

Habitat use and potential interactions between the house mouse and lesser white-toothed shrew on an island undergoing habitat restoration

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To forecast the potential impact of plant community and dry-stone wall restoration on an insular population of the lesser white-toothed shrew *Crocidura suaveolens* Pallas, 1811, shrew and house mouse *Mus musculus* Linnaeus, 1758 abundances were assessed in 3 anthropogenic habitats on Béniguet Island, Brittany, France, by a standardised annual trapping system checked yearly for 9 years and in 6 “natural” habitats by trap-lines. The standardised trapping system showed that abundances of both species fluctuated synchronously for nine years, suggesting that interactions between the species had little impact if any on abundances. Mice were trapped in all habitats, but shrews only in «stone» habitats except for rare occurrences in one damp depression. Ruderal habitat was rarely used by either species. Data suggest that on Béniguet Island: (1) *M. musculus* is associated with anthropogenic habitats but is not as strictly tied to them as at nearby continental sites; (2) *C. suaveolens* is synanthropic, as has been reported in continental northern France; (3) shingle beaches and seashore food resources are particularly important for *C. suaveolens*; (4) the relationship between *C. suaveolens* and *M. musculus* could not be determined by the experiments and, if it exists at all, appears to be more competitive than predatory. Grassland restoration is unlikely to affect shrew populations. Dry-stone wall restoration may temporarily affect shrews but should ultimately benefit them.

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Introduction

Béniguet Island, a wildlife sanctuary in the Molène Archipelago (Brittany, France), hosts

three mammal species: the lesser white-toothed shrew *Crocidura suaveolens* (Pallas, 1811), the western subspecies *domesticus* Schwarz and Schwarz, 1943 of the house mouse *Mus musculus*

Linnaeus, 1758, and the European rabbit *Oryctolagus cuniculus* (Pascal *et al.* 1994). *C. suaveolens* occurred in the continental Mediterranean area of France in the early Holocene (9200 BC in Western Europe; Poitevin *et al.* 1990, Mistrot 2001). Thereafter it invaded part of France north of the Loire River (Pascal *et al.* 2006), the British Channel Islands (Jersey, Sark), and the Scilly Archipelago (Corbet 1961, Yalden 1999). It was present since 1500 BC in archaeological sites of several islands of the Molène Archipelago (Pascal *et al.* 2006, A. Tresset, pers. comm.). Nowadays, this species occupies a wide range of habitats within the southern part of its western European distribution but in its northernmost range remains close to buildings, gardens and parks, behaving as a synanthropic species (Libois *et al.* 1999). *C. suaveolens* has declined in northern France and is on the verge of extinction in continental Brittany, the only healthy populations being insular ones (Pascal *et al.* 2006). Moreover, when introduced to islands, the greater white-toothed shrew *Crocidura russula*, an alien Holocene species for France, induced quick extinction of *C. suaveolens* (Cosson *et al.* 1996, Pascal *et al.* 2006).

The house mouse did not reach France before the middle of the first millennium BC (Auffray *et al.* 1990, Vigne 1997). It behaves as a commensal species, always found close to buildings in the non-Mediterranean part of France. The Béniguet population is an exception, a preliminary inventory of the island mammal fauna having shown that the species occupied various natural habitats far from human settlements (Pascal *et al.* 2006). The rabbit was introduced north of the Loire River during the 9th century AD (Callou 1995, 2003), and the genetics of Béniguet rabbits show a southwestern Iberian component, suggesting recent introduction (Letty *et al.* 2007).

One goal of the European Union program Life Nature “Archipels et îlots marins de Bretagne” (1999–2001) was to develop a strategy to restore maritime grasslands on Béniguet Island (Le Nevé 2002). This habitat is listed as being of European interest for conservation under the Euro-

pean Council Directive on the conservation of natural habitats and of wild fauna and flora (Anonymous 1992). The question of the potential impact of plant community restoration on the local *C. suaveolens* population arose. As data on the life history of insular *C. suaveolens* populations were scarce, an investigation of abundance was planned for all main habitats. This investigation offered an opportunity to study the synanthropic behaviour of this species in an unusual environment by tallying its distribution among human artefacts (buildings and the network of dry-stone walls) and to assess the potential consequences of the planned restoration of dry-stone walls. This investigation also entailed the study of the distribution of *M. musculus* over several insular habitats and allowed us to enhance the description of its linkage to human dwellings, which is not as strict in this insular context as in continental populations in northern France. Finally, when rats are not present (as on Béniguet), introduced house mice can prey on native animal species with devastating impact (Wanless *et al.* 2007, Angel *et al.* 2008).

Our goals in this study are (1) to define more precisely habitat use by *C. suaveolens* on Béniguet Island, (2) to investigate aspects of the relationship between *C. suaveolens* and *M. musculus*, (3) to predict the possible consequences for the shrew of a habitat restoration project on the island, either directly through modification of habitat availability or indirectly through changed populations of a potentially interacting species, the house mouse.

Study area and restoration processes

Béniguet Island (48°21'N, 4°51'W; 60 ha; 2.3 km long; max 0.5 km width) is flat (maximum elevation 16 m a.s.l.) and lies ca five km from continental Brittany (Fig. 1a). Agricultural activities were present until 1954, and permanent human impact ceased in 1984 when the last permanent warden left the island (Yésou and d'Escrienne 2007).

The major means of restoring maritime grasslands on Béniguet has consisted of mowing several times, at precise times of the year, several bracken plots that were located close to well preserved maritime grassland strips. It was assumed that preventing bracken from overgrowing plots

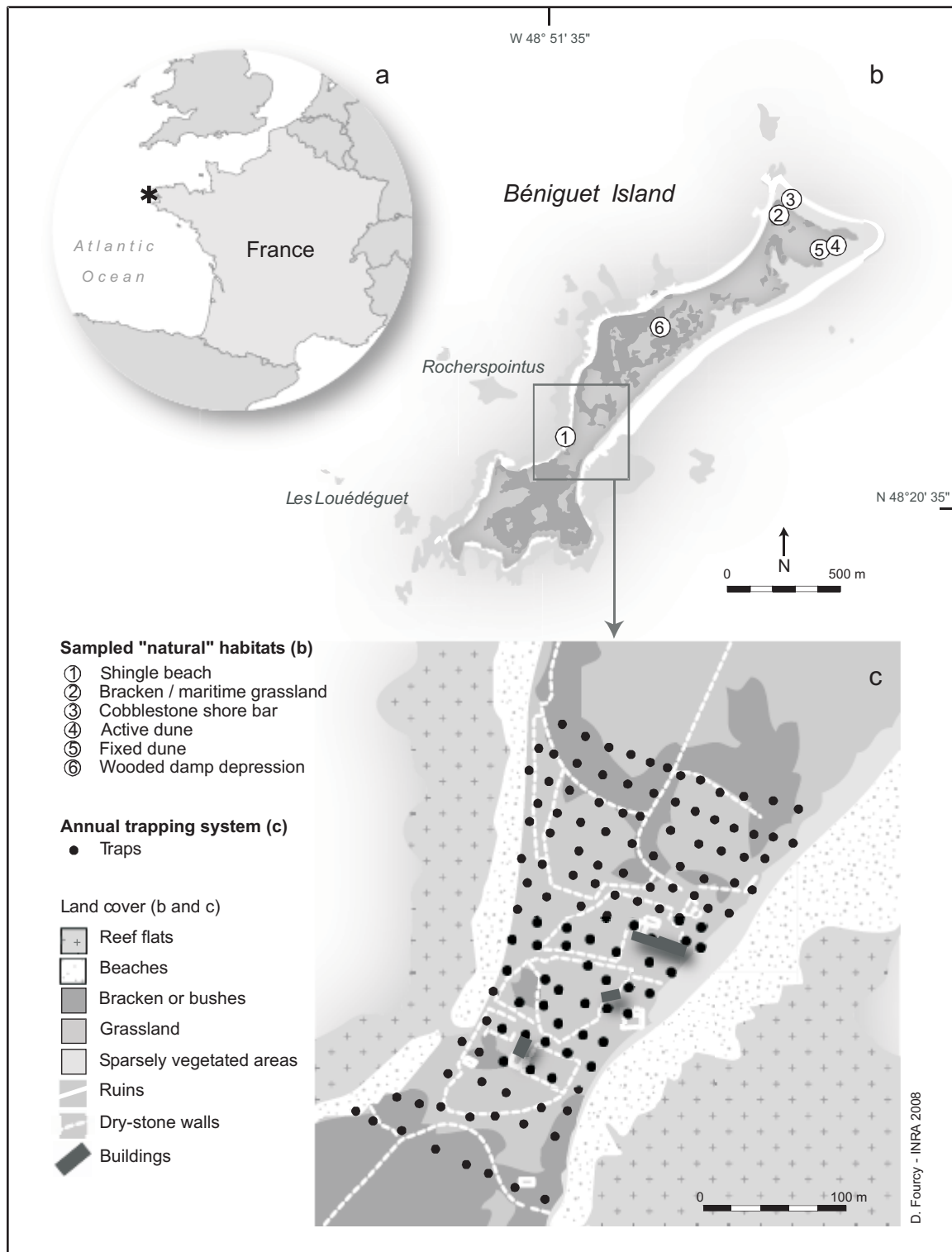


Fig. 1. Location of Béniguet Island off the coast of Brittany, in the Molène Archipelago (a). Location of trap lines set on Béniguet Island according to habitat (b), and trap locations of the standardised annual trapping system (c).

would afford maritime grassland plants the opportunity to reoccupy lost areas. The dense network of dry-stone walls was erected in the past to lessen the impact of wind on crops. The main source of stones was cultivated plots, and lack of maintenance for half a century led to the total collapse of many walls. Priority was given to reconstructing these walls and restoration has entailed removing all the stones and rebuilding walls at their previous locations using the original techniques.

Material and methods

To assess inter-annual fluctuations in *C. suaveolens* and *M. musculus* abundance, a trapping system of 131 INRA live-traps (Guédon *et al.* 1990) was set up for one week (seven days except for 1999 – six days, and 2000 – eight days) in June or July each year from 1998 to 2006. This standardised annual trapping system consisted of 16 almost parallel lines crossing the narrowest part of the island from the western to the eastern coast (Fig. 1c). Distance between lines was between 20 and 30 m. Traps of each line were set 20 m from each other at precisely the same place (determined by GPS) each year. Humans occupied the central area of the island since at least the Neolithic period (Dreano *et al.* 2007), and this area presently holds all the buildings that are not ruined and most of the well preserved dry-stone walls. Owing to this ancient and permanent human settlement, this area is characterised by ruderal vegetation. Three among the most anthropogenic habitats of the island were sampled by virtue of the standardised annual trapping system: dry-stone wall, masonry wall, and ruderal vegetation.

To complement the standardised annual trapping system, the abundance of both species was assessed in six contrasting “natural” insular habitats that were described by Bioret *et al.* (1989) and Bioret (2007). We used nine lines of 20 INRA traps each, the first set in July 1999, the other eight in July 2002 (Fig. 1b). Traps were 20 m from each other as in the standardised annual trapping system. The 1999 line was operated for five days along the foot of a cliff three meters high fringing a western shingle beach (“W. shingle beach”) reached by waves during the highest tides. In 2002, five habitats were sampled, four with one line each, the last (“wooded damp depression”) with four lines, all operated for six days. The first habitat, “bracken/maritime grassland”, was a boundary between bracken *Pteridium aquilinum* and maritime grassland dominated by *Armeria maritima*. The second, “N. cobblestone shore bar”, was the top of the northern 10 m high cobblestone shore bar, which was free of vascular vegetation and never covered by the sea. The third, “active dune,” was the backside of an embryonic shifting dune covered by maritime grassland dominated by *Silene maritima* and undergoing colonisation by bracken *P. aquilinum*. The sandy soil of this dune contained some shingles. The fourth, “fixed dune,” was the upper part of a sandy fixed coastal dune covered by vegetation dominated by *S. maritima* and *Erodium cicutarium* with a nitrophilous *Senecio jacobaea* facies. The last, “wooded damp depression,” was a damp depression with the only wooded plot (planted willow *Salix atrocinerea*) on the island.

All traps were baited with a mixture of oat-flakes, peanut butter and sardine oil. A preliminary experiment using a trap-line of 20 traps checked every two hours for five days provided 53 *C. suaveolens* capture events, including 23 recaptures. As 43 (80%) of these capture events occurred during night time, we chose to keep traps open day and night and to check traps daily in early morning. This option did not completely prevent mortality, but mortality remained low (16 individuals for all the experiments), probably because of the insular temperate climate. All trapped mice were euthanized. All shrews were marked by a one-phalanx toe amputation and immediately released where trapped. As a different toe was used each year, this marking technique allowed us to know the year each shrew was trapped for the first time, but it did not allow precise individual monitoring from year to year. Nevertheless, hair cutting showed that a shrew had been trapped previously during the trapping session. Hair cutting also showed that shrews were mainly recaptured in the same trap. Moreover, when a shrew was captured in several traps, the number was never more than four, and the four were always in the same habitat, and always in the same line for the standardised annual trapping system as well as for the trap-lines set in “natural” habitats. Phalanxes were preserved in ethyl alcohol for genetic studies (Calmet *et al.* 2004). All field operations were performed under control of the rangers of the National Office of Game and Wildlife.

As the number of trap-nights differed among sampling operations, we computed an abundance index (*MmA* for the mouse, *CsA* for the shrew) in order to compare abundances. This index was the ratio of the number of trapped animals to the number of trap-nights. As mice were removed, each could be trapped only once. As shrews were released and may be trapped several times, the number used for this species was the number of individuals trapped for the first time in each session.

When checked, several traps appeared to be inoperative for one or both of the target species. Traps were inoperative for both species when they were found closed and empty, a situation usually caused by gulls or rabbits. Traps were inoperative for one species when they contained an individual of the other species, or, for shrews, when they contained an individual previously trapped during the same trapping session. Consequently, the number of trap-nights used to compute abundance indexes was the number of functional trap-nights for each target species. Mouse and shrew abundance indexes were computed as follows:

$$MmA = MmC / (NT - NTO - CsC)$$

$$CsA = (CsC - CsR) / (NT - NTO - CsR - MmC)$$

MmC and *CsC* are the number of trapping events for mice and shrews respectively, *CsR* is the number of shrew recaptures, *NT* is the trap-night total number, and *NTO* is the number of trap-nights the trap was inoperative for both target species.

To compare species abundances between anthropogenic and “natural” habitats, we performed χ^2 tests on trapping frequencies: *MmC* and $(CsC - CsR)$ vs $(NT - NTO - CsC)$ and $(NT - NTO - CsR - MmC)$ for mice and shrews, respectively. We used either 1999 or 2002 data provided by the standardised annual trapping system to compare anthropogenic habitats with W. shingle beach habitat and with the other “natural” habitats, respectively.

Results

The total trapping effort of 9233 trap-nights for the combined sampling operations yielded

849 mice and 579 shrews plus 176 shrew recaptures (Table 1). Figure 2 shows the variation in the abundance index for both species as given by the standardised annual trapping system during

Table 1. *Crocidura suaveolens* and *Mus musculus* trapping data recorded during 9 consecutive years in 3 anthropogenic habitats with the standardised annual trapping system and during 2 years in 6 other habitats with trap lines (NT – night-trap total number, NTO – number of trap-nights the trap was inoperative for both target species, MmC – number of trapped *M. musculus*, CsC – total number of *C. suaveolens* capture events, CsR – *C. suaveolens* recapture number).

Year	Habitat	NT	NTO	MmC	CsC	CsR
Standardized annual one-week trapping censuses trapping census						
1998	Ruderal	525	38	24	30	15
	Masonry wall	147	7	16	12	4
	Dry-stone wall	245	17	22	23	7
1999	Ruderal	450	78	32	21	0
	Masonry wall	126	20	17	16	0
	Dry-stone wall	210	32	42	24	0
2000	Ruderal	600	100	18	11	0
	Masonry wall	168	14	15	3	0
	Dry-stone wall	280	26	49	13	2
2001	Ruderal	525	76	28	36	12
	Masonry wall	147	11	15	20	12
	Dry-stone wall	245	25	39	39	12
2002	Ruderal	525	84	29	17	5
	Masonry wall	147	12	18	9	2
	Dry-stone wall	245	31	34	31	9
2003	Ruderal	525	61	58	22	15
	Masonry wall	147	19	22	14	7
	Dry-stone wall	245	43	40	46	18
2004	Ruderal	525	84	27	6	2
	Masonry wall	147	7	15	9	1
	Dry-stone wall	245	21	33	23	6
2005	Ruderal	525	82	37	25	5
	Masonry wall	147	20	18	18	8
	Dry-stone wall	245	24	39	47	20
2006	Ruderal	525	68	26	10	1
	Masonry wall	147	6	25	5	5
	Dry-stone wall	245	29	31	18	5
Total	Ruderal	4725	671	279	178	55
	Masonry wall	1323	116	161	106	39
	Dry-stone wall	2205	248	329	264	79
Trap line censuses						
1999	W. shingle beach	100	0	5	15	0
2002	N. Cobblestone offshore bar	120	14	23	8	2
2002	Wooded damp depression	400	29	2	8	1
2002	Active dune	120	23	16	0	0
2002	Bracken/maritime grassland	120	13	23	0	0
2002	Fixed dune	120	16	11	0	0

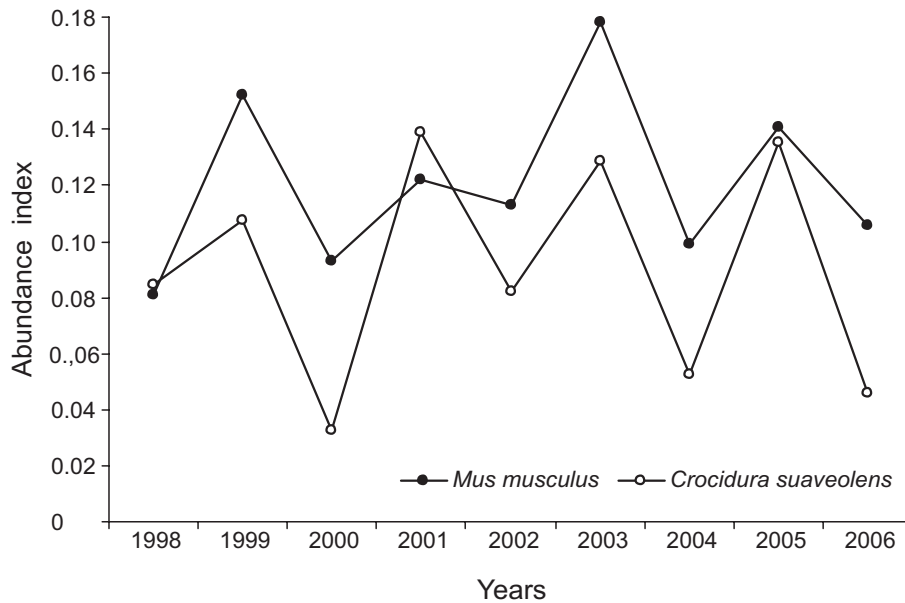


Fig. 2. Nine-year abundance index variation of *Crocidura suaveolens* and *Mus musculus* determined by the standardised annual trapping system.

the nine study years. For both species, abundance indexes have fluctuated around mid-values of 0.108 for *C. suaveolens* and 0.143 for *M. musculus*, with no overall tendency; the highest values were 4.7 and 2.2 times the lowest for *C. suaveolens* and *M. musculus*, respectively. Every year but 2001, the mouse abundance index exceeded or at least equaled that of the shrew. Moreover, the yearly changes in abundance indexes for the two species were synchronous.

Figure 3 shows variation in abundance indexes of both species as recorded in the standardised annual trapping system in the three most anthropogenic habitats. Data collected with the standardised annual trapping system over the 1998–2006 period show that trapping frequencies of both species were significantly higher near dry-stone walls than near masonry ones and significantly lower in ruderal habitats than near the two types of wall (χ^2 -test: $p < 0.0001$). Moreover, the abundance index in the three most anthropogenic habitats changed in the same direction for each species from year to year, except for that of the mouse in 2002 and 2006.

The 1999 data were used to compare species trapping frequencies recorded in anthropogenic and W. shingle beach habitats. For both species, trapping frequencies remained significantly higher near dry-stone and masonry walls than in ruderal habitats but did not differ significantly between dry-stone and masonry walls (Table 2). Further, mouse trapping frequency was significantly lower along shingle beach habitat than near dry-stone and masonry walls, but this was not the case for the shrew.

The 2002 data show that shrews were absent from the bracken/maritime grassland and from the active and fixed dune habitats. Mouse trapping frequencies were not significantly different in these habitats than near masonry and dry-stone walls except for the fixed dune, which was significantly less occupied than dry-stone walls (Table 3). Trapping frequencies recorded for both species near masonry and dry-stone walls of the standardised annual trapping system did not significantly differ from those obtained along the cobblestone shore bar, which was 10 m high, and were significantly higher than those recorded in the wooded depression.

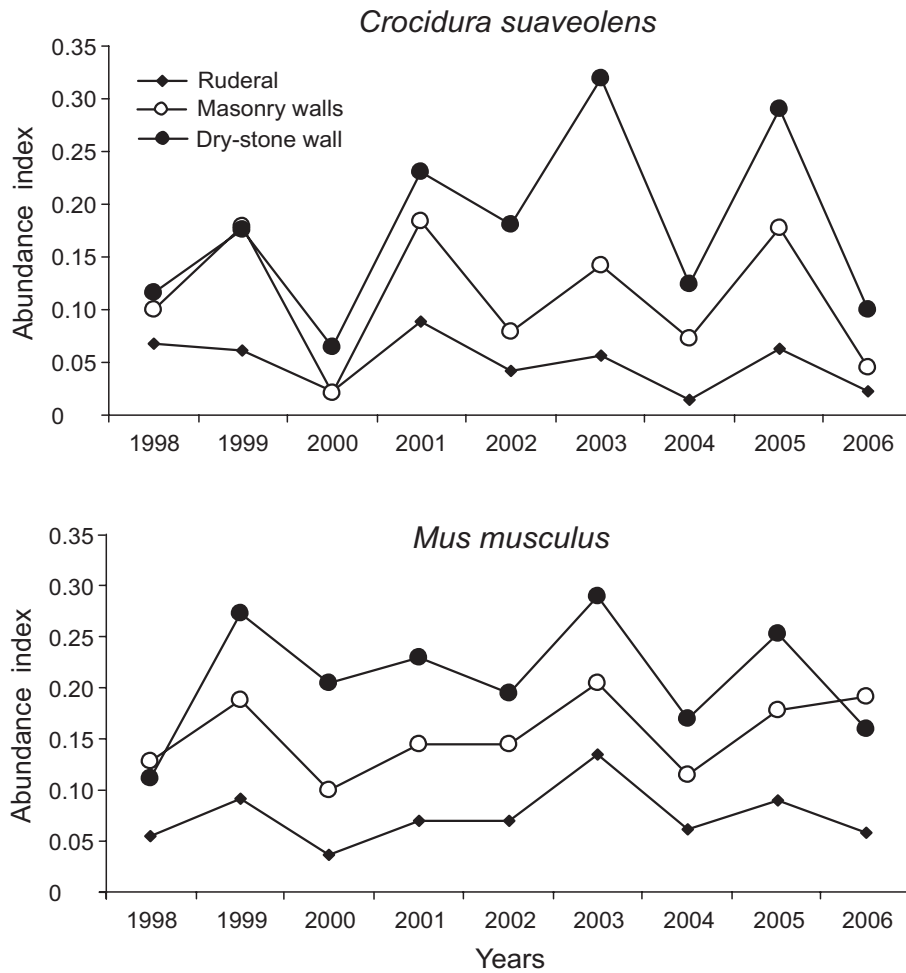


Fig. 3. Nine-year surveys of *Crocidura suaveolens* and *Mus musculus* abundance indexes in the three most anthropogenic habitats sampled by the standardised annual trapping system.

Table 2. χ^2 probabilities obtained when 1999 trapping frequencies of *Crocidura suaveolens* and *Mus musculus* recorded in the three habitats sampled by the standardised annual trapping system are compared with trapping frequencies obtained with trap line set in the western shingle beach habitat (ns – not significant, ** – $p < 0.01$, *** – $p < 0.001$).

	W. shingle beach	Ruderal	Masonry wall	Dry-stone wall
<i>Mus musculus</i>				
W. shingle beach		ns	**	***
Ruderal	**		**	***
Masonry wall	ns	***		ns
Dry-stone wall	ns	***	ns	
<i>Crocidura suaveolens</i>				

Table 3. χ^2 probabilities obtained when 2002 trapping frequencies of *Crocidura suaveolens* and *Mus musculus* recorded in the 3 habitats sampled by the standardised annual trapping system are compared with trapping frequencies obtained with trap lines set in 5 other habitats (CB – N. cobblestone shore bar, WD – wooded damp depression, AD – active dune, BG – bracken/maritime grassland, FD – fixed dune, R – ruderal, MW – masonry wall, SW – dry-stone wall, ns – not significant, * – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$, dots reflect absence of capture of *C. suaveolens* in one or both habitats).

	CB	WD	AD	BG	FD	R	MW	SW
<i>Mus musculus</i>								
CB		***	ns	ns	*	***	ns	ns
WD	***		***	***	***	***	***	***
AD	.	.		ns	ns	**	ns	ns
BG	.	.	.		*	***	ns	ns
FD		ns	ns	*
R	*	ns	.	.	.		**	***
MW	ns	**	.	.	.	ns		ns
SW	ns	***	.	.	.	***	*	
<i>Crocidura suaveolens</i>								

Discussion

The abundance indexes of the two species varied synchronously, showing no long-term trend. These results suggest that abundances of both species may be controlled by similar sets of constraints, and interactions between the species, if any, were either too rare to allow detection with the trapping system or had little impact on abundances. The second suggestion contrasts with the conclusion of a previous study that showed that another alien murid, the Norway rat *Rattus norvegicus*, strongly affected shrew abundance in another archipelago in the same region (Pascal *et al.* 2005). Although this rat-shrew relationship was elucidated in an eradication context that is quite different from the present one, the contrasting results suggest that the impact of invasive species must be investigated case by case even for related taxa. Three years after the successful eradication of the Norway rat from the Cancale Archipelago Islands (Pascal *et al.* 1996), there was an outbreak of the house mouse, which was present before eradication, but we have no data on consequences of this outbreak. Rat eradication on islands is often followed by explosion of house mouse populations; Caut *et al.* (2007) cite eight

such examples (mostly unpublished), and a similar explosion after rat eradication occurred on Quail Island, New Zealand (M. Bowie, pers. comm. 2007).

Over the nine years, both the shrew and the mouse were systematically more frequently trapped near dry-stone and masonry walls than in ruderal vegetation. Moreover, both species were more frequently found in dry-stone walls than in masonry ones, except on two occasions for the mouse. These results accord with previous descriptions of *C. suaveolens* behaving synanthropically in continental northern France (Libois *et al.* 1999) and *M. musculus* behaving as a commensal found in or close to buildings in the non-Mediterranean part of its French range (Pascal *et al.* 2006).

For both species, abundances changed in the same direction between years in all three habitats of the standardised annual trapping system, except for the mouse in 2002 and 2006. This fact suggests that each habitat played the same role each year, none of them acting as a refuge in any particular year, even when abundances were low.

Although the shrew abundance index took into account recaptures only for determining the number of inoperative traps, the fact that

shrews were always captured and recaptured in the same line and in the same habitat of each line increases our confidence in the abundance index values. Though this observation is trivial for lines set in “natural” habitats, because distance between two lines was always large, this is not the case for the standardised annual trapping system. The lines of the trapping system were set along paths, dry-stone walls and building walls, which are east-west linear landscape features giving access to the seashore. These linear features are not only habitats for small mammals but act as pathways for them as well, increasing capture probability, as the trap intercepts target species. We deliberately chose this trap arrangement for these reasons, and trapping results accord with this choice.

Abundance indexes indicate that mice were trapped in all sampled habitats, but shrews were absent from three of them. Though the mouse abundance index in the dry-stone wall habitat was one of the three highest found for the species, indexes obtained in two “natural” habitats situated more than one km from buildings and dry-stone walls (shingle coastal bar and bracken/maritime grassland) were even higher. This fact indicates that, on a small island lacking any murid competitor, the house mouse does not behave strictly as a commensal as on the nearby continent (Auffray *et al.* 1988) or on islands where another murid species occur (Pascal *et al.* 2002, 2006). To our knowledge, the Béniguet house mouse is currently the only population occupying natural habitats in the non-Mediterranean part of France (Pascal *et al.* 2006).

The four highest shrew abundances were in stony habitats (dry-stone walls, shingle beach, masonry walls and shingle coastal bar), which probably provide shelter and/or food. Indeed, Heim de Balzac (1951) noted the high trapping frequency of *C. suaveolens* on shingle beaches of Ushant. As shingle beaches are inundated during the highest tides, this habitat cannot provide permanent shelter, so high shrew abundances in this habitat may be related to food. If this hypothesis is correct, it points to a major role this habitat plays for this species on French Atlantic and Channel islands.

The ranking of abundance indexes of both species by sampled habitats shows partial sharing of habitat, though nothing resembling total overlap. The habitat distribution of the mouse is wider than that of shrew, which is restricted to stony habitats except for the wooded damp depression. On Béniguet Island, the mouse appears to depend less than the shrew on human dwellings and stony habitats.

Neither the Norway rat eradication (Pascal *et al.* 2005) nor the present study were planned specifically to address the kind of relationship occurring between the shrew and the two alien rodents, but circumstantial evidence from both operations serves this purpose. Rats were introduced to Bono Island no more than two centuries ago; when rats were present the shrew abundance index (0.007) was 50 times lower than on an island without rats in the same archipelago, and shrews were restricted to a very small area away from the seashore. Four years after rat eradication, the shrew abundance index increased 15-fold, and shrews were distributed over a major part of the island, reaching the seashore. In the present study, the shrew abundance index was more or less stable during the nine years of the survey, with a mean value of 0.108, ie more than 15 times higher than on Bono when rats were present, but similar to the values obtained four years after rat eradication. Further, the shrew is distributed over most of the island owing to the wide distribution of occupied habitats. These results suggest that: (1) the seashore is important for insular *C. suaveolens* populations mainly for trophic reasons because this habitat hosts a rich community of invertebrates year-round; (2) after two centuries of cohabitation, rats had dramatically reduced the *C. suaveolens* population on Bono. The data from Bono Island do not suggest how rats depressed shrew populations (Pascal *et al.* 2005), but predation is a strong possibility, as Norway rats are strong predators of small vertebrates (eg, Lorvelec and Pascal 2005); (3) rats may have prevented shrews from efficiently using the seashore, although our experiments did not test for this possibility; (4) although shrews may prey on pups of small rodents (Ruzik 1972), the fact that the nine-year survey on Béniguet Island showed

similar trajectories of the abundance index for both species renders the hypothesis of a predatory relationship between the house mouse and *C. suaveolens* unlikely. If predation was the main interaction, one would expect predator cycles to lag slightly behind those of prey (eg, Taylor 1984); (5) Norway rats have a larger effect on *C. suaveolens* abundance, by whatever means, than does house mouse competition.

On Béniguet Island, *C. suaveolens* is abundant in stony habitats and scarce or absent from “natural” ones, particularly from active and fixed dunes and bracken/maritime grasslands that were major habitats considered by the Life Nature Programme. Consequently, there is no reason why rehabilitating maritime grasslands should adversely affect the shrew population. The restoration of dry-stone walls may adversely affect shrew populations simply by disturbance during active construction, but this impact, if it exists, may be reduced if restoration is spread out over several years, and preliminary results suggest impacts will be quickly redressed. The ultimate impact on the shrew population of restored dry-stone walls should be positive, as this is a favoured habitat.

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