Rat Control in New Caledonian "Mainland Island" Rainforests: Will the Game be Worth the Candle?

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ABSTRACT: Due to its unique biodiversity and extreme endemism rates, New Caledonia archipelago is listed as one of Earth's 35 biodiversity hotspots. New Caledonian biota is now threatened by invasive species, with introduced rats considered to be particularly damaging. At the initiative of local institutions and NGOs, an innovative scientific experiment has been launched to quantify the Response of Forest Ecosystems to Rodent and Cat Control (REFCOR) and to test the relevance of such control at a large spatial scale (200 ha) on a dense evergreen rainforest (Mont Panié Wilderness Nature Reserve). Rat control will begin mid-2014 with a short toxin knockdown, and will thereafter involve intensive trapping sessions over the next 6 years, together with biodiversity monitoring and experiments. Rat impact studies initiated in early 2013 also aim to identify possible biodiversity indicators that could be used for a rapid assessment of rat control efficiency and effects. One of the major impacts of invasive rats is the disruption caused to plant and bird reproduction processes, placing them at high risk. Pre-and post-control experiments include the assessment of palm fruit consumption rates and of predation risk to artificial bird nests. Initial surveys of both rat populations and palm fruits (2 species), as well as artificial bird nest predation experiments, were conducted in 2013. Rat abundance was high, fluctuating among study areas and seasons, with more individual reproducers in December than in May. Fruit predation was high for one of the two species, in line with the rat abundance pattern. Surprisingly, artificial bird nest predation by rats was far lower than expected. These first results corroborate the influence of rats on some taxa. Monitoring and experiments will be repeated after and throughout rat control. This "before-after-control-impact" project, conducted in close collaboration with local stakeholders (Dayu Biik NGO), offers a unique opportunity to evaluate 1) the feasibility of controlling rat populations in the New Caledonian rainforest by trapping as an alternative to long-term poisoning, and 2) the benefits of rat control for native biodiversity and rainforest ecosystem functioning.

KEY WORDS: native biodiversity, New Caledonia, rainforest, *Rattus*, rodent control, trapping, tropical island

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INTRODUCTION

Rats, introduced by humans to over more than 80% of the islands of the planet (Atkinson 1985, Harris 2009), represent a major threat to native island biodiversity (Towns et al. 2006). *Rattus rattus* (black rats), *R. norvegicus* (Norway rats), and *R. exulans* (Pacific rats) are the most damaging species, particularly for insular ecosystems (Towns et al. 2006, Harris 2009). These omnivorous and opportunistic species are known to have strong deleterious effects on different taxa such as plants (e.g., Meyer and Butaud 2009, Pender et al. 2013), birds (e.g., Robinet et al. 1998, VanderWerf 2001, Jones et al. 2008), reptiles (Towns 1996), invertebrates (e.g., Wagner and Van Driesche 2010, Ruscoe et al. 2013), as well as on overall ecosystem functioning (Fukami et al. 2006, Towns et al. 2009). For example, rats can disrupt plant dispersal (Wegmann 2009), pollination (Pattemore and Wilcove 2012), germination (Perez et al. 2008), and mutualism (Aizen et al. 2008). Moreover, they usually prey extensively on bird eggs and chicks, and also induce changes in birds' behavior (Towns et al. 2006).

Currently, eradication of invasive rats is one of the most effective conservation tools to preserve or restore native communities on small or medium-sized islands (Brooke et al. 2007, Howald et al. 2007). However, on very large islands, eradication is impossible, and population control (i.e., limiting rat abundance by recurrent poisoning and trapping), is one alternative. To date, few

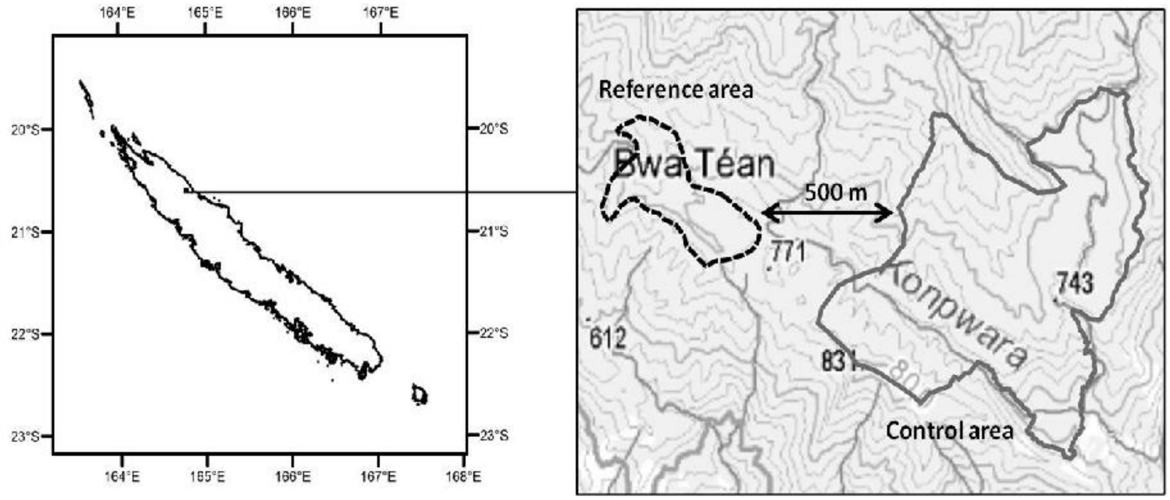

Figure 1. Location of REFCOR project in New Caledonia, Mont Panié. The bounds of the Control Area are represented by a solid line and those of the Reference Area by a dotted line.

studies have evaluated the impact of rats and the effects of rat control on "mainland island" forest ecosystems (e.g., King et al. 2011, Ruscoe et al. 2013).

With endemism rates among the highest on Earth, New Caledonia archipelago is listed as one of 35 global biodiversity hotspots (Mittermeier et al. 2012). Unfortunately, New Caledonian biota is highly threatened by invasive species (Beauvais et al. 2006, Pascal et al. 2008), with introduced rats considered to be particularly damaging for the forest ecosystem. Two species of invasive rats are particularly present: *R. exulans* and *R. rattus. R. exulans* reached New Caledonia 3,000 years ago with the Melanesians, while *R. rattus* arrived with European settlers about 150 years ago (Beauvais et al. 2006). However, their impact on the New Caledonian forest remains largely unknown (Pascal et al. 2006, Rouys 2008). The New Caledonia mainland is large (Grande Terre: 16,360 km²), mountainous (reaching 1,629 m above sea level) and megadiverse due to its peculiar geological structure and its isolation from the ancient Gondwana continent (Grandcolas et al. 2008). Despite the need to protect its original biodiversity, the size of the island precludes the eradication of rats. Consequently, less ambitious alternative pest control solutions need to be sought for New Caledonian fauna and flora conservation, particularly in areas known for their biodiversity richness.

The REFCOR project (Response of Forest Ecosystems to Rodent and Cat Control) implemented in a New Caledonian rainforest involves a local authority (the Northern Province), a local NGO (Dayu Biik) for management implementation, and a local research team (IMBE-IRD) for scientific assessment and planning. The aim of the REFCOR project is to test the feasibility of a large-scale (200-ha) rat control project, mainly based on intensive trapping in a remote rainforest, and to assess the benefits induced by rat control on rainforest biodiversity and ecosystem functioning. This "before-after-control-impact" (BACI) project offers a unique opportunity to 1) investigate the little-known effects of two species of invasive rats (*R. rattus* and *R. exulans*) on tropical rainforest biodiversity and ecosystem functioning, and 2) evaluate the feasibility of such challenging projects led by local stakeholders. Ultimately, the results of this pioneering work will inform and guide future conservation plans for New Caledonia.

Here, we present the structure of the REFCOR project and the strategy used to evaluate the feasibility and the benefits of control, as well as initial results from the rat population survey and biodiversity monitoring. The population dynamics of the two species of rats was assessed via trapping: fluctuations in population structure, morphology, and breeding biology were examined. Different biodiversity monitoring experiments were also set up to estimate the extent to which rat control could be of benefit to native fauna and flora and critical ecosystem processes. Here, we focus on fruit survival analysis for palm species, along with differential sensitivity of artificial bird broods to rat predation according to egg size and nest height.

METHODS

Study Site and BACI Experiment

This study was conducted in a dense evergreen rainforest located between 550 and 950 meters above sea level on the slopes of Mont Panié (20°37'30"S, 164°46'56"E, 5400 ha) in the northern province of New Caledonia (Figure 1). The climate is moist subtropical with a hot season between December and mid-April and a cool season between mid-May and September. Tropical depressions tend to bring most rains in the hottest period, from December to March. Mean annual precipitation in the rainforest is probably around 3,500-4,000 mm, while mean temperatures range from about 18°C to about 25°C throughout the year. Minimum temperatures can approach 0°C.

Because of the cultural importance of Mont Panié and the high endemism rates in local fauna and flora, this area has been protected since 1950, becoming a wilderness reserve in 2009 (IUCN category 1b). It is mainly covered by rainforest lying on a special metamorphic substrate that induces a high rate of micro-endemism. In 2010, a rapid assessment survey (RAP) evaluated the fauna and flora biodiversity of the Mont Panié region, listing 617 species of plants, 29 of birds, 18 of reptiles, 19 of freshwater fishes and crustaceans, and 23 odonates (Tron et al. 2013). Unfortunately, the RAP also confirmed the presence of exotic species such as rusa deer (*Rusa timorensis russa*), feral pig (*Sus scrofa*), feral cat (*Felis s. catus*), stray dog (*Canis lupus familiaris*), and rats (*R. rattus* and *R. exulans*) (Theuerkauf et al. 2013).

The REFCOR project will examine two study areas 500 m apart (to allow for rat mobility and study site topography): the "control area" (CA), where a rat control program will be underway by July 2014; and the "reference area" (RA), where there will be no rat control (Figure 1). Rat control will begin in mid-2014 by a short toxin-based knockdown and will thereafter involve intensive trapping sessions over the 6 subsequent years, together with biodiversity monitoring and experiments. The originality of this conservation project lies in the strong involvement of the local Melanesian community, so the operation plan must respect their cultural beliefs and their way of life. This is why intensive trapping will be used in preference to poison drops. However, intensive trapping is more time-consuming and labor-intensive, and consequently the efficiency and sustainability of such a project need to be assessed.

Monitoring of Rat Populations

Our survey performed two-season-specific monitoring of rat abundance, population structure, and diet both before and after control as well as between seasons. Rats were caught with the "Snap E Rat Trap" (Kness Mfg. Co., Albia, IA, USA) on 3 distinct line-transects in RA and CA. Thirty traps were set up every 20 m along 600-m transects. Two trapping sessions (over 5 consecutive nights) took place in April-May 2013 and in November-December 2013, and several more sessions will take place in the years to come. Traps were baited with coconut chunks at sunset and checked at sunrise. Animals caught were identified (*R. rattus* versus *R. exulans*), sexed, aged (juvenile or adult), weighed, and measured. Their stomachs and guts were collected for diet analyses. We calculated an index of abundance (IA) as the number of captures per 100 trap-nights adjusting for the corrected number of trap-nights (Nelson and Clark 1973). We examined for any effect by season, area (RA or CA), night of trapping (1 to 5) on the IA, the proportion of *Rattus* species, the weight and body size of adult rats.

Fruit Predation Experiment

A fruit predation experiment (Chimera 2004, Pender et al. 2013) was carried out in both areas (CA and RA) prior to rat control in July and November-December 2013; it will be performed again after rat control. To assess the rate of fruit predation due to rats, ripe and intact palm fruits were collected from two abundant species: *Burretiokentia vieillardii* (BU) and *Cyphophoenix alba* (CY). For each species and each area, we set up 30 experimental feeding stations on the bare ground. The stations were all at least 50 m apart, so as to avoid any possibility of one rat feeding over multiple stations. The feeding stations carried a number of fruits varying with the size of the chosen species (BU: 5 fruits, CY: 10 fruits). The fruits were put in place just before nightfall and checked at the beginning and the end of the following days, so as to distinguish between diurnal and nocturnal predation. The number of fruits consumed was recorded daily over 7 nights. Missing or nibbled fruits were counted as consumed fruits; a feeding station with at least one fruit consumed was considered to be predated. In addition, 4 infrared cameras (Ambush IR Cuddeback®, Cuddeback, Green Bay, WI, USA) were used to check for predators other than rats. They were placed at the base of tree trunks 50 cm from the feeding station. All the photos were analyzed and visitors or predators were identified. The Kaplan Meier survival curves for both species were drawn and their estimators were compared between seasons and areas.

Artificial Bird Nest Predation Experiment

This pre-rat-control experiment took place in both areas (CA and RA) from September 30 to October 16, 2013, coinciding with the start of the reproduction period for most native birds. The aim was to provide a proxy for rat predation on bird nests respecting egg size and nest height. Artificial nests were constructed with wire mesh and garnished with moss, ferns, and leaves in order to mimic real nests of a variety of native birds (from pigeons to passerines). They were filled with 2 eggs each of 3 different sizes: large – hen eggs [(*Gallus gallus*), 55.2 ±2.5 SD × 42.7 ±0.8 SD mm]; medium – quail eggs [(*Coturnix japonica*) 33.9 ±1.5 SD × 25.9 ±1.5 SD mm]; small – zebra finch [(*Taeniopygia guttata*), 15.7 ±0.5 SD × 11.5 ±0.4 SD mm], and placed at two different heights (on the ground and in trees 1.50 m high). Five combinations of egg size and nest height were tested: large egg on the ground, large egg 1.5 m high, medium egg on the ground, medium egg 1.5 m high, and small egg 1.5 m high. For each of these 5 combinations, in both areas 20 nests were randomly placed 50 m apart; a total of 178 artificial nests were tested. Nests were checked at sunrise and sunset to discern nocturnal predation from diurnal predation over 7 days, additionally being checked on days 11, 14, and 16 in CA. If one of the two eggs was pierced, nibbled or had disappeared, the nest was considered as depredated (Martin and Joron 2003). When possible, eggs remaining were used to identify the predators. To further identify the different species of predators involved, 15 cameras (11 Ambush Flash Cuddeback® and 4 Ambush IR Cuddeback®) were used.

Statistical Analysis

Generalized linear models for data with binomial errors and Wilcoxon tests as well as fruit and nest predation analysis were implemented with R version 2.15.3 (R Development Core Team 2013). Model selection was based on Akaike's information criterion for small samples (AICc, Burnham and Anderson 2002).

RESULTS

General Structure of REFCOR Project

Because of its complexity and its originality, designing the project involved a lengthy process of reflection and consultation with various stakeholders, taking over 10 years (Figure 2). The project officially began in 2013 with 1) the redaction of a protocol reference document listing the main monitoring and experiments to be implemented before and after rat control, and 2) the rat survey, the fruit and egg predation experiments, and insect and reptile monitoring. Once these operations have been repeated following the rat control, we should be able to evaluate the usefulness of the project.

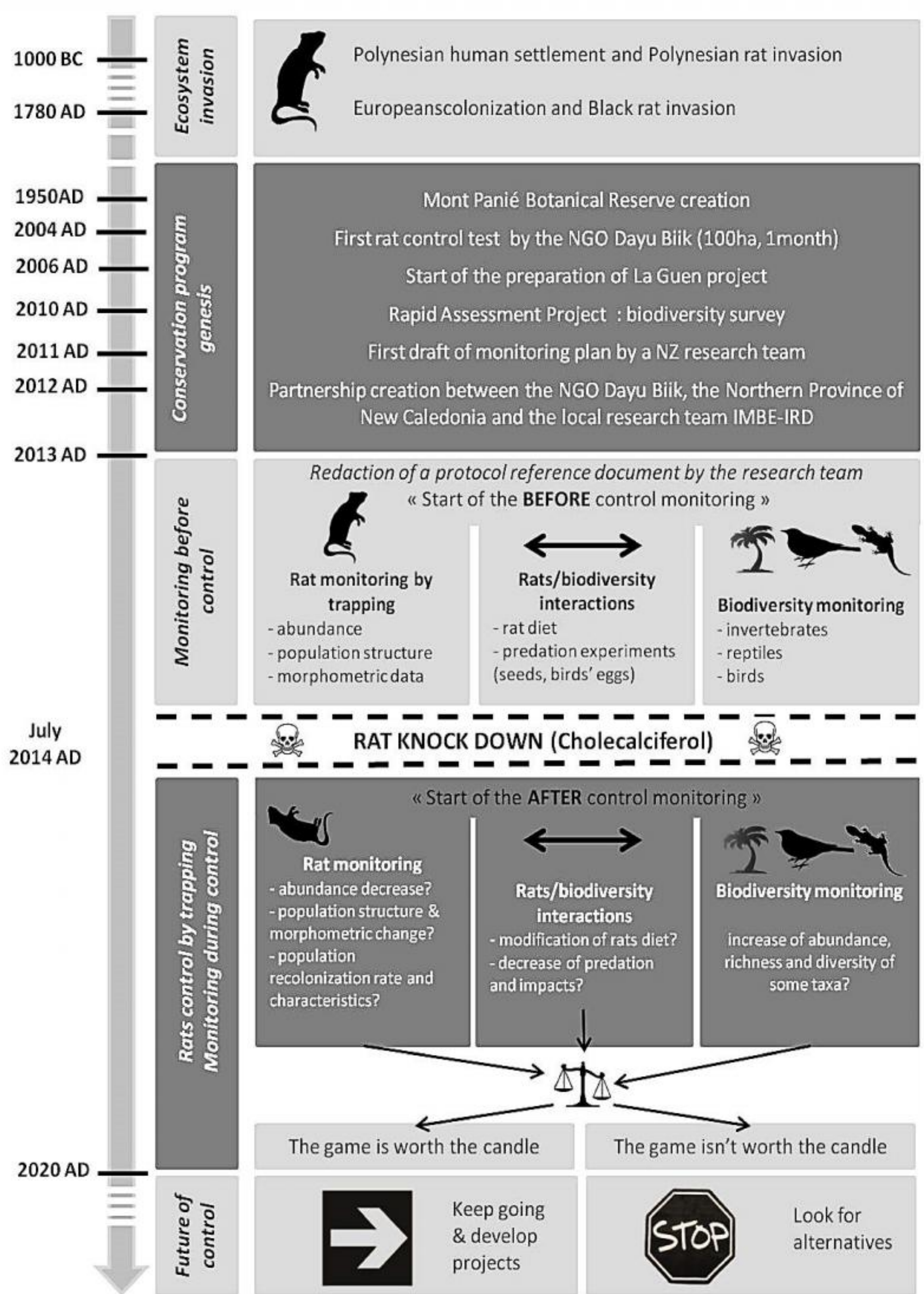

Figure 2. Genesis and presentation of the REFCOR project's scientific structure.

Monitoring of Rat Populations

The rat abundance index was significantly higher in the hot season than in the cool season in CA ($W = 119$, $P = 0.002$) because of the high number of rats caught in CA in December (Table 1). In December, the abundance index was higher in CA than in RA ($W = 185$, $P = 0.003$). Abundance decreased significantly with the night of trapping in May ($Z = -3.12$, $P = 0.002$) but not in December, where there was almost no drop. *R. exulans* (RE) were less abundant than *R. rattus* (RR), with a proportion varying between 9% and 22%. This proportion decreased with RR abundance ($Z = -3.04$, $P = 0.002$).

Table 1. Population structure (Index of Abundance - IA, proportion of *Rattus exulans*) and morphological data for *Rattus rattus* and *Rattus exulans* of trapped rats. Mean weight (± es), mean body size (± es), sex ratio, and proportion of juveniles for both species in Control Area (CA) and Reference Area (RA) during cool and hot seasons.

	CA cool	RA cool	CA hot	RA hot
Mean IA ±es	13.6 ±9.5	18.9 ±9.3	31.5 ± 5.7	13.3 ±9.0
Proportion of RE	22%	16%	9%	20%
Rattus rattus				
Number	40	61	102	43
Mean Weight ±es	177.7 ±23.3	174.5 ±24.6	184.9 ±36	185.4 ±35.7
Mean Size ±es	18.9 ±1.1	19.0 ±1.0	18.7 ±1.4	18.6 ±1.7
Sex ratio	0.5	1.03	1.09	0.83
% Juveniles	37%	34%	38%	52%
Rattus exulans				
Number	11	12	10	11
Mean Weight ±es	76.4 ±10.5	69.8 ±9.7	90.3 ±2.3	76.5 ±23.3
Mean Size ±es	14.6 ±0.3	14.8 ±0.6	15.3 ±0.3	14.0 ±1.5
Sex ratio	1.4	0.57	1.5	1.75
% Juveniles	42%	55%	70%	82%

We recorded 137 adults of RR and 17 adults of RE. There were too few RE to detect morphological differences by area and by season, so we only analyzed morphological data for RR. There were no significant differences in adult mean weight and size between areas, nor between males and females. However, the adult RRs were heavier in December than in May ($W = 2804$, $P = 0.02$). The sex ratio was between 0.5% and 1.09% and the proportion of juveniles was between 34% and 52% (Table 1). Adult females and males showed more development of sexual characteristics in December than in May: in May, 1.5% of adult females were lactant as opposed 32% in December, and adult males had bigger testicles and epididymis in December.

Fruit Predation Experiment

Rats were the sole predators observed via the camera traps set up during this experiment. Fruits were either eaten on the spot or transported one by one outside the area during the night. The fruit consumption rate differed between tree species. Few CY fruits were consumed, with only 27.5% of fruits eaten after 7 days, and no difference between seasons and areas was noted. For BU fruits, consumption was high: after 7 days, 91.7% of fruits were consumed.

When the Kaplan Meier estimators were compared between seasons and areas, the BU survival rate for RA was found to be significantly higher in December than in July ($Chi^2 = 6.3$, $P = 0.012$) and significantly lower in CY than in RA in December ($Chi^2 = 11.2$, $P < 0.001$). These results point to the fact that the main differences in survival appear from the December data (Figure 3). When the Kaplan Meier estimators were compared with the index of abundance of rats in December, we found that survival rate decreased with increasing abundance of rats.

Artificial Nest Experiment

In total, 24.2% of the nests were depredated. The 15 camera traps detected nocturnal rat visits (but no predation) and one diurnal predation by a Caledonian crow (*Corvus moneduloides*). For all the nests in both areas ($n = 178$), the identified predators ($n = 43$) were, in order of importance, Caledonian crows (62.9%), rats (22.9%), ants (11.4%), and pigs (2.9%) (Figure 4). Predation varied over the 5 combinations of egg size and nest height. Crows ate all egg sizes (mostly large eggs) at any height; rats did not consume large eggs but only medium and small eggs; and ants ate small eggs with thin shells. On the first 7 days, 10 nests in CA and only 2 nests in RA were attacked. This difference could be explained by the fact that many eggs were preyed on by a single family of crows in CA (pers. observ.).

DISCUSSION

Estimated rat abundances based on the number of individuals per 100 trap-nights varied from 13.3 to 31.5. These abundances seem particularly high for a tropical rainforest, compared with findings from other studies. For example, in Hawaii an abundance index of roughly 8-17 was recorded in wet forest on Maui (Sugihara 1997) and of roughly 11-25 in wet forest on Hawai‘i Island (Lindsey et al. 1999). On Mont Panié, rat populations exhibit fluctuations of abundance, structure, and morphometrical characteristics between areas and seasons. More rats were caught in December during the hot season, which is also the reproduction season as the higher number of lactating females and the enlarged testicles and epididymis in males indicate (Efford et al. 2006). The difference in rat abundance between areas was greater in December, with more rats in the future control area than in the reference area. This difference remains, however, unexplained. These fluctuations in abundance highlight the need for preliminary studies on population dynamics, enabling the start of control to be programmed for a time with lower abundance and fewer reproducers. *R. rattus* currently prevail over *R. exulans*, accounting for 80% of the rats trapped. However, our results show that the proportion of *R. exulans* trapped depends on the abundance of *R. rattus*, which means that checks should be made for expected release effects (Caut

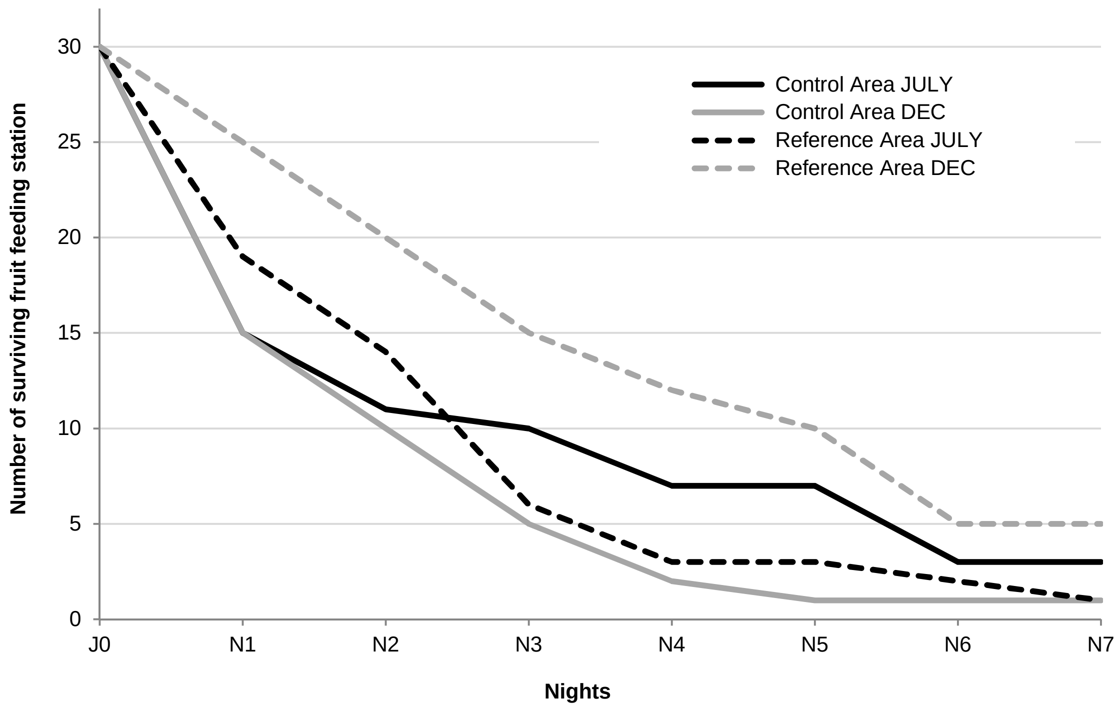

Figure 3. Number of surviving fruits at feeding stations of *Burretiokentia vieillardii* over a 7-night survey for both areas [Control Area CA (*solid line*) and Reference Area RA (*dotted line*)] and both seasons [July (*black*) and December (*grey*)].

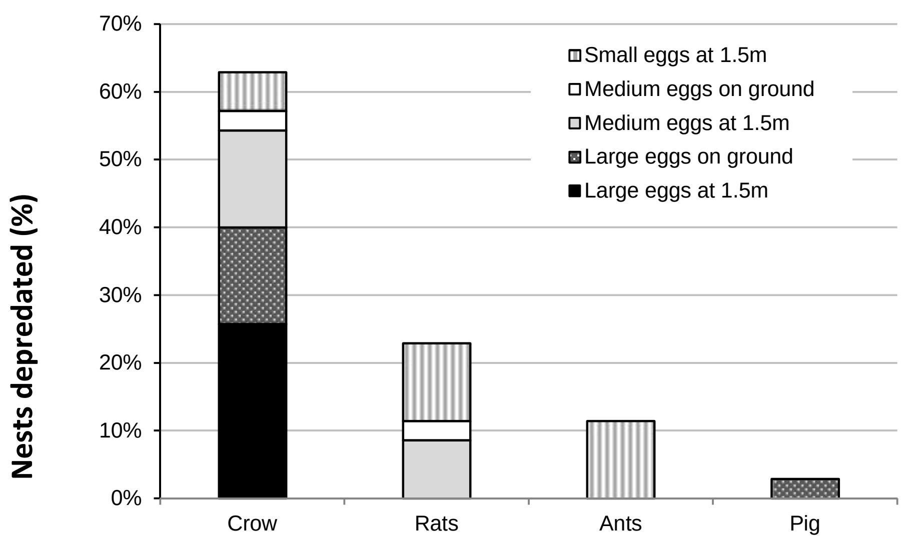

Figure 4. Nest predation on 5 combinations of egg size and nest height, showing impact of the different kinds of predators (crows, rats, ants, and pigs).

et al. 2007, Ruscoe et al. 2011). Useful further steps towards understanding rat biology and ecology would be a diet study based on stomach contents analysis, and a study of recolonization of the area by rats from adjacent uncontrolled areas.

The fruit predation experiment revealed the same pattern as for the rat population, with faster consumption of fruits in December in CA than in RA for BU. Increased consumption coincided with higher rat abundance. In total, only 8.3% of feeding stations remained intact. By reducing rat abundance, therefore, we can expect to increase fruit survival and enhance the germination recruitment process. Using a similar experiment, Pender et al. (2013) showed that controlling rats increases fruit survival from 0 to 73% for an endangered tree, *Cyanea superba*. In the same way, Auld et al. (2010)

reduced the impact of rats on palm trees by poisoning. In our case, only BU is found to be a good indicator to quantify rat predation, and more candidate species will need to be identified, despite the inherent difficulty of collecting large quantities of ripe fruits from high-canopy trees.

The main purpose of the artificial bird nest experiment was to detect differences in sensitivity to rat predation risk according to egg size and nest height. Surprisingly, very few eggs were eaten by rats, so that we are unable to compare predation risk among the 5 combinations. Most studies (see Towns et al. 2006 for a review) conclude that rats are a highly threatening species for bird communities. However, in a Hawaiian forest, Amarasekare (1993) revealed that only 4% of artificial nests were depredated by rats, and attributed these results either to low rat presence or to a great abundance of alternative foods. Moreover, birds' eggs and birds have been found to be absent from rat stomach contents in forest (Sugihara 1997, Shiels et al. 2013). In our case, the abundance of rats was high, ruling out the low rat presence hypothesis. However, the hypothesis of alternative food resources could usefully be verified through a rat diet study. In conclusion, egg predation was not found to be a good indicator to monitor any decrease in the impact of rats on birds on Mont Panié.

The REFCOR project is a mid- to long-term experiment combining scientific research and conservation actions to evaluate 1) the feasibility of controlling rat populations in New-Caledonian rainforests by trapping as an alternative to long-term poisoning, and 2) the benefits of rat control for native biodiversity and rainforest ecosystem functioning. This project officially started in 2013 and rat control begins mid-2014. The monitoring and experiments performed prior to commencing rat control point to a major impact of rats on the rainforest ecosystem. Further project assessment will involve the study of rat (2 species) population dynamics, structure, and diet, along with the monitoring of several biodiversity groups potentially impacted by rat populations [palms, snails, insects (particularly stick insects), wetas and crickets, reptiles (skinks and geckos), and nesting birds]. Large-scale trapping itself will be studied, to assess the trapping effort required to reduce rat density to low rates and to limit rat colonization from adjacent untreated areas. The success of the REFCOR project will be judged not only on recovery of biodiversity or ecosystem functioning, but also on socio-economic or technical parameters such as how far biodiversity monitoring operations can be transferred from scientific teams to local NGOs, or whether the long-term trapping program is successfully implemented by local NGO rangers (Lund 2014). The results obtained will be vital both to the future of the REFCOR project and to the genesis of other similar projects.

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