Strategies for detection of house mice on a recently invaded island

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Published online: 31 October 2012

Abstract: Invasive rodents pose a grave and persistent threat to New Zealand's native biodiversity. Rodent eradication is a successful conservation tool on islands. However, eradications may fail, and there is always potential for reinvasion. It is therefore essential that effective systems are in place for the early detection of rodents in the case of eradication failure or reincursion. We used data from a small New Zealand island experimentally colonised with house mice (*Mus musculus*) to investigate the effectiveness of selected mammal surveillance practices, including detection device choice, duration of deployment period, and device placement. The effect of population density on mouse detectability was assessed using population abundance estimates made regularly throughout the experimental island colonisation. We found that commonly used detection practices were highly effective for the detection of mice, even at low population density.

Keywords: *Mus musculus*; population density; rodent; invasion; surveillance; tracking tunnel; WaxTag®

Introduction

Invasive species are a significant component of global change, impacting on human health and economies, and damaging native biota and ecosystems (Vitousek et al. 1997; Mack et al. 2000), particularly on islands (Courchamp et al. 2003). In 1991, more than half of New Zealand's offshore and outlying islands were inhabited by at least one species of invasive mammal, including no less than 26 inhabited by house mice (Atkinson & Taylor 1991). Many successful eradication operations have since taken place, resulting in considerable benefits for native species and ecosystems (Towns & Broome 2003). However, large-scale eradications are expensive, particularly so when rodents are the target (Martins et al. 2006). It is therefore important that islands that are free of animal pests, through either non-arrival or eradication, and are maintained as such (Dilks & Towns 2002; Leung et al. 2002). The prevention or early detection of unwanted arrivals is vital, as is the rapid deployment of contingency responses where necessary (Simberloff 2003; DOC 2008). In New Zealand, island biosecurity is an important component of the Department of Conservation's (DOC) overall strategy for invasive pest management, providing a cost-effective alternative to mainland pest management (Broome 2007).

Rodent behaviour at low population density, such as occurs during the incursion phase of invasion or when individuals survive an attempted eradication, is poorly understood (Dilks & Towns 2002; Russell et al. 2005). Consequently, efforts to detect individuals at low density can be frustrating. For example, a single, radio-collared Norway rat (*Rattus norvegicus*) released onto rat-free Motuhoropapa Island evaded capture or detection by other means over 4 weeks despite a range of devices being employed at double the density previously used to eradicate existing populations, before finally being captured on the adjacent island 18 weeks after release (Russell et al. 2005, 2008a). In the same study, rats displayed significant individual variability in behaviour; half of all released rats were caught within 2 weeks, but the range was 1–85 days (Russell et al. 2008a). This shows that behaviour during incursion is highly unpredictable. There are many reasons why detection may be particularly difficult at low population density, including neophobia, trap aversion (Moors 1985) or simple failure to encounter devices. Perhaps most importantly, at low density there are likely to be abundant uncontested food resources in the environment, potentially reducing the attractiveness of baits or lures on detection devices (Dilks & Towns 2002; Hoare & Hare 2006).

The disproportionate difficulty of detecting and eradicating rodents at low density has long been recognised by conservation managers and is considered to be a significant impediment to advances in island conservation (Towns & Broome 2003). In 1992, a DOC conference on predator management established that improvement of rodent detection at low density was a research priority (DOC 1992). A decade later, island managers recognised that considerable knowledge gaps in this area still existed (Dilks & Towns 2002). Recently, however, encouraging progress has been made, with research into the colonising behaviour of Norway rats (Russell & Clout 2005; Russell et al. 2008a, 2010), and ship rats (*Rattus rattus*) (Speedy et al. 2007; Innes et al. 2011).

Our aim in this study was to address some of these issues in relation to house mice, using data from an experimentally colonised island. Specifically, we tested the ability of selected surveillance methods to detect mouse incursions, and whether detectability is density-dependent.

Methods

We conducted the study on Te Haupa or Saddle Island (Hauraki Gulf, New Zealand, 36°31' S 174°47' E) between January and August 2010. The island has an overall area of 6 ha (Tennyson & Taylor 1999), of which 4.65 ha lies above the high-tide line (T. Wilson, DOC, pers. comm.). The data presented here

were collected during the experimental colonisation of Saddle Island by house mice, initiated by the release of one male and one female mouse in December 2009 (Nathan 2011). Errors presented around means are standard deviations.

Device choice and length of deployment period

Two different devices were tested for their relative effectiveness at detecting mice: corflute tunnels with tracking cards (i.e. tracking tunnels; Black Trakka, Gotcha Traps, Warkworth, NZ) baited with peanut butter, and peanut-butter-flavoured WaxTags® (Pest Control Research, Christchurch, NZ). In addition, two different durations of device deployment were trialled: 3–4 nights and c. 1 month.

During 12 test periods (see Table 1), a line of detection devices was laid out at 50-m intervals above the high-tide line along the western coast of Saddle Island. The line consisted of six of each of the two devices, arranged as shown in Fig. 1. The non-alternate arrangement was necessary due to unsuitable terrain for tracking tunnels at the northern end of the island (cliff faces). This quantity of devices equated to a device density of two per hectare (or one tracking tunnel and one WaxTag® per hectare) consistent with DOC (2008) recommendations. Tracking tunnels were baited once at the beginning of each test period. At the end of the test period, presence or absence of mouse sign on each device was recorded. Some exceptions to this standard methodology are noted in Table 1.

The effectiveness of the two detection devices was assessed based on the mean proportion of devices marked by mice per line over the full study period (after Gillies & Williams 2007). The same method was used to compare the effectiveness of devices deployed for 3–4 nights with those deployed for c. 1 month. Note that the Gillies & Williams (2007) method was designed for abundance monitoring purposes rather than surveillance. In practice, any device-marking rate greater than zero (i.e. detected / not detected) constitutes successful detection in the context of incursion detection. However, we used this method to compare the effectiveness of different detection devices and strategies. To assess whether marking rates per line were more variable for WaxTags® or tracking tunnels we used Levene's test for equality of variance.

For the purposes of these analyses, data from test periods 1 and 2 (see Table 1) were excluded from the dataset, as the use of non-flavoured WaxTags® during these periods meant that results were not directly comparable with those from the rest of the study.

Tracking tunnel placement

To address the question of best placement of detection devices, two broad detection strategies were trialled. These were categorised as 'ease of access' and 'broad coverage', as described below. For both strategies tracking tunnels only were used, at a density of one per hectare (after DOC 2008).

Ease-of-access strategy

Where rapid servicing is imperative, it is convenient to place devices where they are easily accessible. On Saddle Island, presence/absence data from the tracking cards placed along the western-coast beach were used to represent this strategy.

On Saddle Island, placement of detection devices along the beach might also represent a 'point of entry' strategy, as the beach is frequented by boat traffic and is the most likely place for a mouse incursion to occur. However, at the time the founder mice were released onto the island there were no detection devices in place. Thus, we were unable to test whether detection devices placed at points of entry are likely to be effective at the initial incursion phase.

Broad-coverage strategy

A strategy of spreading one or two devices per hectare over a whole island is recommended by DOC (2008) as best practice for islands that have easy or regular servicing and are small enough to cover with a grid of detection devices. This would therefore be considered appropriate for Saddle Island.

Throughout the experimental colonisation period, a grid (25 × 25 m) of tracking tunnels was present throughout the interior of Saddle Island and was used to monitor mouse ranging behaviour (Nathan 2011). Six tracking tunnels from this grid were selected to represent a 'broad coverage' strategy of detection device placement. The 62 tunnels forming the grid were divided into six approximately equal groups to represent each hectare of island area. The two areas encompassing the widest points of the island contained 11 tunnels each, while all other groups contained 10 tunnels each. One tunnel from each group was randomly selected using associated random numbers generated in Microsoft Excel.

The data record for the inner island grid was then checked

Table 1. Test periods for analysis of device effectiveness and appropriate deployment duration for detection of house mice on Saddle Island. Exceptions to standard test periods are as follows: * non-baited WaxTags® used, $^{+}$ 5 tracking tunnels and 7 WaxTags® used, $^{\wedge}$ test periods took place subsequent to extensive removal trapping effort.

Test period	Dates (2010)	Length of time deployed
1*	9–12 Feb.	3 nights
2*$^{+}$	12 Feb. – 18 Mar.	c. 1 month
3	18–22 Mar.	4 nights
4	22 Mar. – 19 Apr.	c. 1 month
5	19–23 Apr.	4 nights
6	23 Apr. – 26 May	c. 1 month
7	27–30 May	3 nights
8	30 May – 29 June	c. 1 month
9	29 June – 3 July	4 nights
10	3 July – 8 Aug.	c. 1 month
11$^{\wedge}$	15–19 Aug.	4 nights
12$^{\wedge}$	19–23 Aug.	4 nights

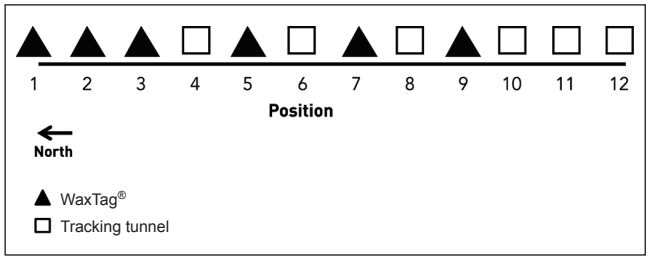

Figure 1. Schematic of detection device layout along western coast of Saddle Island, for the detection of house mice. Devices were spaced at 50-m intervals.

to confirm presence or absence of mouse tracks on tracking cards from the six selected tunnels during periods corresponding to test periods 2, 4, 6, 8, 11 and 12 (described in Table 1). In addition, data from the selected tunnels were also available for the period 18–22 January 2010 and were included in the dataset.

Data analysis

The relative effectiveness of the two device-placement strategies was assessed by comparing the mean percentage of tracking cards marked by mice per line using each strategy over the full study period (after Gillies & Williams 2007). We used Levene's test to assess whether variability in marking rates per line differed between placement strategies.

Population density and detectability

Tracking tunnels

Data from tracking cards placed along the beach and within the island interior (selected tunnels as used for the 'broad coverage' strategy, above) were pooled and divided into four groups based on population density: low, medium, high, and reduced. The first three categories were based on independent estimates of monthly population density throughout the experimental colonisation period (Nathan 2011) and comprised tracking data as shown in Table 2. Here, the terms 'low', 'medium' and 'high' are used relative to each other within the experimental mouse population and are not representative of a range of natural populations of varying densities. Indeed, the density of the Saddle Island population remained comparatively moderate throughout the study period (Nathan 2011). A fifth group, 'incursion', was created using previously gathered data from experimental mouse releases on Saddle Island (MacKay 2011). These data describe the movements of mice released in male–female pairs ($n = 7$ trials, in one case a single female was released). Although density for this group is equal to that of the 'low' density category, the division of the two groups is appropriate as behaviour during initial incursions is expected to differ from that in a familiar environment (O'Connor & Eason 2000). For the first and second trials, one set of tracking cards was deployed from 4 to 8 days after release. For the remaining trials, two sets of tracking tunnels were deployed; from 4 to 8 days after release, and from 12 to 16 days after release, as shown in Table 2.

The mean percentage of tracking cards marked by mice per line was calculated for each density period, and linear regression was used to test for evidence of a relationship between population density and tracking rates. Note that the data from the 'incursion' group are the most directly relevant to island surveillance practice as in all other test periods some degree of familiarity with the detection devices present can be assumed.

WaxTags®

Rates of mouse markings on WaxTags® were plotted against time for 3–4-night and c. 1-month periods of deployment. For the 3–4-night periods, the minimum number of mice alive (MNA) on the island was known (Nathan 2011). MNA was therefore plotted along with the detection data to identify any trends in detectability that could be related to population density. Linear regression was used to test for evidence of a relationship between marking rates on 3–4-night WaxTags® and MNA. Although the time periods did not correspond exactly, we also tested for a relationship between marking rates on 1-month WaxTags® and MNA, using linear regression. To this end, the 1-month-WaxTag® detection data were paired with the MNA corresponding to the 3–4-night period directly *after* the test period. As it was possible for mice to gnaw the WaxTags® at any stage during the test period, it is most conservative to assume the maximum density for that period.

Results

Device choice

For both tracking tunnels and WaxTags® a one device per hectare distribution detected mouse presence. For comparison, tracking tunnels had considerably higher average marking rates per line (95.0% ± 11.2) than WaxTags® (53.3% ± 32.2). This was a statistically significant difference ($t = -3.86$, $P < 0.01$, d.f. = 18). The marking rate of tracking tunnels was also less variable over time than that of WaxTags® ($F = 4.60$, $P < 0.01$, d.f.= 1, 14; Fig. 2).

Duration of deployment

The average marking rate of tracking tunnels was similar whether used for 3–4 nights or 1 month (Table 3, Fig. 2). WaxTags® deployed for 1 month appeared to have somewhat higher marking rates than those examined after 3–4 nights,

Table 2. Tracking periods for analysis of relationship between population density of house mice on Saddle Island and rate of mouse tracking in tracking tunnels.

Category	Mean population density (mice ha^{-1})	Tracking periods
Incursion *	0.3 (known abundance of 2 mice)	Data pooled from releases of 7 females and 6 males between 4 Feb. and 21 Dec. 2009
Low	0.3 (known abundance of 2 mice)	18–22 Jan. 2010; 9–12 Feb. 2010
Medium	3.7 (range: 2.8–5.3)	13 Feb. – 18 Mar. 2010; 18–23 Mar. 2010; 23 Mar. – 19 Apr. 2010
High	9.8 (range: 9.4–10.1)	19–23 Apr. 2010; 23 Apr. – 26 May 2010; 26–30 May 2010; 30 May – 29 June 2010; 29 June – 3 July 2010; 3 July – 8 Aug. 2010
Reduced	Unknown	15–19 Aug. 2010; 19–23 Aug. 2010

*Data in this category were from island interior tunnels only.

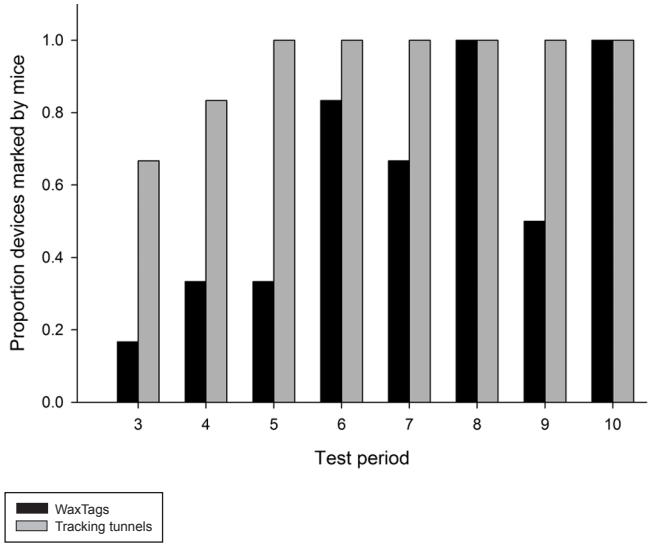

Figure 2. Proportion of WaxTags® and tracking tunnels marked by house mice on Saddle Island. Odd-numbered test periods were 3–4 nights, even-numbered test periods were c. 1 month long.

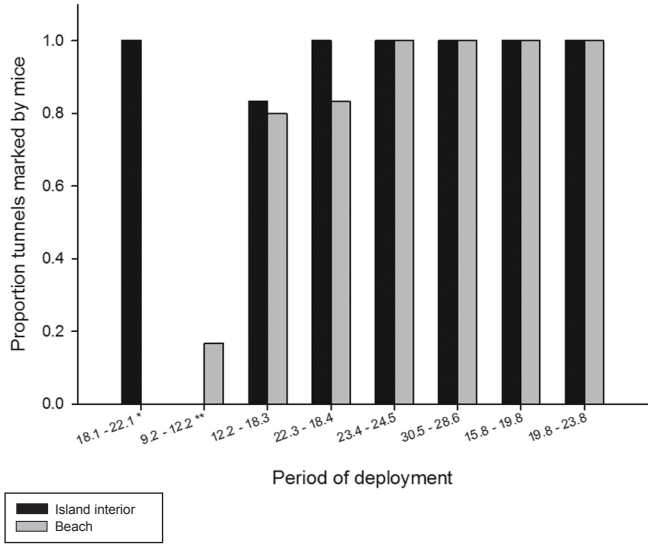

Figure 3. House mouse tracking rates in tracking tunnels placed along the beach and in the interior of Saddle Island. *Data from the beach not available, **data from the island interior not available.

Table 3. Mean (± standard deviation) percent of WaxTags® and tracking tunnels marked by house mice over deployment periods of 3–4 nights and 1 month on Saddle Island, showing *t* and *P* values.

Time period	WaxTags®	Tracking tunnels
3–4 nights	36.1% ± 19.5	94.4% ± 31.5
1 month	79.2% ± 13.6	95.8% ± 8.3
t statistic	−1.96	−0.45
P value	0.10	0.67

although the difference was not statistically significant (Table 3; Fig. 2).

Tracking tunnel placement

Tracking tunnels were effective at detecting mice irrespective of situation (Fig. 3), with no significant difference between average marking rates on tunnels in the island interior (97.6% ± 6.3) and those on the beach (82.9% ± 30.4) ($t = 1.26$, $P = 0.23$, d.f. = 12). There was no significant difference in the variability of marking rates per line based on tunnel situation ($F = 4.74$, $P = 0.23$, d.f. = 1, 12).

Population density and detectability

Tracking tunnels

Unequal variance necessitated the transformation of the tunnel tracking data to the power of 2. Using the transformed response, the proportion of tracking tunnels that detected mice increased linearly with increasing population density ($R^2 = 0.97$, $P = 0.02$, d.f. = 2). However, tunnel performance was satisfactory even during the low-density phase, with tracking rates per line averaging greater than 50% (Fig. 4).

WaxTags®

Marking rates on WaxTags® left in the field for 3–4 nights closely followed trends in population density, with detection rising to a peak in May along with density, before declining (Fig. 5). Unequal variance necessitated the transformation of the WaxTag® marking data to the power of ¼. Using the transformed response, a linear regression explained 98% of the variance ($P = < 0.01$, d.f. = 2). For WaxTags® left in the field for 1 month, marking rates increased with increasing population density, but did not decline when population density decreased after the peak was reached (Fig. 5). In this case, a transformation of WaxTag® marking data to the power of −¼ was necessary and the relationship between transformed marking rates and density was not significant ($R^2 = 0.86$, $P = 0.24$, d.f. = 1).

Discussion

Device choice and length of deployment period

In binary (detected / not detected) terms, tracking tunnels and flavoured WaxTags® were equally and consistently effective at detecting mice. In terms of average device marking rates per line, tracking tunnels detected mice more frequently and more consistently than WaxTags®.

Similarly, in recent trials Sweetapple and Nugent (2011) found that (non-flavoured) WaxTags® were insensitive to mouse presence compared with polypropylene chew-track-cards, a detection device that combines tooth-impression and tracking methods of detection. Further, it was found that of the mouse detections recorded on chew-track-cards, only 5.9% were identified by tooth impressions alone, compared with 23.9% identified by ink tracks alone (Sweetapple & Nugent 2011).

For tracking tunnels, the duration of deployment was unimportant. Current DOC best practice suggests running tracking tunnels for at least five nights (DOC 2008). Our results indicate that, where this is not logistically feasible, a shorter period of deployment is likely to be adequate. In contrast, our results suggest that lengthier periods of deployment may

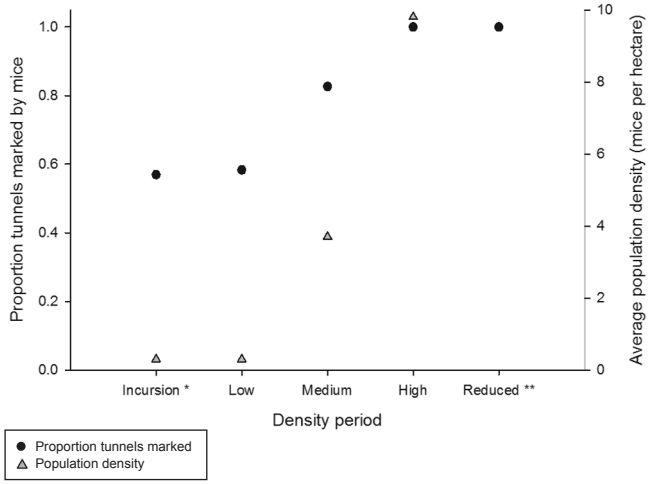

Figure 4. Proportion of tracking tunnels marked by house mice at different estimated population densities on Saddle Island.*Population density known at incursion period (two invaders), **estimate of population density unavailable for reduced density period.

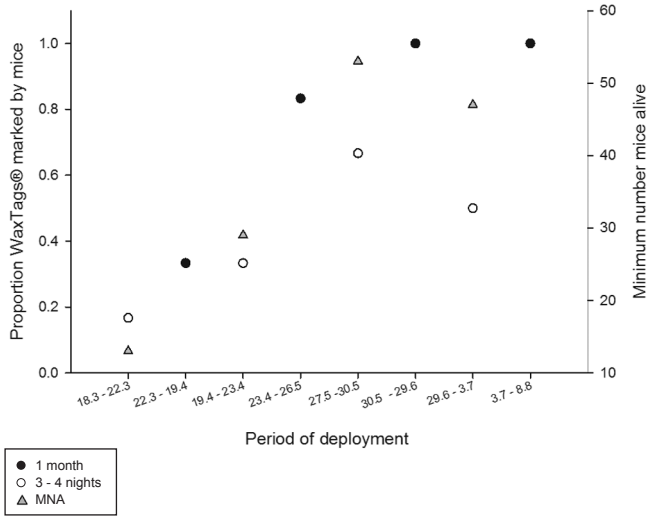

Figure 5. Proportion of WaxTags® marked by house mice over 3–4 nights and 1 month at different population densities on Saddle Island as approximated by the minimum number of mice known to be alive (MNA).

be necessary where WaxTags® are used for surveillance, although further tests are needed to confirm this assertion. Research aimed at determining an optimum duration would be informative.

Device marking rates were positively related to population density for both tracking tunnels and WaxTags® deployed over 3–4 nights. This is consistent with the view that detection of rodents is particularly difficult at low population density (Dilks & Towns 2002; Towns & Broome 2003). Low rates of mouse detection may be related to attributes of the mice (e.g. neophobia, trap aversion), attributes of the tracking tunnels (e.g. spacing, bait palatability), or both. However, as we lack independent measures of mouse movement, speculation on the relative importance of these alternative mechanisms is inappropriate. It is possible that increases in marking rates were due to mice habituating to the detection devices after the initial incursion period, rather than to increases in population density. However, if this were the case, we would not expect to see the difference between marking rates at medium and high population density that we recorded. We are therefore confident that population density was the relevant factor determining device marking rates in our study.

Current best-practice recommendations suggest a variety of different detection devices can be used for island surveillance (K. Broome, pers. comm.). Each device has different advantages and disadvantages, which makes a combined approach prudent. The most appropriate combination of devices will be dependent on the particular circumstances of each surveillance operation, such as island characteristics (e.g. size, remoteness), known history of invasion, the frequency at which devices will be checked, and potential impacts on non-target species (DOC 2008). Both tracking tunnels and WaxTags® have the advantages of being non-destructive, easy to use, able to gather information on a variety of species, and non-harmful to non-target species (Thomas et al. 1999; Gillies & Williams 2007). Potential disadvantages of tracking tunnel use are that bait may be quickly consumed, including by non-target species, and that tracking cards may deteriorate in adverse weather conditions or where impacted by non-target species (e.g. snails). In contrast, WaxTags® are durable enough to remain in the field for months without replacement (based on manufacturer information) and, because the peanut-butter lure is incorporated throughout the wax, potentially retain attractiveness for a longer period than tracking tunnels (Russell et al. 2008b). However, wax has been shown to be of low palatability to rodents (O'Connor & Eason 2000), suggesting that even flavoured WaxTags® may not be sufficiently attractive to detect rodents when an abundance of alternative food is available, such as during initial incursion upon an island.

Our results suggest that both tracking tunnels and flavoured WaxTags® are effective devices for the detection of house mice at moderate population density. During the incursion phase, tracking tunnels demonstrated high sensitivity to mouse presence. Tracking rates in tunnels were significantly related to population density, in contrast to a previous study by Ruscoe et al. (2001), which found that tracking tunnel indices were unrelated to mouse population abundance. This inconsistency may result from the fact that population density on Saddle Island remained moderate throughout the experiment when compared with established mouse populations (Nathan 2011). However, differences in methodology between the two studies may also explain the contrasting results. Ruscoe et al. (2001) used a line of 9 tracking tunnels spaced at 80 m in each of three 3-ha grids over a period of 3 nights, equating to a device density of three per hectare. In contrast, we used 6 tracking tunnels on one 6-ha island, spaced unevenly and deployed for varying lengths of time. Further tests of the relationship between population density and mouse tracking rates are recommended to resolve this conflict.

Flavoured WaxTags® were not trialled at low density, but non-flavoured WaxTags® failed to detect mice. When flavoured WaxTags® were used over 3–4 nights trends in detection followed MNA closely, suggesting high sensitivity to changes in population density. This indicates that WaxTags® are an ideal tool for monitoring fluctuations in mouse population abundance at moderate to high density.

Device placement

At high population density, 100% of deployed tracking tunnels detected mice, regardless of situation. At low and medium population density, tunnels placed on the beach appeared to have slightly lower tracking rates than those placed in the island interior; however, this difference was not statistically significant. This suggests that where a wide dispersion of detection devices across an island is logistically infeasible, placing devices in readily accessible areas is an acceptable alternative so long as the habitat is suitable for the target species. This strategy is consistent with current DOC island biosecurity best practice, which suggests that where an island-wide distribution of devices cannot be managed to a high standard, devices should instead be placed in readily serviced areas (DOC 2008).

In our study, we were unable to evaluate the performance of a 'point of entry' strategy for early detection of incursion events. In experimental releases of individual animals MacKay (2011), Russell et al. (2008a) and Speedy et al. (2007) found that house mice, Norway rats, and ship rats (respectively) all remained close to the point of release for 2–4 days. Thorsen et al. (2000) also reported that Norway rats initially settled in a relatively small area close to the point of arrival after invasion of Frégate Island. These results indicate that 'point of entry' monitoring may be rewarding in the early stages of incursion. The Pribilof Islands, Alaska, offer an example of the successful implementation of this strategy. There, trapping and poisoning efforts are concentrated at docks. Although several rats have been intercepted and killed since 1993, there is no evidence of rats becoming established anywhere in the Pribilof Islands (Sowls & Byrd 2002). It is recommended that the potential utility of a 'point of entry' detection strategy in the New Zealand island context be experimentally tested.

It must be emphasised that, in our study, data were sub-sampled from a larger dataset in order to represent the 'broad coverage' strategy. Therefore, there were more baited devices available to mice than are accounted for in the results presented here. It is unclear how this may have affected our results. Potentially, detection may be underestimated if mice are sated by bait eaten elsewhere. Conversely, the presence of a permanent dense grid of devices may have led to reduced neophobia, resulting in overestimates of detection rates. It is therefore recommended that, to corroborate the findings of this study, similar trials are undertaken where detection strategies are implemented exactly as they would be for surveillance purposes.

Conclusions

Overall, the results of this study are encouraging. They show that current island-surveillance best practices are likely to detect most incursions of house mice. While detection rates increased linearly with population density, these were high even during the incursion and low-density phases. This demonstrates that there is considerable value in investing in island surveillance for house mice. Tracking tunnels are an especially effective detection tool for this species

It has long been recognised that an improved understanding of the colonising behaviour of mammalian pests is necessary for the advancement of island biosecurity practice. Recent research on the behaviour and detectability of Norway rats (Russell et al. 2005, 2008a, 2010) and ship rats (Speedy et al. 2007; Innes et al. 2011) upon island incursion has been groundbreaking and informative. Our research, along with that of Mackay (2011), makes a further contribution to the growing knowledge base in this area. To our knowledge, no similar island release experiments have yet been attempted with stoats (*Mustela erminea*), another problematic island invader in New Zealand (Veale et al. 2012). We suggest that experimental island invasions are the best way to gain detailed information about the incursion behaviour and detectability of the full suite of high-risk island invaders. This knowledge would be an invaluable asset to conservation managers charged with designing effective, broad-spectrum island surveillance systems.

Acknowledgements

The New Zealand Department of Conservation approved the use of Saddle Island as a field site, allowed us to camp on the island during fieldwork, and provided logistic advice via Thelma Wilson. All animal work was performed under approval from the University of Auckland Animal Ethics Committee (R579 and amendments). Many people assisted with fieldwork, with particular acknowledgement due to Sandra Anderson. Keith Broome, John Innes, Jo Hoare, Kevin Burns and one anonymous reviewer obliged us with valuable comments on drafts of this manuscript. This work was undertaken with funding from the New Zealand Department of Conservation and the University of Auckland.

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Editorial Board member: Hannah Buckley
Received 4 October 2011; accepted 16 March 2012

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