with a minimum density of 4.4 ind/ha and a maximum density of 52.2 ind/ha. The corresponding



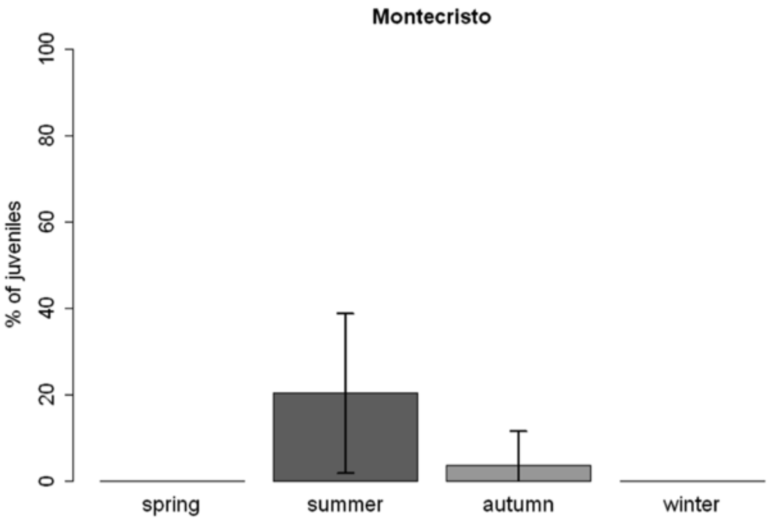


Fig. 10.4 (continued)

Minimum Number Alive (i.e. the number of rats actually captured) was of nine rats within the study area, corresponding to a density of 2.6 ind/ha. Sex ratio of the nine captured individuals was of 0.8.

Home Range and Movements

Rat movements by radio tracking were utilized to evaluate home range (Capizzi et al. in prep.). In autumn 2009, radio collars (manufactured by Sirtrack Ltd.) were fitted to nine adult females and six adult males. In winter, four new individuals were collared, in addition to the eight survivors from the autumn session already fitted with radio collar.

Rats had an average home range of 1685.36 m^2, with a 95 % confidence interval ranging from 1171.14 to 2200.19 m^2. The average home range was also calculated separately for the two study seasons, but the difference between the two values was not statistically significant (Student's *t* test: $t = 0.971$; $p = 0.34$). Similarly, no significant difference emerged from the comparison of the average home range of males and females (Kruskal–Wallis test: $\chi^2 = 1.125$, $p = 0.29$), although males home range (1882.0 ± 412.1 st. error) were on average larger than those of females (1447.9 ± 274.1 st. error) (Fig. 10.5). It is likely that the lack of statistical significance was due to the low number of sampled rats, especially males ($n = 6$). However, this pattern was partly in agreement with what was found in other studies on black rat movements from New Zealand (Hooker and Innes 1995; Ringler et al. 2014), which have shown that male home range are much larger than those of females.

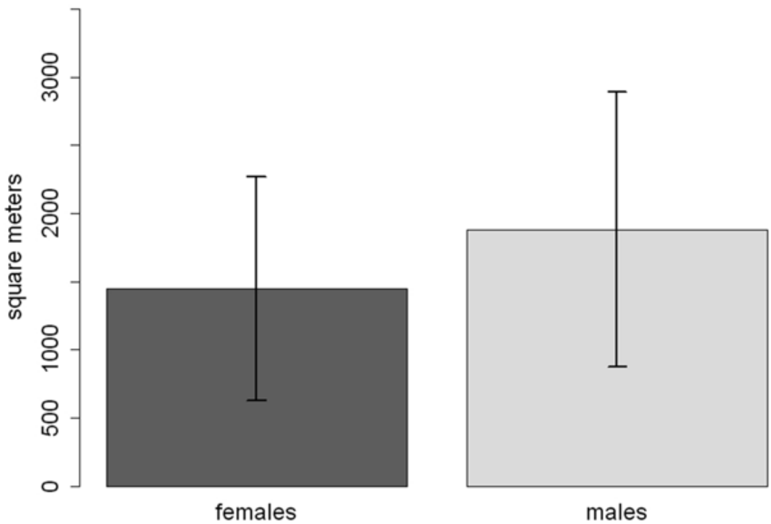


Fig. 10.5 Mean and standard deviation of home-range size of black rats at Ponza (nine females and six males) (method: MCP) (from Capizzi et al. in prep.). Differences between sexes were not statistically significant

Benefits from Rat Eradication and Control to Seabirds

The detrimental impact of invasive rats on nesting success of shearwaters has been highlighted by several studies (see Introduction). Detailed surveys on Italian islands corroborated the evidences, showing a strong difference in reproductive success between islands with or without rats (Fig. 10.6). Pooling together data of both shearwater species, it was determined that pairs breeding on islands without rats attained a much higher reproductive success (0.78 ± 0.17, $n = 15$) than those breeding on islands with rats (0.14 ± 0.25, $n = 11$), and the difference was statistically significant (one-way ANOVA, $F_{1,24} = 60.66$, $P < 0.00001$). The benefits derived from rat removal (either by eradicating or locally controlling them) to seabirds were confirmed by monitoring programmes, showing that controlling or eradicating rats significantly improved shearwater reproductive success, as well as enabling an increase in colony size on islands, where eradication was carried out. At La Scola, following rat eradication, Cory's shearwater reproductive success increased from zero (i.e. total reproduction failure) to about 0.8, and the size of the colony from 70–100 nesting pairs in 1999 to 150–250 in 2010. At Zannone, local control (2004–2006) and eradication (2007) allowed an increase of Cory's shearwater reproductive success from zero (2003) to over 0.8. At Montecristo, the Yelkouan shearwater colony showed maximum productivity values as well as signs of population increase

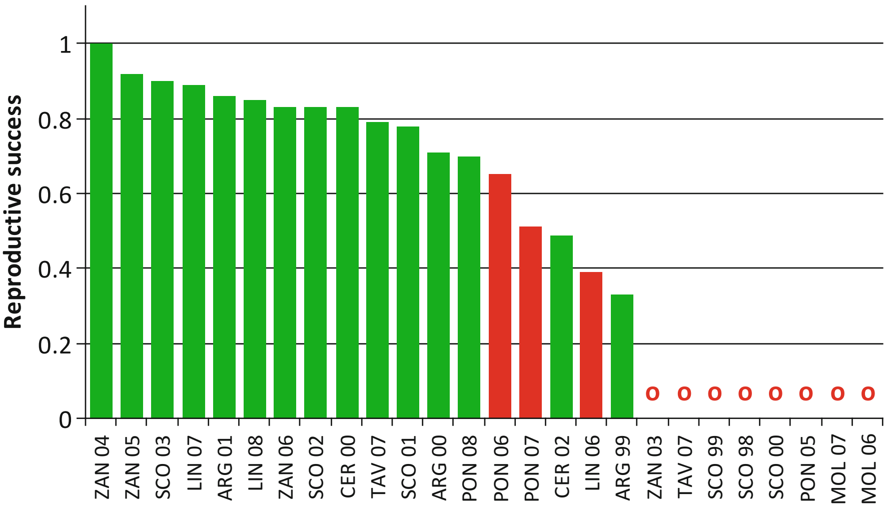


Fig. 10.6 Reproductive success of Yelkouan and Cory's shearwaters on Italian islands/years with (*red bars* or *zeros*) or without (*green bars*) black rats. Values were significantly higher in the latter islands. Data of the two shearwater species are pooled together. *ZAN* Zannone, *PON* Ponza (Latium), *SCO* La Scola, *ARG* Argentarola, *CER* Cerboli (Tuscany), *LIN* Linosa (Sicily), *MOL* Molara, *TAV* Tavolara (Sardinia). Rat absence was either natural (Cerboli, Argentarola) or due to local control or eradication (Zannone after 2003, Linosa after 2006, La Scola after 2000, Ponza after 2007, part of Tavolara in 2007)

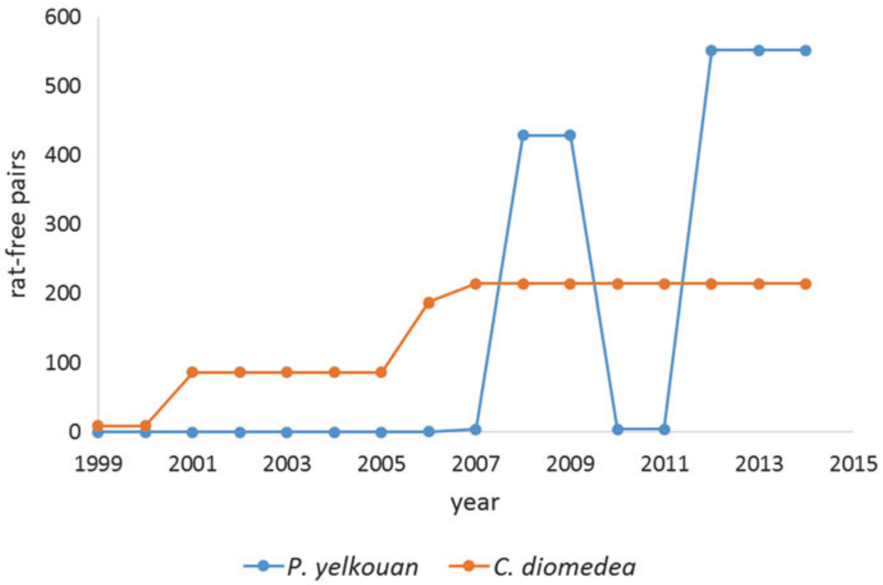


Fig. 10.7 Number of pairs of both Yelkouan and Cory's shearwater released from rat predation during the period 1999–2014 following the various rat eradications. The number of rat-free pairs of the former species increased in 2008 after eradication at Molara, but decreased in 2010, following rat reinvasion

and the occupation of previously unused burrows from the first season after rats were eradicated (Gotti et al. 2014).

The number of shearwater pairs released from rat predation pressure following rat eradication is shown in Fig. 10.7. Early eradication projects have been performed at islands hosting colonies of Cory's shearwater only (La Scola, Giannutri, Zannone), but after 2007 these projects included islands with important colonies of Yelkouan shearwater (i.e. Molara and Montecristo). The number of shearwater pairs on rat-free islands will increase greatly for both species when planned rat eradications are implemented on Tavolara and Linosa (both in 2015, area of 602 and 545 ha, respectively), the most important colonies, respectively, of Cory's and Yelkouan shearwater.

Establishing Priorities

An important issue was the identification of priority islands for rat eradication—i.e. which ones should be implemented. As the implementation of a management strategy can be quite demanding in terms of monetary, safety and image costs, restoration programmes on various islands are inevitably in competition for the same limited monetary budget (Dawson et al. 2015). We addressed this problem by comparing effectiveness (i.e. importance of shearwater populations) and estimated monetary costs for rat eradication for each island. We took into consideration all Italian islands, including inhabited ones, selecting those that host colonies of two shearwater species, i.e. the Cory's shearwater and the Yelkouan shearwater, as these represent beneficial species for implementing conservation actions against introduced predators (see Capizzi et al. 2010) and assists in guiding prioritization.

For each island, we evaluated the effectiveness of rat eradication considering the relative importance of the island's nesting population of the two species at the national and local scale (see Capizzi et al. 2010 for details). We analytically estimated monetary costs of a rat eradication programme on each island (i.e. summing the various costs that are required for an eradication programme, such as labour, materials and travelling expenses). Finally, islands considered at high risk of recolonization on the basis of their proximity to mainland or to other rat-inhabited islands, and the intensity of marine traffic were excluded from the analysis. However, we included in the ranking some groups of islands, considering that rat eradication had to be implemented simultaneously on islands of each group.

Following our analysis (see Table 10.2), rat eradication was most cost-effectively carried out on the island hosting the largest colony of *P. yelkouan* (i.e. Tavolara). Benefits to 63.9 % of the Italian population of *P. yelkouan* derived from eradicating rats from all the islands in the ranking, but only to 7.1 % of *C. diomedea*.

Table 10.2 Islands' ranking according to cost-effectiveness of rat eradication, excluding islands at high risk of recolonization, but recovering four groups of islands, where rat eradication has to be performed simultaneously (from Capizzi et al. 2010)

Islands (or groups)		Area (ha)	Actions implemented or planned
1	Tavolara	602.0	Eradication planned (2015?)
2	Palmarola	125.1	Feasibility study available
3	Barrettini	10.3	
4	Montecristo	1071.7	Eradication (2012)
5	Giannutri	239.5	Eradication (2006)
6	Zannone	104.7	Eradication (2007)
7	Soffi Group	53.4 (four islands)	
8	Santo Stefano Ponziane	31.0	Feasibility study in progress
9	Molara	347.8	Eradication (2008), reinvaded (2009)
10	Mortorio	55.7	
11	La Vacca	9.1	
12	Santa Maria Group	556.1 (14 islands)	
13	Pianosa + La Scola	1028.4 (two islands)	Eradication in La Scola (2001), eradication planned in Pianosa (2016)
14	Rossa di Teulada	10.5	
15	Spargi	421.9	
16	Serpentara	31.3	
17	Cavoli	42.1	
18	Corcelli Group	16.7 (three islands)	

The analysis has not been just a theoretical exercise. Comparing the ranking with Table 10.1, it is noted that rat eradication had already been carried out on many of the islands (Montecristo, Giannutri, Zannone, La Scola, Molara). Furthermore, rat eradication on Tavolara is planned for autumn 2015, and planning for a project aimed at removing rats from Palmarola and S. Stefano is currently under way. Finally, knowledge gained about the effectiveness of quarantine measures (e.g. Dilks and Towns 2002; Russell et al. 2008) has led to programming rat eradication on those islands that host important Mediterranean colonies (e.g. Linosa, the main Italian colony of Cory's shearwater: Baccetti et al. 2009) that are also subject to human pressure.

Rat Reinvasion

Rat reinvasion following an eradication programme is a distinct threat (Russell and Clout 2005), risking the great financial, time and field effort investments clearing the island of rats in the first place. Rat reinvasion has occurred on six islands, five of them being very small and closer than 500 m to mainland or other rat-infested islands, and in two cases it occurred more than once: La Scola (three times in a 15-year period since 2001, i.e. in 2005, 2009 and 2011) and Cavalli (at least twice in the period 2010–2014). The only reinvaded island more than 500 m distant from mainland was Molara. Genetic analyses highlighted the difference between eradicated population and the new invaders, thus supporting the evidence of a successful eradication, and indicated that reinvasion may be caused by a rat exchange between the Molara Island and Sardinia mainland populations (Ragionieri et al. 2013). The considerable distance from the mainland (more than 1000 m) led us to exclude the possibility that rats may have reached the island by swimming (Russell et al. 2008), thus hypothesizing that reinvasion was probably driven by humans (Ragionieri et al. 2013; Sposimo et al. 2012). At Barrettini (Sardinia, distant 700 m from the nearest island), we recorded a black rat reinvasion at least 12 years after from its natural extinction (Baccetti, pers. obs.). It is likely that reinvasion occurred by swimming, since the islet benefits from a high level of protection under the national park zonation and landing of boats is not allowed (Cecere and Nissardi, pers. obs.). This also suggests that islands within 700 m of a rat population are at risk of reinvasion. These reinvasions highlight the importance of strengthening biosecurity measures to both protect the investment in conducting eradications and secure the conservation benefits accruing to seabird species.

Impact on Non-target Species

An important concern in all rat eradication projects is the impact of rodenticides on non-target species (Fisher et al. 2011; Masuda et al. 2015). Here, we present evidences (before and after eradications, see Table 10.3) outlining impacts on several

Table 10.3 Summary table showing the observed impacts on non-target species following rat eradication on the various islands

Species	Island(s)	Observed impact
Mouflon (*Ovis aries*)	Zannone	Population stable (about 45 individuals before and after)
Goats (*Capra hircus*)	Montecristo	Population decrease after eradication (2012), then fully recovered after 2 years (Gotti et al. 2014)
Asp viper (*Vipera aspis*)	Montecristo	No direct impact observed
Western whip snake (*Hierophis viridiflavus*)	Giannutri, Molara, Proratora	No impact observed
Italian wall/Wall lizards (*Podarcis* spp.)	All islands	No impact observed, increase in La Scola and Zannone
Turkish gecko (*Hemidactylus turcicus*)	Palmaiola, Giannutri, Montecristo	No impact observed
Common wall gecko (*Tarentola mauritanica*)	Giannutri, Montecristo	No impact observed
European leaf-toed gecko (*Euleptes europaea*)	Isola dei Topi, Palmaiola, Gemini Alta, Gemini Bassa, Giannutri, Molara, Proratora, Isola Piana, Montecristo	No impact observed
Ocellated bronze skink (*Chalcides ocellatus*)	Molara, Proratora, Isola Piana	No impact observed
Fitzinger's algyroides (*Algyroides fitzingeri*)	Molara	No impact observed
Tyrrhenian painted frog (*Discoglossus sardus*)	Montecristo	No impact observed
Yellow-legged gull (*Larus michahellis*)	All islands	No impact observed in all island but Montecristo, where a decrease in population has been recorded
Common raven (*Corvus corax*)	La Scola, Molara, Montecristo	1–2 pairs possibly extinct at Montecristo, no impact observed elsewhere
Peregrine falcon (*Falco peregrinus*)	La Scola, Isola dei Topi, Palmaiola, Giannutri, Zannone, Molara, Montecristo	No impact observed
Barn owl (*Tyto alba*)	Giannutri, Molara	Extinction of 1–3 pairs in Molara, maybe one pair in Giannutri (uncertain presence before eradication)

Only vertebrate species were considered (mammals, reptiles, amphibians and birds)

species of mammals, reptiles and birds from 12 islands, showing no significant impact at the population level, with the exception of *Larus michahellis* and wild goats *Capra hircus* at Montecristo (population decrease after the eradication, now recovered to the levels present prior to the intervention). Furthermore, we guess that Barn owl *Tyto alba* became possibly extinct at both Giannutri (one pair, but the presence before eradication was uncertain) and Molara (1–3 pairs). However, it has to be noted that Barn owl may not be able to survive on islands without rodent prey; therefore, their extinction may be due either to effects of anticoagulants or to island abandonment due to lack of suitable prey. This also raises the question of whether barn owls existed on the islands prior to their colonization by rats, but this goes far beyond the aims of this chapter. No impact has been recorded on reptiles (geckos, lizards and western whip snakes) or amphibians, as well as on ravens (with the exception of one or two pairs which were possibly impacted by primary or secondary poisoning at Montecristo) and diurnal raptors (*Falco tinnunculus* and *F. peregrinus*). A detailed report of the fauna present on the 12 islands and the evidences regarding the impact on their populations are shown in Table 10.3.

Conclusions and Management Perspectives for Italian Islands

Rat eradication proved to be a valuable tool for restoring island ecosystems and provided actual benefits to rat-impacted native species. Although the cost of eradication is often perceived to be high because it incurs a one-off cost, by comparing available management options (i.e. control or eradication) our analysis suggested that it may be cheaper than the cost of long-term control or the cost of doing nothing. Projects carried out on Italian islands are an example of an effective and lasting solution to an environmental problem and demonstrate a cost-effective conservation management action. The conservation status of species such as Cory's shearwater, Yelkouan shearwater and Storm petrel is closely linked to the outcome of these restoration projects. As it hosts important nesting seabird colonies, Italy has a major responsibility with regard to their conservation. However, problems may come from a new Italian regulation on the use of rodenticides, allowing aerial distribution, but imposing the use of low persistence active ingredients. According to this regulation, the only allowed active ingredients are first-generation anticoagulants (e.g. chlorophacinone and warfarin), ineffective for eradicating rats from islands by aerial baiting (see Parkes et al. 2011) and hardly available on the market. This restriction would significantly reduce our ability to achieve meaningful conservation outcomes on islands with invasive rodent populations.

The opposition of animal rights movements may also hamper the implementation of such projects. However, although present, such opposition is not as strong as in the case of Italian projects aimed at managing other invasive species (e.g. Grey squirrel *Sciurus carolinensis*, see Bertolino and Genovesi 2003).

The challenge for the future is twofold. First, there is the need to improve the effectiveness of biosecurity (quarantine) measures, thus achieving protection from the risk of reinvasion (e.g. Dilks and Towns 2002; Russell and Clout 2007). This will allow the potential to eradicate rats even in islands connected to mainland or other islands by regular boat service, thus extending the benefits to other important colonies (e.g. Linosa, currently the most important European colony of Cory's Shearwater). Secondly, implementing the appropriate biosecurity measures may also allow eradication of rats from islands with small human settlements, considering the benefits in terms of the welfare of the resident population (Oppel et al. 2011; Hilton and Cuthbert 2010; Bell 2011). This may be a strategic advantage, as it may strengthen public support for these strategic projects. Furthermore, if residents appreciate the increased natural biodiversity after removal of rats, they may encourage other island communities to support the same measures—this seems to be happening on the Scilly Isles (UK) at the moment (Bell 2011).

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