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Impact of the introduced small Indian mongoose (*Herpestes auropunctatus*) on abundance and activity time of the introduced ship rat (*Rattus rattus*) and the small mammal community on Adriatic islands, Croatia

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Abstract

The small Indian mongoose (*Herpestes auropunctatus)* is one of the world's 100 worst invasive species (IUCN 2000). It has negative impacts on several small mammals on islands where it was introduced. We assess the abundance of small mammal populations and the activity time of introduced ship rats (*Rattus rattus*) on three mongoose-infested and three mongoose-free islands in the Adriatic Sea, Croatia. We set up three transects on each island with a trapping system consisting of 30 small live traps to capture small mammals under 30 grams and 30 larger traps to capture ship rats and mongooses, on each transect. Our results support an already large but mostly speculative literature that suggests inability of the small Indian mongoose to reduce high abundances of introduced *R. rattus*. Further, we suggest that the low abundance of native small mammals is probably not solely caused by the mongoose but also by high *R. rattus* populations on all six islands. In addition, we provide evidence that *R. rattus* has changed its activity time to become more nocturnal on mongoose-infested islands, possibly to avoid predation by the mongoose. As *R. rattus* became more nocturnal, the diurnal mongoose may have become the main predator on amphibians, reptiles, and poultry.

Keywords

introduced predator, *Apodemus*, *Crocidura*

Introduction

The small Indian mongoose (*Herpestes auropunctatus*) has been listed by the IUCN (2000) as one of the world's 100 worst invasive species. Native to southern Asia, it was introduced to many islands in the Pacific, the Indian Ocean and the Caribbean Sea (Simberloff et al. 2000, Thulin et al. 2006).

Most mongoose introductions were in the late 19th and early 20th century to control introduced rats in sugar cane fields, but evidence of its success as a ratter is conflicting and mostly negative (Espeut 1882, Urich 1914, Pemberton 1925, Barnum 1930, Doty 1945, Seaman 1952, Hinton and Dunn 1967, Stone et al. 1994, Hays and Conant 2007). Statements on this matter are mostly anecdotal, and there are no controlled studies looking at the mongoose's ability to control rats.

No comprehensive study has been devoted to the impact of the mongoose on the abundance of native small mammal populations, although several studies have proposed the mongoose as a major cause for the decline of species. For example, Woods and Ottenwalder (1992) suggested that introduction of the mongoose has contributed to extinction of four species of Haitian island shrews (*Nesophontes* spp.). Borroto-Paéz (2011) believed that the mongoose has been largely responsible for the endangered status of the Cuban solenodon (*Solenodon cubanus*) and is suspected in the likely extinction of the dwarf hutia (*Mesocapromys nanus*). Yamada and Sugimura (2004) linked the decline in the abundance of the threatened native rabbit (*Pentalagus furnessi*) on the Japanese island of Amami-Oshima to the spread of the mongoose across the island.

On Adriatic Islands, the mongoose was introduced in 1910 to Mljet Island to control a poisonous viper (*Vipera ammodytes*) and subsequently to several other islands (Korčula in 1921 , Hvar (early 1950's), Čiovo (ca. 1950's), Škrda (ca. 1950's), Kobrava (unknown) (Tvrtković and Kryštufek 1990, Barun et al. 2008). It was introduced to the Pelješac Peninsula repeatedly from 1921 to 1927, and it is spreading along the southernmost part of the Dalmatian coast and has reached the Neretva River in the north (Barun et al. 2008) and Albania in the south (Ćirović et al. 2011). Nearly all Croatian large islands host a native carnivore, the stone marten (*Martes foina*), plus feral domestic cats (*Felis sylvestris*) and the ship rat (*Rattus rattus*). The latter was introduced to the western Mediterranean region over 2000 years ago (Audouin-Rouzeau and Vigne 1994, 1997, Martin et al. 2000). The impact of the mongoose on rat and native small mammal abundance is unknown, but assessing the impact of one particular species among a predator community is not easy. Fortunately, the mongoose has been introduced to some but not all islands of Dalmatia. Although we do not have censuses of small mammals before and after the introduction, we attempted to compensate for this shortcoming by comparing mongoose-infested and mongoose-free islands to try to determine the impact of the mongoose on the abundance of rats and native small mammals.

If introduced predators are capable of changing the abundance of their prey, conversely, prey may be able to assess predation risk and may behave accordingly, shifting their feeding, social, or escape behavior (Lima and Dill 1990, Kronfeld and Dayan

2003). For example, *R. rattus*, generally nocturnal, will be active and forage during the day if benefits outweigh risks. Berdoy and Macdonald (1991) have shown that socially subordinate individuals were forced to be diurnal to escape competition from dominants, and Fenn and Macdonald (1995) have shown that nocturnal visits by predators made it more dangerous for rats to be active by night than by day, forcing rats to be diurnal. Nellis and Everard (1983) found that rats on a Caribbean island became primarily nocturnal and arboreal after the introduction of the mongoose. In sum, rats can become more active diurnally, but cases of such a shift are scarce and possible mechanisms untested.

The goals of this study are: i) to assess the abundance of introduced rats and native small mammals on mongoose-infested and mongoose-free islands; ii) to compare rat activity times on mongoose-infested and mongoose-free islands, to test the hypotheses that activity times will be primarily diurnal where only the noctural marten is present (all the mongoose-free islands), but shifted towards night time when the diurnal mongoose is also present.

Methods

Study area and field methods

We conducted this study in 2008 on six islands in the southern part of Adriatic Sea: Lastovo (5,300 ha), Brač (39,400 ha), Dugi Otok (11,400 ha), Mljet (10,000 ha), Korčula (27,000 ha) and Hvar (29,900 ha). The first three are mongoose-free and the others are mongoose-infested. These islands are relatively similar in elevation, karst geology, Mediterranean climate and vegetation, but vary in surface area. They have a similar history of agricultural practices, human occupation, and timing of introduction of most exotic species. Their landscape is a fine-grained mosaic of small agricultural fields, scrublands (garrigue), thickets (maquis, mattoral), and forests. Agricultural production is mainly for local consumption and consists of olive groves and vineyards, with a few small vegetable fields with rich soil. A full description of these habitats is provided by Barun et al. (2010).

To determine small mammal abundance on every island, we set up three transects of 30 trapping spots distributed at 30 meter intervals in 900m long transects along narrow dirt roads, each running through all four vegetation types described previously in a proportion that may vary among transects. On each transect, trapping spots were placed alternatively on one side of the road and its opposite, and each trapping spot received two live traps: one INRA trap (stainless steel, horizontal bar-sprung trap similar to Sherman traps) to capture mammals weighing less than 30 g and one ratière trap (collapsible, wire and hanging bait-sprung trap, Guédon et al. 1990) to trap heavier mammals, particularly ship rats and mongooses. All traps were baited with a mixture of oat-flakes, peanut butter, and sardine oil, and bait was changed once during the three-day trapping period or just after rain. We ran the trapping system for three days and three nights in April and repeated the procedure in May at the same locations. We did not trap during rainy nights. We checked each trap early in the morning to collect nocturnal specimens and before sunset to collect the diurnal ones. Trapped animals were either euthanized and preserved for museum deposition or released at least one kilometer away from the transects.

Local habitat structure and analysis

To describe vegetation structure, four sample locations were evenly spaced along each transect, and the following data were collected within a 50-meter radius: % cover of bare ground, dead wood, rock, detritus, grasses in three layers (0–0.25 m, 0.25–0.5 m, 0.5–1 m); % cover of vegetation layers (0–0.25 m, 0.25–0.5 m, 0.5–1 m, 1–2 m, 2–4 m, 4–8 m, 8–16 m, 16–32 m, >32 m), maximum height of vegetation, canopy height, and % cover of each woody plant species. Within each vegetation layer, the relative cover was defined as the projection of the foliage volume of the layer on a horizontal plane. This was estimated by comparison with a reference percent cover chart (Prodon and Lebreton 1981). At each point we also recorded percent cover of each woody plant species present and its average height.

We used PRIMER (Plymouth Marine Laboratory, UK) to conduct an analysis of similarity (ANOSIM) followed by pairwise comparisons to examine if two habitat variables (habitat characteristics and percent cover of each woody plant species) differed between islands with and without the mongoose. In the analysis, we nested six islands into two main grouping factors: mongoose present and mongoose absent. For each habitat variable, habitat characteristic, and percent cover of each woody plant species, we constructed a nonmetric multidimensional scaling (NMDS) plot, a nonparametric approach, using Bray–Curtis similarity coefficients from a triangular matrix (Bray and Curtis 1957) of Euclidean distances of islands with the mongoose versus islands without it. The NMDS plot can also illustrate similarity and/or dissimilarity in habitat characteristics between the two island groups.

Abundance analysis

To compare abundances of single species between islands with and without the mongoose, we calculated a Minimum Number Alive index (MNA) (Krebs 1966, Hilborn et al. 1976). This index is a ratio of the number of trapped animals belonging to one species to the number of trap-nights. However, several traps may be inoperative for one or all target species during parts of trapping sessions. Traps were inoperative for all species when they were found closed and empty (NTO). Traps were inoperative for a species when they contained an individual of any other species (Sum AllSpp). The number of trap-nights used to compute the MNA index was the number of functional trap-nights for each target species (Pascal et al. 2009). The species one (*Sp1*) MNA index was computed as follows:

*Sp1*MNA = *Sp1*C/(NT-NTO – Sum AllSpp)

*Sp1*C is the number of captures for species one, NT is the total number of trap-nights, and NTO is the number of trap-nights the trap was inoperative for all species, whereas SumAllSpp is the total number of individuals of all other species captured.

To compare *R. rattus* and wood mouse (*Apodemus sylvaticus*) abundances between islands with and without mongooses, we calculated mean MNA indexes for each species for the three transects for each island and compared those values for the three islands with mongooses vs. the three mongoose-free islands with a t-test. To compare *R. rattus* activity times on mongoose-infested and mongoose-free islands, we performed Fisher's exact test on the total number of captured rats for all three transects for each island, but we kept daytime captures separate from night captures. We performed all analyses in JMP, Version 8. (SAS Institute Inc., Cary, NC).

Results

ANOSIM indicated that composition of habitat characteristics did not differ between islands with the mongoose and islands without it (global R = 0.359, P = 0.136), nor did the percent cover of woody plant species differ (global R = -0.457, P = 0.115).

In Table 1 we list the mammal species found on each island according to Kryštufek and Kletečki (2007) and the number of specimens trapped during our field operations. Apart from 23 reptiles (*Pseudopus apodus* and *Dalmatolacerta oxycephala*) and one amphibian (one *Bufo viridis*), the 699 other captures belonged to eight mammal species among the 14 species recorded as present on the studied islands. The largest samples came from three species, two aliens, *R. rattus* (499) and *H. auropunctatus* (57), and one native, *A. sylvaticus* (122). Specimen numbers of these three species together constitute 97 % of all mammalian captures.

Mongooses were most abundant on Mljet and Korčula and much scarcer on Hvar (Fig. 1), where local hunters have conducted intensive, island-wide predator-control operations for several years (Barun et al. 2010). Edible dormice (*Myoxus glis*) were not caught, likely because of the largely arboreal habits of this species and its long hibernation time during trapping months. MNA of rats did not differ between islands with the mongoose and those without it (F = 0.291, df = 5, p = 0.619). Similarly, MNA of *A. sylvaticus* did not differ between mongoose-infested and mongoose-free islands (F = 3.523, df = 5, p = 0.134).

The frequency of rats trapped during the day on mongoose-free islands exceeded that on mongoose-infested islands, (P < 0.001, Fisher's exact test, Fig. 1); in fact no rats were trapped on mongoose-infested islands during the day.

Table 1. Mammalian species distributions on the islands under study, after Kryštufek and Kletečki (2007). X : present; - : absent; numbers are numbers of trapped individuals during our study.

	Mongoose **PRESENT**			Mongoose **ABSENT**		
	Mljet	**Korčula**	**Hvar**	**Brač**	**Lastovo**	**Dugi Otok**
Herpestes auropunctatus	31	21	5	-	-	-
Martes foina	X	X	X	X	X	X
Canis aureus	-	X	-	-	-	-
Felis sylvestris (feral)	X	X	X	X	1	X
Rattus rattus	158	83	62	55	44	97
Mus musculus	1	X	X	X	X	X
Apodemus sylvaticus	-	22	4	54	29	13
Apodemus epimelas	1	X	-	-	-	-
Suncus etruscus	-	-	X	-	-	-
Crocidura suaveolens	2	1	1	6	1	4
Eliomys quercinus	-	3	X	X	X	-
Myoxusglis	X	X	X	X	-	-
Erinaceus concolor	X	X	X	X	X	-
Lepus europaeus	X	X	X	X	X	X

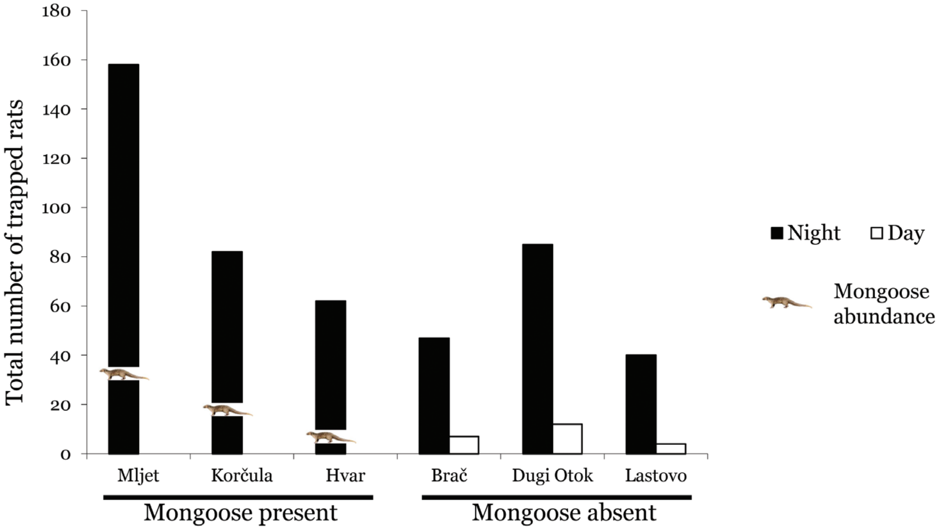

Figure 1. Total number (April and May) of trapped rats during the night and day on three islands with the mongoose and three islands without the mongoose. Mongoose abundance is illustrated with the picture of a mongoose for each island.

Discussion

Our data are too scant to allow a precise sense of the impact of the mongoose on small mammals on these islands. However, combined with previous work on the mongoose diet on these islands (Barun et al. 2010), our results are suggestive. We have previously reported the following results from stomachs of 57 trapped mongooses: 19 were empty, 39 contained vegetation and/or animal remains, and only five produced hairs, one identified to *A. sylvaticus* (Barun et al. 2010). The dietary results accord with those of several studies devoted to mongoose diet in insular ecosystems, which concluded that the spectrum of items is very large and encompasses many plants and animals (i.e., Nellis and Everard 1983). It is likely that few of the small mammals we targeted were potential prey for the mongoose. Among the 14 mammalian species recorded on these islands, three are large and carnivorous, and two are semiarboricolous Myoxidae, all out of reach of the mongoose, which cannot confront the carnivorous species and is a poor climber. Among the nine remaining species, the hedgehog (*Erinaceus concolor)* and the hare (*Lepus europaeus)* both have natural defenses against mongoose predation (spines for the hedgehog and speed for the hare). Among the remaining species that may constitute prey for the mongoose are two shrews, *Suncus etruscus* and *Crocidura suaveolens*, and four rodents, of which two (*Apodemus epimelas* and *A. sylvaticus*) are cryptogenic (Carlton 1996) but probably native, and two are alien and invasive (*Mus musculus* and *R. rattus*).

Although the INRA traps and the bait we used are effective for capturing *C. suaveolens* (Pascal et al. 2009), and despite a significant trapping effort, the number of trapped *C. suaveolens* was small (n=15). Nevertheless, even though the species has been captured on the six islands under study, and even though the total number of captures on mongoose-free islands is higher (11) than on islands with mongooses (4), the sample sizes are insufficient to allow strong conclusions. Moreover, several *R. norvegicus* eradications on islands of the English Channel and French Atlantic coast have shown a strong detrimental effect of that rat on two shrew species, *C. suaveolens* and *C. russula* (Pascal et al. 2005). One cannot yet exclude a similar effect of *R. rattus* on *C. suaveolens* for Croatian populations, and perhaps also on *S. etruscus*, recorded previously only on Hvar, where we did not record it.

As stated previously, the small Indian mongoose has frequently been cited as a species that could send already low island populations to the brink of extinction. In addition to the examples cited above, on Amami-Oshima Island, the shrew *Crocidura orii* is considered endangered because of the mongoose introduction (Yamada and Sugimura 2004). On Adriatic islands, the lesser white-toothed shrew *C. suaveolens* is already considered rare (Dulić 1969), but whether an introduced predator is to blame cannot be determined.

As with *C. suaveolens*, INRA traps and the bait used are efficient for capturing house mice on islands (Pascal et al. 2009). Despite this efficiency and the trapping effort, we captured only one mouse, the species having been recorded previously on these six islands. This result suggests that this mostly synanthropic species is scarce in natural habitats. However, several rodent eradication attempts have shown that mouse outbreaks occur when rats are successfully eradicated (references in Caut et al. 2007), suggesting mouse suppression by rats. Thus, our result does not by itself strongly implicate an impact by the mongoose. Moreover, interaction among several Muridae species in insular ecosystems has been suspected elsewhere. For example, an inventory of the micro-mammalian fauna of the insular system located at the Atlantic mouth of the English Channel and composed of the large island of Ushant (1560 ha) and the 16 islands of the Molène Archipelago (all less than 100 ha) was performed between 1992 and 2000. Four murid species were recorded, three introduced (*R. rattus*, *R. norvegicus* and *M. musculus*) and one native (*A. sylvaticus*). These four species are present on Ushant, but only one or none of the four on each island in the Molène Archipelago (Pascal 2002). Preliminary results of archaeological research suggest that *A. sylvaticus* had been present on all these islands before invasion by the three other murids. These results suggest that strong interactions occur between these species, leading to replacement if island area is small.

Experimental conditions and our protocol do not allow us to address rigorously the question of the specific consequences of the introduction of the two major alien species, *H. auropunctatus* and *R. rattus*, on the native mammals. Nevertheless, the number of individuals captured of native species was more than three times greater on islands without the mongoose (107) than on islands with the mongoose (33); the number of *R. rattus* captures was one-third higher in the first situation (303) than in the second (196). This general trend suggests that at least one of the alien species has a detrimental effect on the native mammalian fauna, and probably both do.

In either case, our analyses show no statistical difference in *R. rattus* abundance on islands with and without the mongoose, and this result is in accordance with an already large but mostly speculative literature suggesting that, in spite of its reputation as a good ratter, the small Indian mongoose does not substantially control introduced *R. rattus*.

Our analyses show that the number of rats trapped during the day on mongoose-free islands exceeded those on mongoose-infested islands. This result accords with the proposed mechanism explaining the poor performance of the mongoose in reducing rat populations (Nellis and Everard 1983) and the shift of rat activity under predation pressure (Fenn and Macdonald 1995). Additionally, as rats become less vulnerable to mongoose predation through modification of their activity time, the mongoose may increase predation pressure on amphibians, reptiles, and poultry (Barun et al. 2010). Our results expand on previous work and show that the mongoose may not only have detrimental effects on native species of conservation concern but may also affect behavior of another introduced species, *R. rattus*, that is a major target species of insular eradication attempts (Howald et al. 2007). Consequences of such interspecific interactions must be taken into consideration in planning eradication operations (Courchamp et al. 2003).

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