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Baiting effectiveness for introduced rats (*Rattus* sp.) on Christmas Island

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Abstract. The importance of oceanic islands for conservation of native species is often affected by the introduction of invasive species. Introduced mammalian predators such as feral cats (*Felis catus*) and rats (*Rattus* sp.), have been responsible for population decline and extinction of many native species on oceanic islands worldwide. Christmas Island, located in the Indian Ocean, is an example of how introduced mammals have influenced the population of endemic species even to the point of extinction. A management plan for the control of feral cats and rats has been implemented on the island since 2010. The effectiveness of a baiting programme for rats within the residential area (as part of the management plan) was monitored in this study. Twenty rats (ten in each site) were trapped in two study areas within townsites (Settlement and Upper Poon Saan). Rats were radio-collared and released, and then bait stations were opened containing Racumin paste sprayed with coconut milk as an additive. The baiting had a mean efficacy of 76.5%. There was a difference between the two sites but it was not quite statistically significant (Fisher's Exact Test $P = 0.053$) with a mortality of 100% at the Settlement site and 55.5% at the Upper Poon Saan site. The mean time of action for bait effect for both sites was 5.6 ± 0.6 days and the total mean bait consumption per bait station was 41.6 ± 9.07 g over 10 days. The results of this study suggest that the type of bait currently in use is adequate, but the spacing of baits may not be sufficient to successfully control rats on Christmas Island, particularly in the residential area where there are other food sources. It is recommended that the rubbish in the residential area be removed to reduce the available habitat and food for rats, which will aid the control programme.

Key words. rats, *Rattus* sp., eradication, trapping, radio tracking, baiting, Racumin

INTRODUCTION

Predation by introduced mammals has affected many native species on oceanic islands worldwide (Sax & Gaines, 2008), resulting in a rapid decline in their population and, in some cases, extinction (Courchamp et al., 1999; Blackburn et al., 2004; Harris, 2009). It has been documented that human-caused introduction of predators, such as feral cats *(Felis catus*) and rats (*Rattus* sp.) has had a major impact on the populations of seabirds, small mammals and other vertebrate species on oceanic islands around the world (Blackburn et al., 2004; Fukami et al., 2006; Harris, 2009).

Introduced rodents are present on almost every island in the world (Rodriguez et al., 2006; Howald et al., 2007) and their ecological success has been largely attributed to their wide-ranging diet, small size and propensity to breed (Kay & Hoeskstra, 2008). The primary food source for rats is plant material, but they will also consume other food sources that are readily available (Taylor et al., 2000; Major et al., 2007; Caut et al., 2008). Some studies reported that rats consume eggs and chicks of breeding seabirds and also adults (Courchamp et al., 1999; Le Corre, 2008) as well as reptiles (Caut et al., 2008; Beeton et al., 2010).

Christmas Island is home to an unusual faunal set that has been threatened since the introduction of exotic mammals (Wyatt et al., 2008). Two of the five native mammals of Christmas Island, the bulldog rat (*Rattus nativitatis*) and Maclear's rat (*Rattus macleari*), have become extinct since the arrival of humans and their commensals over a hundred years ago (Armstrong et al., 1992; Wyatt et al., 2008; Harris, 2009). The Christmas Island shrew (*Crocidura attenuata trichura*), originally common on the island, is critically endangered but is believed by most to be extinct as there have been no confirmed sightings since 1985 (Schulz, 2004; Beeton et al., 2010). Recently in 2009, the Christmas Island pipistrelle (*Pipistrellus murrayi*) became extinct (Martin et al., 2012). Introduced mammals have also had a major impact on seabirds of the island such as the Christmas Island frigatebird (*Fregata andrewsi*), which is listed as vulnerable (Hill & Dunn, 2004; DSEWPC, 2012). Cats and possibly rats have also had a major impact in the breeding success of red-tailed tropicbird (*Phaethon rubricauda*) and it is believed they predate on white-tailed tropicbirds (*Phaethon lepturus*) as well (Beeton et al., 2010; Algar et al., 2012). All four species of land birds that are endemic to the island including the Christmas Island thrush (*Turdus poliocephalus erythropleurus*), the Christmas Island hawk-owl (*Ninox*

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natalis; listed vulnerable), the Christmas Island goshawk (*Accipiter fasciatus natalis*; listed endangered) and the Christmas Island emerald dove (*Chalcophaps indica natalis*) (DSEWPC, 2012) are considered to be threatened, possibly because of cat and rat predation (Hill, 2004a, 2004b; Beeton et al., 2010). According to the Department of Sustainability, Environment, Water, Populations and Community (DSEWPC, 2012), there has also been a recent marked decline of reptile species. Cats and rats are considered to potentially impact all native species of reptiles on the island (Beeton et al., 2010).

Selective poisoning is the most widely used method of controlling introduced rodents on smaller islands, while on larger islands control becomes a high-risk operation due to the necessity for aerial dispersion of bait and thus the high probability of poisoning non-target species (Taylor et al., 2000; Howald et al., 2007, Harris, 2009). Some methods to avoid poisoning non-target species include the selection of bait type and the use of bait stations (Howald et al., 2007) which are less accessible to non-target species than baits on the ground (Donlan et al., 2003). The choice of rodenticide must be balanced between efficacy and the risks to non-target species (Donlan et al., 2003). Additives can increase rodent consumption of the toxin by making the bait more palatable and therefore may improve the efficacy of the baiting programme. Some additives used to increase palatability of baits include: yeast, eggshell, egg yolk, sheep blood, chicken blood, minced meat, different types of rice grains and coconut milk (Bullard & Shumake, 1977; Shafi et al., 1992; Hayes, 2011). Successful control relies on the distribution of baiting points and compliance by people involved in the programme (Endepols et al., 2003). Also, potential avoidance of bait by the target species may occur when other food sources are available (Leung & Clark, 2005).

As part of the management plan for feral cats and rats implemented on Christmas Island (Algar & Johnston, 2010), a dietary study was conducted in 2011 to determine the predatory impact of those introduced mammals and to identify bait preference for use in the rat eradication programme. The results of the bait trial for rats showed that the preferred bait (and the easiest to handle) was Racumin in the form of paste sprayed with coconut milk (Hayes, 2011). Racumin is a first generation anticoagulant that requires several feedings to achieve a lethal dose. This toxin was preferred over second generation anticoagulants to minimise the potential secondary poisoning risks to the Christmas Island hawk-owl and the Christmas Island goshawk. The manufacturers state that death occurs 3–8 days after ingestion of a lethal dose (LD_{50} rat: 1000 mg kg^{-1}; Bayer Animal Health Australia, 2012). A study of the distribution and home range size of rats on Christmas Island was also conducted and the results suggested that for a successful control programme, two bait stations per ha was required and these should be placed on a 50 × 50 m grid (Low et al., 2012).

Although preliminary rat control had commenced on Christmas Island, there was no information regarding its effectiveness, and whether the bait type and bait spacing were appropriate to successfully complete the programme. To determine the effectiveness of rat baiting we examined (i) the mortality of radio-collared rats at two sites during a field control programme (ii) the time of action for the bait to be effective and (iii) the amount of bait consumed during these trials.

MATERIAL AND METHODS

Study sites. Christmas Island is a tropical island located in the Indian Ocean approximately 2,600 km northwest of Perth and 360 km south of the Indonesian capital of Jakarta. The total area of the island is approximately of 135 km^2 (Algar & Johnston, 2010). It is a "raised" island, reaching 343 m above sea level at its highest point (Armstrong, 1992). The island includes a national park with unique and dense rainforest that covers 63% of the island (DSEWPC, 2012). The introduced rats have been previously identified as black rats (*Rattus rattus*), but recent genetic studies have suggested they may be a different species (Donellan, pers. comm.), so we refer to them here as '*Rattus* sp.' or rats.

This study was focused in the residential area rather than the rainforest. Locations for this study were restricted as some of them had been used for a previous study (Low et al., 2013) and other sites had ad hoc rat control programmes in place. Two study sites, both located in the north-east corner of the island, were used for this project:

1) The 'Settlement' site, where red-tailed tropicbird colonies are found along the shoreline, is mainly on a rocky terrace with mixed vegetation. There were a few houses along the shoreline; and although not quantified there was very little rubbish present around their backyards in comparison with the other study site. There were also no orchards or chickens being fed along the site where the research was conducted;
2) 'Upper Poon Saan' is an area of small semi-detached houses with back lanes and communal vegetable gardens and orchards. This site also contained a number of carports filled with disposed items and it was common for residents to feed chickens in this area.

Trapping. Trapping was conducted in May 2012. Forty-four Sheffield wire traps (Sheffield Wire Industries, Welshpool, Western Australia) were used in each study site with 28 being medium-sized (170 × 170 × 450 mm) and 16 small-sized (110 × 100 × 325 mm). Trap placement was based on previous studies of home range size and distribution of rats (Low et al., 2013) and on local knowledge of areas frequented by rats such as vegetable gardens, sheds and orchards. Traps were set for two nights providing a total of 88 trap nights in each site.

At the Settlement site, traps were placed in a two-row grid approximately 50 m apart along the road on the coastline at the edge of the rocky terrace as well as near the houses and under the house decks. At Upper Poon Saan, traps were located in the proximity of vegetable gardens, in sheds and under vegetation. Each trap site was tagged using flagging tape and recorded with a GPS device (Garmin GPSmap 60CX) as a reference of where rats were trapped and released (Fig. 1).

To attract rats into the traps, bread with peanut butter and chunks of pawpaw/papaya were placed in each cage. Hessian sacks were used to cover the traps and to provide protection to the trapped animals.

Radio collaring and tracking. Financial constraints limited the number of radio-collars available for this study to twenty units. Radio-collaring of rats took place in the Christmas Island National Park laboratory. Trapped rats were transported to the laboratory where they were sexed and weighed. Rats were sedated with 0.04 ml of Zoletil 100 (Virbac Australia Pty Ltd.), which is a combination of a dissociative anaesthetic (Tiletamine) and a tranquilliser (Zolazepan) to make handling easier and safer for both animal and handler. The radio-collars used for this project were PIP2 button-celled with a two-stage transmitter and activity sensor (Biotrack, Dorset, United Kingdom). The activity sensor meant that when the animal was moving, it transmitted a variable signal, whereas when the animal was static (or dead) the signal was constant. Radio-collar signals were tested prior to and following collaring.

Rats were released that same evening at the location of capture, several hours after they recovered from the sedation. A signal check was performed at the time of release and normal radio-tracking started the following day and was conducted with a Sirtrack (R100) radio receiver and a three element yagi antenna. Estimated locations for each rat were established by signal strength and constancy at dawn and late in the evening when the rats were likely to be active. This was conducted every day following release.

Baits and bait stations. Baiting commenced 24 h after the last rat was released at each site. To avoid poisoning of non-targeted species, baits were placed in bait stations. Each bait station consisted of a 20 l plastic bucket with a lid and a hole on the wall large enough to allow a rat to enter. Bait stations were spaced as suggested by Low et al. (2013), with two bait stations per hectare on a 50 × 50 m grid (Fig. 2). It was not possible to locate the bait stations at exactly the correct location because of the landscape characteristics of each site.

The toxic agent used for this project was Racumin (Bayer) in the form of paste. Two 100 g sachets sprayed with coconut milk for attraction (Hayes, 2011) were placed in plastic trays in each bait station. Each tray containing the bait was weighed before the installation of bait stations and after five days to check consumption by rats. Baits were replaced or re-sprayed with coconut milk at day five depending on consumption. After ten days, bait stations were collected and trays weighed again to record the amount of bait consumption. The length of time from bait stations being opened until each animal was confirmed dead was recorded and referred to as 'time of action'. 'Bait efficacy' was defined as the percentage of radio-collared animals confirmed dead following baiting.

Necropsy. A post-mortem examination was planned for all deceased animals to investigate the cause of death. However, to confirm the death of the rats, the signal from the radio-collars had to be constant for a minimum of two days. The necropsy was therefore not possible due to advanced stage of decomposition of the bodies collected and because it was not possible to retrieve the majority of the collared animals due to the characteristics of the terrain.

Statistical analysis. A Fisher's Exact Test was performed to determine statistical difference in bait efficacy between sites. A one-way analysis of variance (ANOVA) was performed to determine the statistical difference between the mean relative time of action of the bait for each site as well as to determine differences in bait consumption and bait consumption through time. Both tests were run in SPSS Statistics (Allen & Bennett, 2012).

RESULTS

Eleven rat captures were recorded at both sites, providing an equal trap success of 12.5%. Of these animals, one individual was too small to be radio-collared and released, and another was a recapture. Ten rats (five males and five females) were radio-collared at each site.

Bait efficacy. At the Settlement site, of the ten radio-collared rats, eight were confirmed dead, one left the baited zone and one was untraceable possibly due to a faulty radio-collar (Fig. 2). The bait efficacy for this site was at least 80% but considering that one rat left the baited area and another had a faulty transmitter, the efficacy for this site was deemed to be 100%. In addition, a number of non radio-collared rats

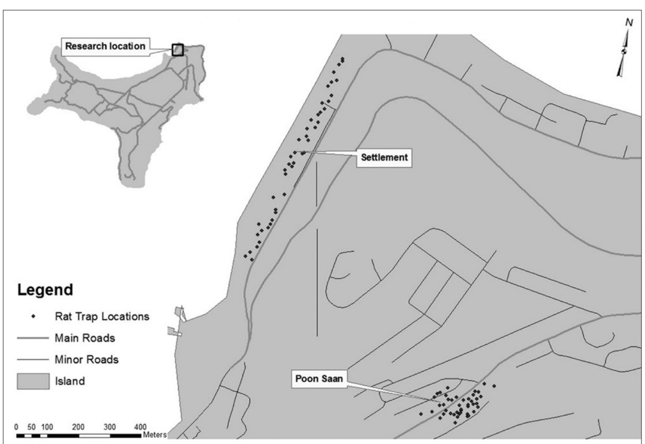

Fig. 1. Research sites and trap locations.

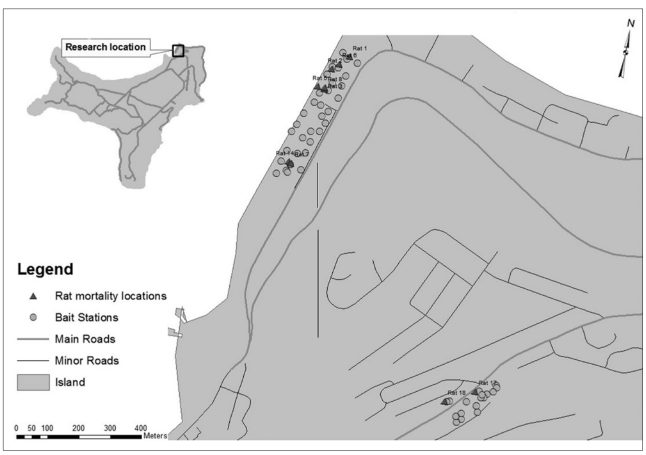

Fig. 2. Bait stations and mortality locations.

Table 1. Total number of radio-collared rats, number of rats that moved outside the baited area, bait efficacy for each site, and total bait efficacy.

	Total radio-collared rats	Total moved outside baited area	Number of dead rats	% of dead rats
Settlement	10	2	8	100
Upper Poon Saan	10	1	5	55.5
Total	20	3	13	76.5

Table 2. Total number of bait stations, total eaten and not eaten stations, total and mean consumption (g).

	Number of bait stations	Total stations eaten	Total stations not eaten	Total consumption (g)	Mean consumption per station (g)
Settlement	33	21	12	1639	49.5 ± 12.07
Upper Poon Saan	17	5	12	447	26.3 ± 12.37
Total	50	26	24	2086	41.6 ± 9.07

Table 3. Initial weight and average bait consumption (g) per bait station through time.

	Initial weight (g)	Consumption (g) after 5 days	Consumption (g) after 10 days
Settlement	205	31.5 ± 10.03	18.2 ± 5.88
Upper Poon Saan	205	18.6 ± 11.79	7.7 ± 4.25

were found dead in the proximity of bait stations. At Upper Poon Saan, five rats were confirmed dead from a total of ten radio-collared animals (Fig. 2). As one rat had left the baited zone, the efficacy for this site was 55.5%. Four rats survived the baiting programme at Upper Poon Saan and were still alive at the end of the monitoring period, 15 days after baiting commenced.

Pooling both sites, a total of 13 out of 17 (76.5%) rats that could be tracked within the baited zones were confirmed dead following baiting. Although there was a difference between the two sites it was considered to be not quite statistically significant (Fisher's Exact Test P =0.053; Table 1).

Bait time of action. For the rats that died during the study, the length of time from the bait stations being opened until each animal was confirmed dead was 5.6 ± 0.6 days. For the Settlement, the mean time of action was 5.7 ± 0.6 days and for Upper Poon Saan the mean was 5.4 ± 1.4 days. A one-way ANOVA test indicated that there was no statistically significant difference (P = 0.792, F = 0.073) between the two study sites or between males and females (P = 0.291, F = 1.231) for bait time of action. The majority of mortality (41.1%) occurred at day four. A survivorship of 23.5% was observed from day eleven until the end of the project (Figure 3).

Bait consumption. A one-way ANOVA indicated no statistical difference between both study sites in terms of bait consumption (P = 0.228, F = 1.488). In the Settlement area (33 bait stations), the mean consumption was 49.6 ± 12.1 g per bait station. At Upper Poon Saan (17 bait stations), the mean consumption was 26.3 ± 12.4 g per bait station. The total mean consumption for all 50 bait stations was 41.6 ± 9.1 g (Table 2). For both sites, most of the bait was consumed within the first five days (Table 3).

DISCUSSION

The bait type recommended for the control of rats on Christmas Island (Hayes, 2011) appeared to be appropriate to achieve satisfactory results, although it was not 100% effective at one of the sites. Rats did consume the bait and most of the radio-collared rats died within a few days of the bait stations being opened. Racumin paste sprayed with coconut milk used for attraction seems to work effectively as the bait, but two bait stations per hectare placed on a 50 × 50 m grid as recommended by Low et al. (2013) may not be sufficient to strategically control rats in a programme that will now be expanded into other habitat types on Christmas Island. Further investigation of bait station density and baiting efficacy is recommended, particularly for sites where other food sources are abundant.

Baiting efficacy between the two sites although different was not considered to be statistically significant, which may have been an artefact of sample size. A higher mortality however was observed at the Settlement area compared to Upper Poon Saan. Although not quantified, there was a distinct difference

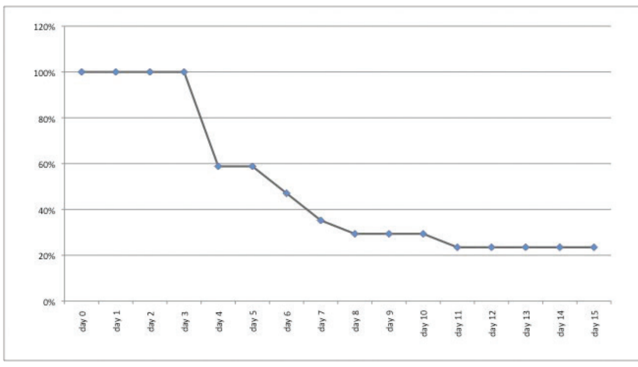

Fig. 3. Bait time of action. Percentage of survivorship through time.

in the abundance of food resource between the two sites. It is likely that the lower availability of food in the Settlement area meant that the bait was eaten more readily by rats, which were then poisoned. The fact that 100% efficacy was not achievable was because some rats left the baited zone and one rat was untraceable due to a possible faulty transmitter, so efficacy may have been under-estimated. However, four rats from the Upper Poon Saan site survived the baiting. This raises questions about the effectiveness of the recommended baiting regime, especially given that populations of rats can rapidly expand from a small number of individuals. In a study performed by Rodriguez et al. (2006) in Isla Isabel, Mexico, the researchers stated that the reason of failure to eradicate rats may have been in part because of a hasty implementation of the eradication programme where the palatability of the bait was not studied as well as the seasonal availability of rat's normal food.

The results for the bait time of action were as expected, with the total mean time of action for both sites being 5.6 days. This is consistent with what is stated on the product label where it is stated that Racumin paste works by preventing coagulation, causing death due to internal bleeding between three to eight days after the intake of a lethal dose (Bayer Animal Health Australia, 2012). A laboratory trial in three species of rats (*Bandicota bengalensis*, *Tatera indica* and *Rattus rattus*) performed by Parshad & Malhi (1995) showed that the ingestion of poison bait containing different concentrations of Racumin resulted in 100% mortality of *Bandicota bengalensis* after feeding bait containing 0.0375% of Racumin for one day. However, it required six and eight days of continuous feeding of the same bait to achieve 100% mortality of *Tatera indica* and *Rattus rattus* respectively. To identify a more accurate time of death for individual rats on Christmas Island, it is recommended to use transmitters with a mortality signal instead of just an activity signal, but unfortunately this function was not available in collars of sufficiently small weight for this study.

Although not statistically significant, bait consumption differed in both sites. Bait consumption was lower in Upper Poon Saan where the food resource was greater (vegetables, fruits and chicken food) compared to the Settlement. Since trap success was the same in both sites, suggesting a similar density of rats, this further supports the assertion that the lower bait consumption at Upper Poon Saan may have been a consequence of greater food availability.

Radio-collared rats (as well as non radio-collared rats) readily consumed the bait and by day ten the majority of rats were confirmed dead. This is consistent with a study of Mushtaq et al. (2012) on Indian crested porcupine (*Hystrix indica*), a large nocturnal rodent considered a pest in Pakistan, where the consumption of Coumetetralyl (Racumin) treated bait started decreasing gradually in time and by day 12 the amount of consumption was negligible due to a reduction in the number of rodents in the baited area.

If necropsies were conducted as planned, the results for this project would have been more conclusive but because of the elevated humidity and heat characteristics of the island, rat carcasses presented with advanced decomposition that made necropsy impossible. Necropsies would have been helpful because the cause of death could have been definitively attributed to poisoning by Racumin. Because the rats died within the expected time frame and there was no other obvious cause of death in the five radio-collared rats collected and in the other rats found dead in the proximity of bait stations, we are confident that rats were killed as a consequence of bait consumption.

Control of rats on Christmas Island is a key aspect of management to conserve the island's native biodiversity. This was a short study conducted over a small area and showed promising results. Strategic control of rats on Christmas Island will be challenging because of the large size of the island, its terrain characteristics, and because of the high risk of reinvasion of rats from boats, but the ecological benefits of control or eradication would be enormous. The potential benefits were illustrated by recent observations of tropicbird nests with chicks in baited areas (Algar et al., 2012), which had been very rare prior to rat control.

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