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# Invasive Rat Research and Management on Tropical Islands: A Case Study in the Iles Eparses

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**ABSTRACT:** Invasive rats on oceanic islands impact a large number of native species. Control programs, and in cases complete eradication, are used to alleviate these impacts. Basic biological data on rodent biology facilitates the design of management plans, and are particularly required for programmes on tropical islands where they are lacking. Here, we test complex environmental effects and their interactions on two tropical islands (Iles Eparses) that may alter black rat demography, space use dynamics, and inform rodent management. Five years of summer and winter trapping data were analysed using spatially explicit capture-recapture to determine rat population dynamics and calculate rat range size, coupled with spool and line experiments. Variation in demography and individual rat space use is primarily driven by bottom-up effects of seasonal rainfall pulses on habitat, but is altered by island-specific contexts. In the absence of other introduced mammals, rats tend to have stable range overlap throughout the year but seasonal home range size fluctuations associated with rat density. The presence of other introduced mammals causes a more variable response in home range size, although predictable, which we hypothesise to be a behavioural adjustment to fluctuating levels of predation pressure on rats in relation to seasonal influxes of breeding seabirds. We eventually discuss relevance of data for eradication strategies.

**KEY WORDS:** black rats, breeding, density, home range, multi-invaded ecosystems, *Rattus rattus*, rodent eradication, spatially explicit capture-recapture

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## INTRODUCTION

Invasive rats are major contributors to the loss of tropical insular biodiversity. From the middle of the 20<sup>th</sup> century, rat eradication has gradually emerged as the best conservation tool to suppress negative impacts on native species (Genovesi 2005). During the last 30 years, the number of successful eradications has increased exponentially (Simberloff 2008). The ongoing success of these ecological restoration projects is from the combination of planning, experience gained under previous operations, technological advances including the aerial distribution of second generation anticoagulants (e.g., brodifacoum), support of stakeholders, and better understanding of the ecology of target animals. On this last point, the current contribution of research has resulted in more reliable feasibility studies and operational protocols for rat eradication (Mulder et al. 2008). However, disparities between regions of the world remain. The failure rate of rat eradication projects in tropical environments is 4 times higher (18%, or 17 out of 97 projects) than the failure rate for the rest of the world (5%, or 7 out of 147 projects) (Varnham 2010). The size of restored islands is also on average lower in tropics (<100 ha) than in other regions (Howald et al. 2007). Lack of knowledge on the ecology and biology of rats in tropical environments has been identified as possible causes of these disparities (Varnham 2010, Dunlevy et al. 2011).

In this paper we review current knowledge on population and individual traits of introduced black rats

(*Rattus rattus*) on French Indian Ocean tropical islands, and inform stakeholders of eradication opportunities. The work reviewed here was carried out on the Iles Eparses 5 small isolated islands of the southwest Indian Ocean with limited human presence (max. 15 people permanently) (Figure 1). Europa, Bassas da India, Juan de Nova, and Glorieuses (Grande Glorieuse and Lys) are distributed from north to south along the Mozambique Channel (between the East African coast and Madagascar), while Tromelin is located to the north of Réunion Island. The Iles Eparses are French overseas territories administered since 2007 by TAAF (French Southern and Antarctic Lands). The climate is characterized by the alternation of warm and wet season (austral summer, between November and March) and a dry and cool season (austral winter between April and October). All islands except Bassas da India (an emerged reef) are invaded by at least one of the three following species: the black rat (on Europa, Juan de Nova, and Grande Glorieuse), the cat (*Felis catus*, on Juan de Nova and Grande Glorieuse), and the house mouse (*Mus musculus*, on Juan de Nova and Tromelin) (Figure 1). Goats (*Capra hircus*) have also been introduced on Europa, and brown rats (*R. norvegicus*) were previously eradicated from Tromelin (Russell and Le Corre 2009). These islands are major breeding sites for seabirds [frigatebirds (genus *Fregata*), tropicbirds (genus *Phaethon*), terns (genus *Sterna*), boobies (genus *Sula*)] and turtles [green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*)]. They are also home to several other native species including



**Figure 1.** Map of the Iles Eparses (south western Indian Ocean) and associated corteges of invasive mammals (cats, rats, and mice).

reptiles, songbirds, and shorebirds, and are crossing points for many migratory species.

### **BIOLOGY AND ECOLOGY OF RATS IN THE ILES EPARSE**

We present research work that has been done, or was generally considered useful to be done, in the Iles Eparses to facilitate rat eradication. Most of the experiments were conducted between 2007 and 2013 on Europa and Juan de Nova, considered as the most contrasting invaded ecosystems within the Iles Eparses.

#### **What Data are Relevant for Eradication Planning?**

Rat eradications are best timed when rat densities and breeding are suppressed. The required bait density on the ground to expose all rats to a lethal dose of poison is also dependent on the density of a population, as well as the bait consumption rate by other non-target species (e.g., land crabs) (Wegmann 2008, Wegmann et al. 2011). It is therefore important to know the temporal and spatial variations in population density and breeding before launching an eradication operation. Another important parameter to consider is the spatial scale at which individuals are operating, e.g., their home-range (Hooker and Innes 1995, Nilsen et al. 2005, Nugent et al. 2012, Nugent and Morriss 2013). The techniques currently used in eradication of invasive rats on islands consist of the broadcast of rodenticides following several methods (hand, station, or aerial) depending on the size and accessibility of the site. These methods all result either deliberately or incidentally in surfaces not covered by

poisoned baits (Nugent et al. 2012). The operator's goal is to determine the maximum size of uncovered surfaces by baits that do not cause eradication failure, which could occur if the untreated surface (i.e., no bait) is larger than the area used by an individual of the target species to fulfill its biological functions. One of the major challenges of eradication of rats in tropical environments is delivering each rat a lethal dose of toxicant despite strong competition with land crabs (Wegmann et al. 2011, Parkes et al. 2011). The various observations during rat eradications on tropical islands suggest that the bait cannot stand more than 4 days on the ground until competitors normally exhaust it (Varnham 2010). Larger areas without poison might therefore be tolerated if they are smaller than the surface covered by a rat in a maximum period of 4 days (Wegmann et al. 2011).

#### **Population Dynamics**

Bottom-up trophic fountain processes are the main drivers of the population dynamics of rats in the Iles Eparses. Seasonal rainfall pulses drive food availability, in turn affecting rats' seasonal cycles of population densities, and the length of the breeding period. Habitat quality sets carrying capacities of rats in the different environments (Russell et al. 2011). Rats can persist for prolonged periods of drought (April to October), but seasonal rainfall (from December to March) usually coincides with the rapid increase in density (2-fold increase), as has been observed in Hawaii (Shiels 2010) and Galapagos (Clark 1980). On Europa, increase in density is related to high recruitment since reproduction is

delayed when food resources are lacking (dry season). Habitat quality also plays a bottom-up regulatory role on rat densities. On Europa, Juan de Nova, and Grande Glorieuse, rat densities in open areas are on average 2 times lower than in closed habitat (forest) (Russell et al. 2011). The lack of habitat complexity (i.e., no tree stratum) is a limiting factor for rats. Trees provide more food resources, nesting, and hoarding sites than any kind of open habitat (Grant-Hoffman and Barboza 2010).

Other bottom-up processes include rats coexisting with mice on Juan de Nova and regulating mice populations through asymmetric competition (Caut et al. 2007). Diet and habitat use overlap suggest that competition for food resources and space (interference or exploitation) governs interactions between the two species. No evidence of rat predation on mice has been found, although it is known in rat-mice interaction (Bridgman et al. 2013). At low rat densities (e.g., grassland), the mice population is not suppressed and fluctuates in relation to food availability, but when conditions are favourable for rats (e.g., high-quality habitat, high food availability in forests), mice are maintained at low densities (Russell et al. 2011).

Additional top-down processes associated with interactions between rats and cats affect the population dynamics of rats, only limiting high rat densities in high quality habitat like dry forest (Russell et al. 2011). Limiting densities is frequently observed in continental environments where rats are in strong interaction with predators (Korpimäki and Norrdahl 1998). In response to a density limitation, rats generally reproduce more (Adler 1994, Adler 1996), which has been observed as an extension of the breeding season on Juan de Nova and Grande Glorieuse where rats coexist with cats (Russell et al. 2011, Ringler unpubl.).

### Individual Traits

Bottom-up processes also affect behavioural traits of rats in the Iles Eparses. Home ranges are larger in poor quality habitat associated with low rat densities, when intraspecific competition is low (Ringler et al. 2014). The home range size difference is about double between the most contrasting habitats of grassland and forest (home range radius ranges from 35 m to 70 m) (Ringler et al. 2014). On cat-free islands, seasonal variations of home ranges are either directly associated to food pulses (i.e., foraging area decreases when food is abundant) or indirectly through seasonal variations of density levels (i.e., intraspecific competition). Thus, rats from Europa prospect farther from their center of vital area when resources are limited during the dry season, which is also likely to be the consequence of compromise between individual traits (large home range) and population traits (low density) to maintain constant overlap level throughout the year (Ringler et al. 2014). Unlike population dynamics, behaviour of rats may be strongly affected by top-down process when cats and rats coexist. On Juan de Nova, seasonal variations of rat movement patterns are linked to an adaptive response of rats to the seasonal variability of the predation pressure exerted by the cats (Ringler et al. 2014). Cats are operating a seasonal change in diet depending on the presence of seabirds on

the island (Peck et al. 2008), switching from seabird-based diet during seabird breeding season (wet season) to rat-based diet the rest of year (dry season). In response to high pressure exerted by cats in the absence of seabirds, rats tend to reduce their foraging area (Ringler et al. 2014). In this specific case, high food availability and elevated population density do not result in a reduction of home range size. High predation pressure on rats is thus simultaneously limiting rat densities and exploration of individuals (i.e., rats remain close to shelters), which result in different individual range overlap levels throughout the year. Behavioural adjustment related to predators has already been observed on various taxa (Laurila and Kujasalo 1999, Losos et al. 2004), including other rat species (*R. fuscipes*) (Strauss et al. 2008). On Grande Glorieuse such response has not been demonstrated, but in the absence of seasonal influx of alternative preys (like seabirds), predation pressure on rats is assumed to be constant and home ranges size variations to be associated with bottom-up processes.

### ERADICATION OPPORTUNITIES

The observed variations of rodent biology between islands, seasons, and habitat types can be used in eradication planning. In particular, it is clear that dry periods should be targeted for management operations. Populations of rats are then at their lowest level and may in some cases have greatly reduced their reproductive effort (Europa), both of which are considered favourable circumstances for successful eradication. The effect of season on movements of rats, however, is related to island specific contexts and more particularly to the presence of any predators and the availability of alternative prey for those predators. Rat eradication should be implemented when rat foraging areas are the largest, since for the same distribution pattern of baits, the probability that a rat encounters bait is higher when rat home range is larger. It is also important to take into account habitat types in the implementation of eradication. Practitioners should particularly consider habitat quality (e.g., open versus closed) to adjust at finer scale bait densities and maximum tolerable space between baits. Regarding the latter, since rats seem to explore infrequently their entire territory in the Iles Eparses (Ringler BAAE), we recommend considering a subset of total home range size as an estimator of the surface covered by a rat during the short period of bait availability.

As reflected in the case study of Iles Eparses, complex interactions may arise between invasive species and their environment. These interactions have to be taken into account when planning eradication(s) to prevent undesired secondary effects (Zavaleta 2002, Bull and Courchamp 2009). Responses to management interventions (i.e., species specific eradications) in the Iles Eparses can be predicted based on functional relationships between rats, and other predators and prey in the system. It is highly recommended that all invasive predators (cats, rats, and mice) be eradicated simultaneously, in order to avoid potential unwanted indirect effects subsequent to the eradication of a single predator (Dowding et al. 2009). For technical or financial reasons, simultaneous eradications may not be possible. Targeting a single

species offers several scenarios, some of which could result in adverse effects on native species. Awareness of the occurrence of rats in the diet of top predators like cats on Juan de Nova and Grande Glorieuse (Peck et al. 2008) and barn owls on Europa (Ringler unpubl.), eradication of rats by poisoning may cause the eradication or at least a strong reduction of the population of these top predators by secondary poisoning.

When the eradication of rats does not cause the eradication of the top predator population, the removal of rats could still affect their dynamics. The risk of non-target impacts on barn owls (*Tyto alba*) on Europa is a problem. The status of the owl population is unknown, and it may be indigenous previous to invasion by rats. In this case, the conservation objective should be to maintain this owl population and therefore put in place measures to prevent secondary poisoning (e.g., setting aviary during the operation; see Empson and Miskelly 1999, Merton et al. 2002). However, if the population genetics of owls shows that their presence is recent and contemporary with the arrival of humans and rats, then we can consider that rats facilitate their own presence and therefore their elimination can be seen as a conservation objective. However, rat eradication only is not recommended on islands with multiple invasive mammals, as the presence of mice (Juan de Nova), turtles hatchlings (Grande Glorieuse), or land birds (both islands) is able to provide sufficient food resources to maintain surviving cat populations, even in the absence of seabirds. Keeping cats on islands, even in reduced numbers, remains a significant threat to the persistence of native prey species.

Indeed, even a very small number of top predators can drive a population of prey to extinction (Vazquez-Dominguez et al. 2004). On Juan de Nova, the eradication of rats may also affect the dynamics of mice, if they are not eradicated at the same time as the rats (which was the case on Tromelin Island). A mouse population might increase rapidly after the elimination of rats (Caut et al. 2007). Mice have particularly irruptive dynamics and could very quickly reach the carrying capacity of their environment (Witmer and Jojola 2006). However, mouse impacts on the Iles Eparses, especially on seabirds and reptiles, remain negligible compared to those of rats. Removal of brown rats (*R. norvegicus*) on Tromelin over 10 years ago has been beneficial to seabird populations and native vegetation, even if high densities of mice measured after rat eradication suggest that outbreaks may have occurred (Le Corre, unpubl.).

On Juan de Nova and Grande Glorieuse, eradication of cats without rat eradication is still recommended, until such time as rodent eradication is possible. Indeed, removal of cats and subsequent “mesopredator release effect” (Courchamp et al. 1999) is unlikely, as control of rat abundance by cats appears limited, and direct impacts of cats on native prey outweighs those of rats (Russell et al. 2009). Cats play an additional role in regulating the morphology (phenotypic plasticity or genetic selection) and behaviour of rats. Thus, changes in individual traits (e.g., change in body size and increase of home range size) more than population dynamics changes are likely to be observed after the removal of cats. With mice being regulated by the combined effects of resources and

competition with rats, their release following the eradication of cats is also unlikely.

## CONCLUSION

The Iles Eparses case study illustrates the role of science in planning the management of invasive mammalian predators on islands. However, the requirement to increase baseline knowledge on the functioning of these invaded ecosystems should not halt the urgency for implementation of eradication operations (Grantham et al. 2009). Scientists and TAAF managers will therefore have to work more closely together in the near future to identify the necessary compromise between study and action towards the removal of interacting invasive predators, in order to reverse the current decline of native species and facilitate island restoration in the Iles Eparses.

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