



A pleasing consequence of Norway rat eradication: two shrew species recover

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ABSTRACT

Four to 10 years after the successful eradication of the Norway rat (*Rattus norvegicus*) from three islands of the Sept-Îles Archipelago and one in the Molène Archipelago (Brittany, France), the abundance index of the lesser white-toothed shrew (*Crocidura suaveolens*) increased by factors of 7–25, depending on the island and the year. Moreover, in the same region, the abundance index of the greater white-toothed shrew (*Crocidura russula*) on Tomé Island increased by factors of 9 and 17, one and two years after the Norway rat eradication, respectively.

The maximum variation of the abundance index for the lesser white-toothed shrew during seven years on the rat-free island of Béniguet in the same region was a factor of only 2.5. Moreover, the distribution of the lesser white-toothed shrew on Bono island, restricted before the eradication to two steep areas with few rats, increased and encompassed virtually the entire island four years after rats disappeared.

These results suggest strong detrimental interactions between the introduced Norway rat and the two *Crocidura* shrew species on temperate oceanic islands. However, our data do not indicate the ecological mechanisms at work in these interactions.

The main reason this shrew recovery was detected after rat eradication was the inclusion in the eradication protocol of the evaluation of impacts on the local biota of eliminating alien species. The rigor of the sampling procedure was also crucial to this discovery. This example demonstrates that an eradication operation can be extremely useful for both scientists and managers if it is planned as a research project.

Keywords

Biological invasions, Brittany, *Crocidura russula*, *Crocidura suaveolens*, eradication, impact, introduced species, island, *Rattus norvegicus*.

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INTRODUCTION

Biological invasions are the second most important cause of biodiversity loss after habitat destruction and fragmentation (Diamond, 1989; Vitousek *et al.*, 1997; Alonso *et al.*, 2001), and many management operations have been undertaken to reduce impacts of non-indigenous populations on native fauna and flora. These operations include eradication attempts, of which the majority (Courchamp *et al.*, 2003), but not all (Simberloff, 2002), have occurred on islands. This island focus is partly due to the fact that island ecosystems are more threatened by biological invasions (Moors & Atkinson, 1984; Atkinson, 1985; King, 1985; Lever, 1994; Chapuis *et al.*, 1995) and are a more appropriate place to test eradication consequences (Simberloff, 1990). Further, eradication attempts are more likely to succeed on small islands than on the mainland (Chapuis *et al.*, 1995; Pascal & Chapuis, 2000), and reinvasion is less likely. Moreover, species introduced on islands offer research opportunities (Vitousek

et al., 1987), and eradication projects should be planned as experiments in research and management (Chapuis *et al.*, 1995; Pascal & Chapuis, 2000). Such experiments can document impacts induced by alien species, including impacts that had not previously been detected.

The Norway rat, *Rattus norvegicus* (Berkenhout 1769), invaded France, along with many other western European countries, during the 18th century. This mammal was unintentionally introduced to nearly all the French Atlantic and Channel Islands (Vigne & Villié, 1995; Pascal & Vigne, 2003a) at roughly the same time it appeared on all the continents, except for Antarctica, and most islands around the world (Atkinson, 1985). It is included in the IUCN list of the world's 100 worst invasive alien species (Lowe *et al.*, 2001) and is known or suspected to cause decline or extinction of many insular species; Atkinson (1985) gives several examples for birds. Concern about their impacts in the Brittany islands has focused mainly on birds (e.g. Kerbiriou *et al.*, 2004). Ceballos & Brown (1995) claimed that, among 80 documented

mammal extinctions, 65 (81%) occurred on islands, and among these species, 9 were Insectivora. However, we have found no published quantitative information suggesting that Norway rats may be detrimental to mammal species. In particular, there is only one anecdotal report (Taylor *et al.*, 2000) suggesting a beneficial effect on shrews of eradicating Norway rats.

Here we show that eradication of the Norway rat demonstrates a detrimental impact of this species on populations of two shrew species, the lesser white-toothed shrew, *Crocidura suaveolens* (Pallas 1811) and the greater white-toothed shrew, *C. russula* (Hermann 1780) in the Brittany islands.

METHODS

All operations described below occurred in the Sept-Îles Archipelago (Moines, Les Mottes, Bono and Rouzic islands), Molène Archipelago (Béniguet and Trielen islands), and an isolated island, Tomé (Fig. 1).

Table 1 lists some geographical characteristics plus the map area of each island. Estimated surface areas are approximately twice the map areas for most islands. This is because most islands have substantial relief, except for Béniguet and Trielen, which are flat. Bono, Les Mottes, and Moines are connected during low tide by a bare pebble isthmus, but all the other islands are fully isolated. All islands except for Rouzic and Les Mottes host the rabbit, *Oryctolagus cuniculus* (Linnaeus 1758). Tomé hosts *C. russula*, while all the other islands contain *C. suaveolens*. The current mammal list for these islands includes only one other species; the western house mouse, *Mus domesticus* Schwarz & Schwarz 1943, occupies only Béniguet, which did not have the rat (Pascal *et al.*, 1994). Like the Norway rat, the rabbit and the mouse are not native to these islands (Pascal *et al.*, 2003).

In the Sept-Îles Archipelago, Rouzic was cleared of Norway rats in 1951 by strychnine poisoning (Lorvelec & Pascal, 2005). The Norway rat was eradicated from all the other islands within this archipelago in September and October 1994, from Trielen in September 1996 and from Tomé in September and October 2002 by means of a two-step method described by Pascal *et al.* (1996). This method starts with intense trapping that removes over 90%

of the rats. The second step entails using baits containing an anti-coagulant (Bromadiolone®) scattered in bait-stations. For several islands, the list of mammal species present before eradication attempts was unavailable. Moreover, the spatial distributions of mammals on all islands were unknown.

The first trapping operation of the Sept-Îles eradication attempt was therefore planned partly in order to perform this species inventory and to gain information on spatial distributions. Eventually, we set 396 trapping posts on a square grid of 30 m × 30 m; each trapping post was equipped with two live traps. One was a Manufrance® trap devoted to *Rattus* captures and the other an INRA® trap aimed at smaller mammals like shrews and house mice. We baited all traps with a mixture of peanut butter, oat flakes and sardine oil. At Bono, Les Mottes, and Moines, there were 269, 7 and 78 trapping posts, respectively; we reduced the number of trapping posts equipped with INRA® traps to 40 for Moines. We checked all Manufrance® traps daily for 16–24 days (depending on island) and all INRA® traps daily for 8 days. We reset a subset of the initial square grid trapping system in 1998 with only INRA® traps, using 200, 9 and 20 traps on Bono, Les Mottes, and Moines, respectively. We checked these traps daily for 6 days. In 1999, we set line transects of 25 and 16 INRA® traps on Bono and Rouzic, respectively; the distance between traps was 30 m. We checked these traps daily for 5 days. In 2004, we again set 25, 40, 10 and 38 INRA® traps on Bono, Moines, Les Mottes and Rouzic, respectively. We checked these traps daily for 4 days.

In 1994, two years before the Norway rat eradication attempt in Trielen Island, we set a line transect of 58 INRA® traps that we checked daily for 5 days; the distance between traps was 30 m. In 2004, 8 years after the Norway rat eradication, we reset a line transect of 50 INRA® traps: the distance between traps was 6 m. We checked these traps daily for 3 days.

On Tomé, before the rat eradication, we set 100 INRA® traps 30 m apart along line transects and checked these traps daily for 4 days. We then set 660 trapping posts equipped only with Manufrance® traps to eradicate Norway rats. In 2003 and 2004, we used the same INRA® trapping protocol but reduced the daily checking to 3 days in 2004.

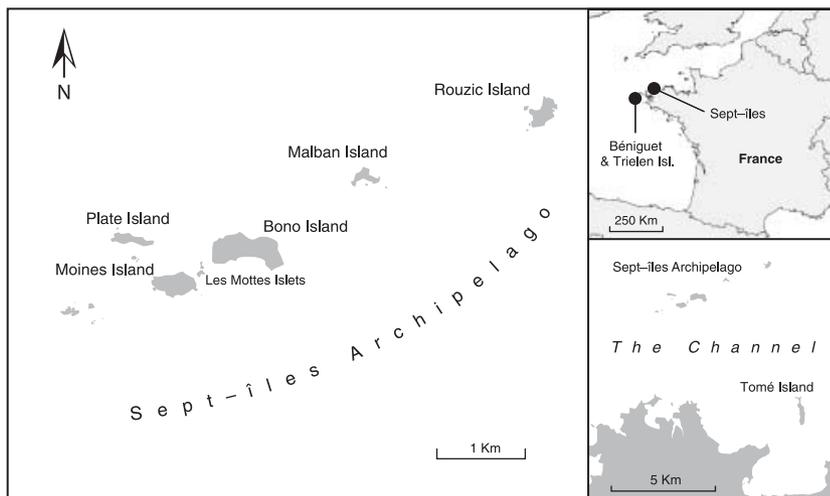


Figure 1 Archipelago and island locations.

As there is no knowledge of the population dynamics and natural history of the insular populations of the two shrew species, we conducted research on Béniguet Island, which is free of rats and hosts the lesser white-toothed shrew. For this purpose we set a 30 m × 30 m square grid of 131 INRA© traps annually from 1998 to 2004, in June or July each year. We checked traps daily for 7 days (6 days in 1999).

We sacrificed all trapped rats and mice in the field and stored each specimen in a plastic bag before performing necropsies in the laboratory. We tagged all trapped shrews by a one-phalanx amputation before releasing them. This tagging technique prevented individual monitoring but allowed us to discard recaptures from population counts.

As the number of traps and the trapping period varied between sampling operations, we defined as an abundance index the number of trapped shrews per trap night and used this index to compare results. Rabbits and tourists occasionally sprung traps:

we reduced the number of tabulated trap nights accordingly. INRA© traps captured both lesser white-toothed shrews and mice on Béniguet. Because traps occupied by mice were unavailable for shrews, we reduced the number of tabulated trap nights by the number of trapped mice.

RESULTS

The numbers of Norway rats trapped during the eradication attempts were 656, 154 and 520 for the Sept-Îles Archipelago, Trielen Island and Tomé Island, respectively. One year after these attempts, we concluded from the trapping results that the Norway rat had been eradicated. We confirmed this conclusion through yearly observations until the end of 2004.

Table 1 includes all information about the trapping effort, i.e. the number of trap nights, the number of shrew captures, and the value of the abundance index.

Table 1 Abundance index (AI = number of trapped shrews, N, per trap nights, T) of *C. Russula* (Tomé Island only) and *C. Suaveolens*; island area in ha

Archipelago	Sept-Îles				Tomé	Molène	
	Bono 21	Moines 9	Mottes 0.2	Rouzic 3	Tomé 30	Trielen 17	Béniguet 60
1994							
T	2035	295	28			290	
N	15	0	0			1	
AI	0.007	0	0			0.004	
1998							
T	1200	100	54				855
N	126	5	6				62
AI	0.105	0.050	0.111				0.073
1999							
T	125			80			695
N	22			31			51
AI	0.176			0.388			0.073
2000							
T							810
N							41
AI							0.051
2001							
T							835
N							94
AI							0.113
2002							
T					400		837
N					7		60
AI					0.018		0.072
2003							
T					400		781
N					63		84
AI					0.158		0.108
2004							
T	99	147	39	140	287	150	843
N	9	20	5	33	90	19	38
AI	0.091	0.136	0.128	0.236	0.314	0.127	0.045

Abundance index (AI) of *Crociodura russula* (Tomé Island only) and *C. suaveolens* (AI = N/T; N: number of trapped shrews; T: number of trap-nights).

For Bono, the abundance index of the lesser white-toothed shrew increased by a factor of 15, 25 and 13, respectively, 4, 5 and 10 years after the rat was eradicated.

For Trielen, the abundance index of the same species increased by a factor of 32 eight years after rat eradication.

On Les Mottes and Moines no shrew was trapped during the 1994 sampling, a result that implies a very low density at most. If we hypothesize that the true value of the abundance index for both islands was the same as the one recorded for Bono in 1994, the year of eradication, then 4 and 10 years after the Norway rat was eradicated, the abundance indices had increased by factors of 16 and 18 on Les Mottes and 7 and 19 on Moines, respectively. The 1951 shrew abundance index for Rouzic was unknown. If the value of this abundance index was the same as the one recorded for Bono in 1994 before rat eradication, this index had increased by a factor 55 and 34 between the eradication and 1999 and between the eradication and 2004, respectively, i.e. 48 and 53 years after eradication.

The abundance index of the greater white-toothed shrew on Tomé increased by a factor of 9 and 17 one and two years after rat eradication, respectively.

During the seven years, 1998–2004, the abundance index of the lesser white-toothed shrew from rat-free Béniguet varied between 0.045 and 0.113, i.e. a factor of 2.5.

The distributions of captures of Norway rats and lesser white-toothed shrews during the Bono Island 1994 eradication campaign and the 1998 control operation are plotted in Fig. 2. The distribution of rat captures shows that the species was concentrated on the north coast of the island and on the western and central part of its central plateau. At the same time, the shrew distribution showed two peaks, the first located on the eastern summit and abrupt slope of the central plateau, the second on the summit of the southern slope of the central plateau. A lone shrew was caught on the westernmost shore of the island. The 1998 shrew distribution still showed an eastern peak, whose area increased in comparison to that of 1994 and reached the north-eastern shore. It also showed a south-central peak that encompassed the entire central plateau and reached the northern shore. Moreover, a third peak appeared on the western shore.

DISCUSSION

Rather few island mammal declines and extinctions are attributed to rats, but this paucity may be attributable to the fact that relatively few small islands invaded by rats had native mammals, at least native mammals adequately researched to know of their existence and guess at the causes of their declines. Nevertheless, the introduction of *R. rattus* in Corsica between the fourth and the second century BC (Pascal & Vigne, 2003b) is suspected to have dramatically contributed to the extinction during the Roman period of two endemic rodents from Corsica and Sardinia, *Rhagamys orthodon* and *Prolagus sardus* (Vigne & Valladas, 1996; Vigne, 2003a,b). More recently, extinctions of Darwin's Galapagos mouse (*Nesoryzomys darwini*) (Baillie, 1996a), the Hispaniolan edible rat (*Brotomys voratus*) (Baillie, 1996b) and several *Oryzomys* rodents endemic to the Lesser Antilles (Pinchon,

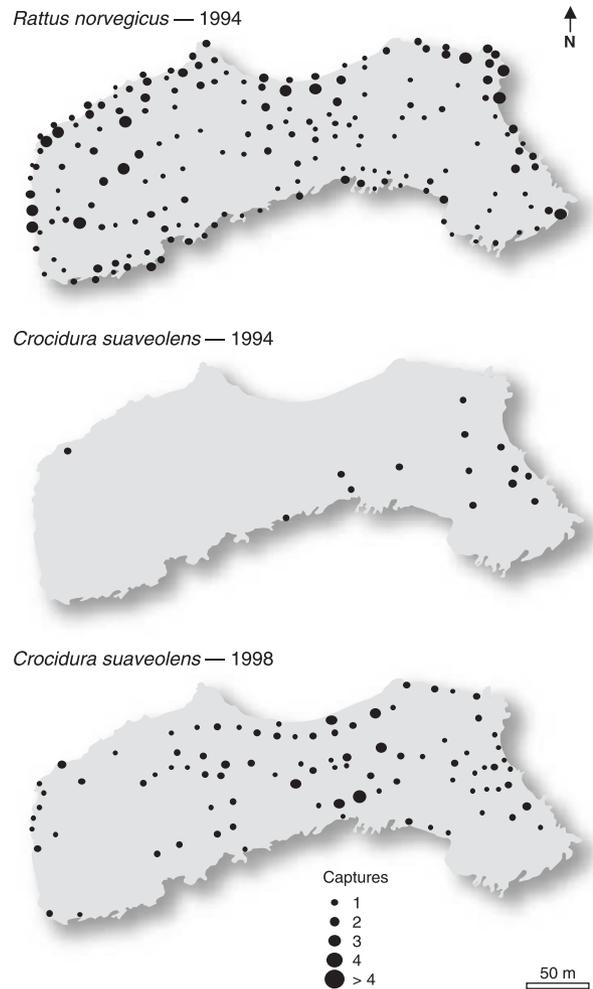


Figure 2 Distributions of *R. norvegicus* during eradication attempt and *C. Suaveolens* before rat eradication (1994) and four years later (1998) (Bono Island, Sept-Îles Archipelago, Brittany).

1967; Lescure, 1979) have been attributed at least partly to interactions with both *R. norvegicus* and *R. rattus*; admittedly, quantitative data are lacking in these cases. *R. rattus* probably contributed to the extinction of deer mice (*Peromyscus maniculatus anacapa*) from East Anacapa Island in the California Channel Islands (Collins, 1979). Eradication of the rat and reintroduction of the mouse have led to high mouse densities (B. Tershie, pers. comm.).

Our data show that the Bono lesser white-toothed shrew abundance indexes were very close on Bono and Trielen islands when rats were present. These indexes increased greatly after Norway rat eradication on all the islands under study. This phenomenon may be explained in two ways: (i) a strong interaction between shrews and rats, or (ii) strong yearly fluctuation of shrew abundance.

The maximum variation of the shrew abundance index checked for 7 years on the rat-free island of Béniguet (2.5) was three to 10 times lower than the differences between pre- and posteradication abundance indexes depending on the island and the year

that were considered. This fact does not support the second hypothesis. Moreover, the restricted areas and habitats (rocky slopes and cliffs) that shrews occupied when rats were present on Bono were those less densely populated by rats, and, after the rat disappearance, the shrews spread all over the island, mainly occupying places that rats had previously heavily occupied. These facts support the first hypothesis of a strong interaction between the two species.

What might this interaction be? Competition for food, with rats reducing the local insect production by their scavenging? Rats preventing shrews from reaching the coast, which is rich in invertebrates? Predation? Interactions of another type? On Langara Island (British Columbia), Taylor *et al.* (2000) noted unquantified reports that populations of the dusky shrew (*Sorex obscurus*) increased after eradication of Norway rats and speculated that reduced competition for insect prey and possibly decreased predation may have been at play. Our data do not permit us to choose among these hypotheses.

Three fully isolated islands of the Sept-Îles Archipelago (Île aux Rats, Île Platte and Malban) were free of shrews before rat eradication. During 1998, 1999 and 2004, controls showed that these islands remained free of shrews. Under the hypothesis that shrews were absent from the very small islets of Les Mottes when rats were present, the shrews trapped on Les Mottes after rat eradication must have come from the neighbouring Bono or Moines islands. This would imply that the species can cross the isthmus between Bono and Les Mottes or between Les Mottes and Moines; the distances are 125 m and 50 m, respectively. Although these bare pebble isthmuses are above sea level at low tide twice daily for 3 h, they contain many tidal pools and are often covered by sea spray. However, although the shrew is a very small terrestrial mammal (7 g), it intensively prospected pebble shores when foraging (Pascal *et al.* unpublished data).

In conclusion, the disappearance of the Norway rat induced (i) an increase of the abundance index of the lesser white-toothed shrew; (ii) the spread of the shrew over the islands; and (iii) the colonization, locally in high density, of habitats where the shrew had been absent when the rat was present. Moreover, data on the greater white-toothed shrew from Tomé converged with those on the lesser white-toothed shrew and support the hypothesis that the Norway rat has a generally detrimental impact on *Crocidura* shrew species.

The main way this detrimental impact was demonstrated was that the qualitative and quantitative evaluation of the impact of the disappearance of non-indigenous species on the local fauna and flora was included in the eradication protocol at the outset of the project. We detected this detrimental effect because of the rigor of the sampling procedure. In our view, this example demonstrates how useful an eradication operation can be for both scientists and managers if it is planned as an experiment in research and management.

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