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First successful eradication of invasive Norway rats *Rattus norvegicus* from a small Mediterranean island (Isola delle Femmine, Italy)

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Abstract. Invasive alien species, once introduced, may affect local biodiversity, both directly (e.g. by predation) and indirectly (e.g. by reducing the vegetation cover). Among those, rats (Rodentia, Muridae) are listed among the most invasive species, exerting strong impacts particularly when introduced to island ecosystems. Accordingly, black rats *Rattus rattus* have been eradicated from a number of islands in the Mediterranean basin to protect breeding seabirds. Where the larger Norway rat *Rattus norvegicus* is present, extent of damage may be even higher. In our work, we present the results of the first eradication program dealing with Norway rats in a small Mediterranean island (Isola delle Femmine, Sicily, Southern Italy). The eradication took place in 2007-2008 and, since then, no rat has been observed on the island, thus proving the success of the management action. Vegetal cover increased on the island after rat eradication. Furthermore, the Sardinian warbler and the blackbird started to breed on the island.

Key words: alien species, biological invasions, Italian wall lizard, vegetal cover

Introduction

Rats *Rattus* spp. are commensal rodents which have been widely unintentionally introduced worldwide (Atkinson 1985, Capizzi & Santini 2007). In particular, three species of rats are exerting serious impacts on native ecosystems and biodiversity on over 80 % of the islands of the world (for a review, see Duron et al. 2017): the black rat *R. rattus*, the Norway rat *R. norvegicus* and the Polynesian rat *R. exulans* (Norman 1975, Towns et al. 2006, Harper & Bunbury 2015). Small islands near the coastline might be colonized by swimming rats from the mainland, whereas their presence on islands distant > 500 m from the mainland is due to human accidental transport (Palmer & Pons 2001, Russell et al. 2010). Colonization of Europe by the Norway rat probably dates back to the end of 18th century A.D. The invasion was mainly due to the intensification of the trade with northern Asian countries, which are the native extent of occurrence of this species (Puckett et al. 2016). The Norway rat is a pest species widely recorded in urban and suburban habitats, e.g. sewers, landfills and ports (Feng & Himsworth 2014, Panti-May et al. 2016). Its ecological plasticity allows this species to adapt to wide feeding habits, involving both vegetarian and carnivore diets (Galef 2003, Klemann & Pelz 2006, Major et al. 2007).

As to the Mediterranean countries, the Norway rat competes with the previously introduced black rat (cf. Colangelo et al. 2015), being larger in size, more adaptable and much more aggressive (Capizzi & Santini 2007, Mori et al. 2017). Breeding birds on Mediterranean islands (mostly on small ones) are mainly threatened by the black rat (Martin et al. 2000, Perfetti et al. 2001, Capizzi et al. 2016, Duron et al. 2017). Black rats are well adapted to small islands, whereas Norway rats are mostly observed on the largest islands where humans also occur (Amori et al. 2008). The Norway rat, indeed, is usually quite rare on Mediterranean coastal rocky environments (e.g. Kryštufek 1983, Angelici et al. 2009), mainly inhabiting water degraded habitats.

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The breeding success of many pelagic bird species, e.g. the Mediterranean storm petrel *Hydrobates pelagicus melitensis*, the Scopoli's shearwater *Calonectris diomedea*, the Yelkouan shearwater *Puffinus yelkouan*, the Balearic shearwater *P. mauretanicus*, and the pallid swift *Apus pallidus*, is strongly affected by the presence of the black rat (Thibault 1995, Penloup et al. 1997, Amengual & Aguilar 1998, Vidal & Zotier 1998). Impacts have also been recorded on invertebrates and plants (Palmer & Pons 1996, 2001, Duron et al. 2017), particularly on small, rocky islands (Martin et al. 2000). Accordingly, over 80 % of rat eradications on islands worldwide have been conducted against the black rat (Capizzi et al. 2016, Duron et al. 2017), and this action represents a very effective conservation tool (Towns & Broome 2003, Igual et al. 2006, Jones et al. 2008, Pascal et al. 2008). Where present, Norway rats may displace black rats on islands (Bertram & Nagorsen 1995) and they may exert a stronger impact on native species, particularly on colonial nesting birds (Norman 1975, Atkinson 1985, Thibault 1992). For instance, in Langara Island (British Columbia, Canada), the Norway rat caused the decline of the imperiled ancient murrelet *Synthliboramphus antiquus* and the population of this seabird species recovered after the rat eradication campaign (Taylor et al. 2000). Eradication of the Norway rat always results in evident native biodiversity and environmental recoveries (e.g. Thorsen et al. 2000, Courchamp et al. 2003); thus, it has been widely proposed as a way to mitigate biodiversity loss, to provide new safe nesting habitats for threatened or migrating birds and to restore the original vegetal cover (Kaiser et al. 1997, Taylor et al. 2000, Harper & Bunbury 2015).

Our paper outlines the Norway rat eradication from a small island (Isola delle Femmine, Southern Italy) in the Mediterranean basin from the project outline to the main eradication campaign in 2008-2009, follow-up and *post-hoc* monitoring. As in most similar projects (see Duron et al. 2017), in this area the impact of rat on natural resources was not quantitatively assessed before rat control; eradication was mainly conducted to mitigate the impacts on native plants, intertidal invertebrate species and native lizards, which were threatened by rat predation.

Material and Methods

Study area

Isola delle Femmine (Province of Palermo, Sicily, Southern Italy: 38.211° N, 13.235° E) is a 15.6 ha island (0-36.8 m a.s.l.) established as a Natural Reserve since 1997 and as a "Special Conservation Area" protected according to the European Union "Habitats" Directive (Council Directive 92/43/EEC). This island, located about 300 m from the Sicilian coast (Fig. 1), is totally covered with forbs and scrubs typical of the Mediterranean scrubland, including *Pistacia lentiscus*, *Thymelaea hirsuta* and *Chamaerops humilis* (Caldarella et al. 2010). Vascular plants of the island mainly include therophytes (~ 62 %), hemicryptophytes (~20 %), geophytes (~9 %), chamaephytes (~5.5 %), nanophanerophytes (~2.3 %) and phanerophytes (~1.8 %). As to chorotypes, the Mediterranean one is the most widespread (~33 %); the wide-range floristic component (cosmopolite, subcosmopolite and xenophyte species) is the most represented (i.e. 39 entities, 17.8 % of the total vegetal taxa on the island). The endemic and subendemic contingent is represented by six taxa, i.e. 2.7 % of the total (e.g. endemic taxa of north-western Sicily: *Limonium bocconei* and *Romulea linaresii* subsp. *linaresii*). Other endemic taxa have a regional (e.g. *Allium lehmani*), extra-regional Tyrrhenian (*Biscutella maritima*) or South Italian distribution (*Carlina sicula* subsp. *sicula*). Other rare species, which range of occurrence is not limited to Sicily, include *Delphinium emarginatum* subsp. *emarginatum*, *Galium verrucosum* subsp. *halophilum*, *Jacobaea delphinipholia* and *Ononis pendula* subsp. *boissieri* (Caldarella et al. 2010).

The only building on the island is represented by a late-Mediaeval tower and by few tanks for fish-working (Riggio & Raimondo 1992) dating back

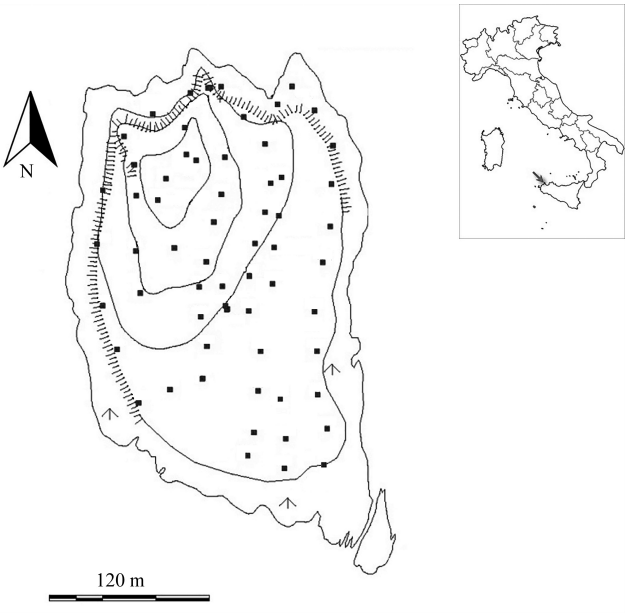

Fig. 1. Location of the study area. Black squares show the placement of dispensers.

Fig. 2. A dispenser baited with three blocks of Brodifacoum (Solo Blox, ©Colkim Service).

to the 4th century B.C. (La Rocca 2004). The island is a resting place for many migratory bird species, especially waders, warblers, herons and cormorants. Despite this, before rat eradication, Sardinian warbler and blackbirds were not present as breeding species. Since the 1980s, a colony of Mediterranean yellow-legged gull *Larus michahellis* (about 500 pairs) breeds on the island. Among other species, the Italian wall lizard *Podarcis siculus* and the black whip snake *Hierophis carbonarius* are present. Before the eradication project, Norway rats and introduced wild rabbits *Oryctolagus cuniculus* were present since after the Second World War. Rats were observed while feeding on plant seeds and gull pellets.

The eradication project

In the first year of the project, we carried out surveys to ascertain whether there were native species which may have suffered for the secondary poisoning. Afterwards, we selected transects where to place bait dispensers. The installation and checking of the dispensers began in October 2007 and continued throughout 2008 and 2009. A total of 70 geolocated dispensers were placed on a grid (50 metres of mesh: Fig. 1) throughout the island (about 4 dispenser/ha) and fixed to the ground through pegs.

We used Ristorat dispensers (Ristorat ®, Colkim Service, Bologna, Italy), which do not allow entry to larger animals than an adult rat and prevent rodents from taking food away, showing a structure which attaches the bait to the dispenser (Fig. 2). Dispenser were visited once every 10 days, and baits replaced when necessary. At each check, we also checked for dead rats and for rat tracks in the surroundings of dispensers (Blackwell et al. 2002).

Information on the project (including name and contacts of the project leaders) and on the presence of poison were placed above each dispenser. Used baits were blocks (200 g each) of Brodifacoum or Bromadiolone, anticoagulant products. Baits inhibit the formation of vitamin K, which is essential for the blood coagulation process. Both used baits have been proven to be effective for rat eradication because of the palatability of the product (Taylor & Thomas 1989, Gill et al. 1994). Furthermore, the amount of time between the ingestion of a lethal dose and death is usually between 4 and 10 days (Buckle 1994, Capizzi et al. 2016); this makes it impossible the association between the illness and the ingestion of

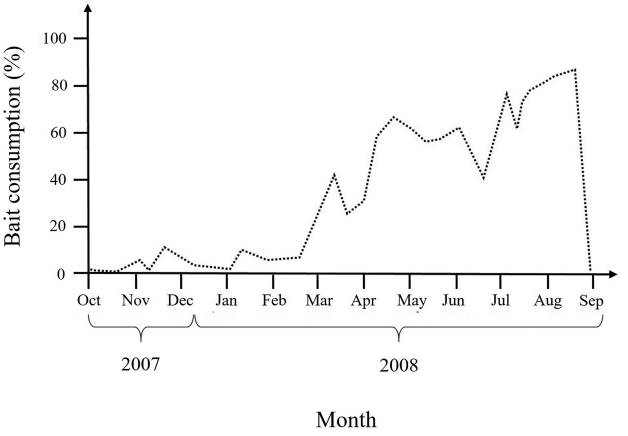

Fig. 3. Percentage of chewed baits by Norway rats in Isola delle Femmine from October 2007 to September 2008. From September 2008 to the end of the monitoring activity, no bait was chewed or consumed by rats any more.

Fig. 4. Vegetal restoration after rat and wild rabbit eradication programs; left) April 2006, i.e. before the eradication; right) April 2010, i.e. after rat eradication project.

the bait by the rodents since the first symptoms of the poisoning occur after a few days from the ingestion. Rodents are therefore unable to develop distrust of the bait (Meehan 1978). Despite being so effective for rat control, in the first months they were poorly used by rats, which avoided the dispenser possibly because of the high food availability on the island or for neophobia, typical of these rodents.

Since July 2008, 20 dispensers were implemented with a 20 grams block of beef taste, to increase the palatability of the bait and to entice rats to visit the dispenser. Monthly monitoring of dispenser continued for three years after the eradication project to detect possible bait consumption. Vegetal cover of the island before and after rat eradication was compared by visual sampling (LIPU 2009).

Results

From October 2007 to the beginning of March 2008 only a small percentage of baits were consumed or chewed by rats (i.e. only one bait in one box was consumed). From the middle of March 2008 to August 2008 a sharp increment in the percentages of consumed/chewed baits was registered. From September 2008 onwards, no sign of rat activity was detected in any of the dispensers (Fig. 3). Since the end of summer 2008, no rat was observed anymore during nocturnal addressed visual counts. Vegetation analysis, carried out through visual sampling (LIPU 2009) showed that vegetal cover of the island remarkably increased after the rat eradication (Fig. 4). Visual sampling made by qualitative transects along the island recorded more land snails (e.g. *Eobania vermiculata*) and intertidal invertebrate species populations (e.g. *Pachygrapsus marmoratus*), with respect to the period before the eradication project. The Sardinian warbler *Sylvia melanocephala* started to nest on the island after the rat eradication, with at least two fledglings observed and up to five territorial males observed during the breeding period in the first year after the eradication (LIPU 2011). Eventually, the blackbird *Turdus merula* started to nest on the island in 2018.

Discussion

The eradication of the Norway rat at Isola delle Femmine (Sicily, Southern Italy) has been successful, as no rats have been observed anymore after the summer of 2008. Since September 2008, no bait was anymore consumed on the island. The eradication project was necessary to restore the natural and original conditions of the island, degraded by the presence of the Norway rat. We observed that rats, at the start of the eradication program, did not feed upon the baits, maybe as the animals tend to avoid any novelty in their habitat. This form of temporary "neophobia" did not affect the numerical control invasive rats in our study (cf. Barnett 1958, Thorsen et al. 2000). A possible way to minimise temporary neophobic avoidance by rats on islands would be the prebaiting, i.e. to leave empty bait stations for at least one month before poison is laid (cf. Taylor & Thomas 1989, for the Norway rat).

Besides "neophobia", another explanation for the poor bait consumption at the start of the project, particularly in autumn and winter, may be due to the fact that, in these seasons, the island is rich in fruits and other food resources for rats. For instance, a Vermetidae reef (Mollusca, Sorbeoconcha) was present in the intertidal zone, and it was easily accessible to rats during low tides. Few dead rats have been observed on the island, possibly because they found shelter between the rocks (Harper & Bunbury 2015), thus becoming hard to be detected. This behaviour may furtherly decreased the possibility of secondary poisoning of raptor birds. The eradication of Norway rats has been reported to remarkably help the vegetation recovery on small island (e.g. Tromelin Island in the Indian Ocean: Le Corre et al. 2015): accordingly, the vegetal cover increased on Isola delle Femmine after rat eradication, together with the eradication of the local population of wild rabbit. As a consequence, the native Sardinian warbler and the blackbird may have started to breed on the island. Both the species were not present as nesting through over 14 years before rat eradication. Thus, given the long-dated absence of these species on the island, we suggest to rule out the role of chance in the start of their nesting behaviour after rat eradication.

Norway rats are a rare presence in Mediterranean islands, with respect to the very widespread black rat (Angelici et al. 2009). Black rats are also known as "ship rats", because they have a slender body structure with respect to Norway rats (Mori et al. 2017), which allows them to climb along ropes of the ships at docks. This made them the best island colonizers (Capizzi et al. 2016). However, where Norway rats succeed to arrive (i.e. mainly on island not far from the coastline, e.g. Isola delle Femmine, in Mediterranean countries: Kryštufek 1983, Angelici et al. 2009), they are strong competitors and may displace other coexisting rat species, rapidly becoming the only rat species locally present (Amori et al. 2008).

Rat eradication from Isola delle Femmine is the first one in the Mediterranean basin carried out against the Norway rat (cf. Bertolino et al. 2015, Capizzi et

al. 2016). The rapid effectiveness of this intervention in an island of such a small size has been surprising. In small islands, rat populations may reach higher densities than in large islands and they are also subject to less population fluctuations (Thibault 1995, Taylor et al. 2000).

In order to maintain the positive outputs of the project for long and to prevent a recolonization of the island by the Norway rat, and in accordance with available "best practices" (Duron et al. 2017), strict controls of shipping to the island was implemented. Furthermore, half of the dispensers with poison were maintained on the island and checked once every two months, to survey potential chewed blocks (cf. Blackwell et al. 2002). Crowley et al. (2016) suggested that the management of biological invasions strongly benefits from the assessment of social impacts: therefore, 2200 copies of a flyer were distributed to the general public at the presentation of the final results.

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