Using social attraction to enhance trappability of invasive Norway rats (*Rattus norvegicus*)

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Abstract

The Norway rat (*Rattus norvegicus*) is one of New Zealand's most destructive invasive species and poses a significant threat to rat-free native refuges via incursions. The Norway rat is a highly social species with complex intraspecific interactions. A series of experiments have demonstrated that the social traits of this species can be manipulated to enhance the detection and capture of invasive animals. Using laboratory rats (*R. Norvegicus*) as conspecific lures for wild Norway rats, it was found that live laboratory rats were more efficient in attracting wild Norway rats than food bait. In this report, the advantages and disadvantages of the live lure method are discussed and potential uses of the method as an additional pest control tool are suggested.

Keywords: Norway rat, *Rattus norvegicus,* invasive species, rat control, conspecific attraction, live lure, incursion

1. Introduction

1.1 Colonisation and ecology of Norway rats in New Zealand

The Norway rat (*Rattus norvegicus*) is one of the most widespread and destructive invasive species worldwide (Long 2003). The species first arrived in New Zealand with European ships during the 1770s and by the mid 1800s, Norway rats were widespread over New Zealand's two main islands, as well as being present on many offshore islands (Innes 2005a). By the late 1800s, however, Norway rats were beginning to disappear from many mainland sites, probably due to competition from ship rats (*R. rattus*) (Innes 2005a; King et al. 2011) and predation by mustelids (*Mustela* spp.) (Innes 2005a).

Like other invasive rodents, Norway rats exhibit a short reproductive cycle and high dispersal capacity (Nowak 1999; Long 2003; Innes 2005a). They are omnivorous with extremely broad diets (Nowak 1999; Long 2003; Innes 2005a) and when they have access to sufficient shelter and food resources, can survive in both hot and cold environments (Long 2003; Galef 2005). Norway rats are active learners (Galef & Allen 1995; Galef 2005), and highly commensal with humans (Innes 2005a). All of the above attributes contribute to their remarkable potential for invasiveness. Along with ship rats and mice, (*Mus Musculus*), Norway rats can have severe (potentially catastrophic) effects on New Zealand's native flora and fauna (e.g. Atkinson 1978; Holdaway 1989; Towns & Broome 2003.

New Zealand invasive rodent communities have been subject to various shifts in species dominance and their distributions have fluctuated significantly since their arrivals (e.g. Taylor 1975, 1978; Yom-Tov et al. 1999; King et al. 2011). Currently, however, ship rats and mice are arguably the most widespread species, especially on the mainland (Innes 2005b; Ruscoe & Murphy 2005). The kiore (*R. exulans*), once the only rodent present across the archipelago, is now confined to a few small populations (Atkinson & Towns 2005). Although common in commensal situations, Norway rats are generally scarcer in mainland natural habitats, occupying mainly wet areas (Innes et al. 2001; Innes 2005a). However, in the absence of ship rats they were, until recently widespread on many offshore islands (Innes 2005a).

1.2 Rat incursions to rat-free islands

Rodent eradication programmes have been carried out in New Zealand from the 1960s onwards, within important conservation areas on the mainland and on entire offshore islands (Dilks & Towns 2002; Towns & Broome 2003; Russell & Clout 2005). In recent years, more than 95% of eradication attempts of rats on islands worldwide have been successful (Howald et al. 2007). In New Zealand, many offshore islands have been made rat free and now provide refuges for endangered native species (Towns & Broome 2003). On the mainland, efforts are being concentrated mainly on the control of rodents in nature reserves and other protected areas. Some of the mainland protected areas use pest-proof fences to control reinvasion, and are able to eliminate resident pest populations and manage new incursions in a similar way to offshore islands (Atkinson 2006).

As Norway rats are a commensal species (Innes 2005a) with high capacity to survive on small vessels (Harper et al. 2005) and exhibiting remarkable swimming capacities (Harper et al. 2005; Russell et al. 2005), they pose a real reinvasion threat to rat-free islands. For example, Norway rats recently invaded and established a population on Ulva Island, a native species refuge just off the coast of Stewart island/Rakiura (Musada & Jamieson 2013). In some other recent incursions, it sometimes took 3–4 weeks to capture individual rats after an incursion was detected (F. Buchanan, S. O'Connor, DOC, pers. comm.). As such, the detection of reinvasions or the eradication of remnant populations that have evaded control measures remains a challenge (Russell et al. 2005; Russell et al. 2008a, b.

When rats move into novel environments or when their populations are at low densities, natural food is usually abundant and animals tend to be wary and/or well fed and thus may avoid trapping devices (Russell et al. 2005; Russell et al. 3008b; Masuda & Jamieson 2013). Moreover, Russell et al. (2010) found that the exploratory and movement behaviour of invading Norway rats is thus far unpredictable, which makes it difficult to efficiently deploy means of surveillance and capture. As a result, the capture of new invaders, when detected, usually requires extensive effort in additional capture systems, manpower and time (Russell et al. 2005; Clapperton 2006; Russell et al. 2008b). Therefore, finding new methods for rodent detection and capture in incursion scenarios is of major importance.

1.3 Norway rat social interactions

Norway rats are highly sociable animals and populations exhibit complex inter- and intra-sexual interactions, within and between familiar and unfamiliar individuals (e.g. Barnett 1958; Calhoun 1963; Galef 2005). These interactions reflect not only in the formation of hierarchal social groups that might include tens of animals, but also interactions between groups and between new individuals and established groups. In general, dominant males and females are more active within these interactions, but all ranks exhibit interest. The investigations of new individuals by group members are intensive for both sexes, although males are, in general, more active than females in this respect. Further, both olfactory communication (Cheal 1975) and vocalisation (Barfield et al. 1979) play crucial roles in Norway rat social behaviour.

A recent study by Ben-Ami Bartal et al. (2011) demonstrated that social traits in rats may be the motivation for individuals showing interest in, and performing 'helping' actions towards captive conspecifics. However, despite the apparent relevance of species-specific traits for invasive species control measures (Clapperton 2006), they have not been applied in current practices, which mostly use general food items as lures. In the case of the Norway rat, there is the possibility that the highly social traits exhibited by this species could aid in the detection and capture of invading animals.

1.4 Conspecific attractions as a tool to trap invading Norway rats

One example of using conspecific attraction as a component of a control method is the use of 'Judas goats', where radio-collared goats have been used to detect remnants of feral goat populations by allowing the collared animals to join the remnant population (Taylor & Katahira 1988; Campbell et al. 2004; Cruz et al. 2009). With Norway rats, a strategy that involved attracting wild animals to a caged laboratory animal has so far seemed the most practical approach. The experiments described in the following text were based on the principle of social attraction in Norway rats, with the hypothesis that when food is abundant, these highly social animals will be more willing to approach a caged conspecific rather than a food-baited device.

A preliminary study, run by Gsell et al. (2014), showed that wild rats were attracted to cages housing laboratory rats (*R. norvegicus*). Despite the inability of the study to determine species, gender and numbers of the visiting animals, its results provide the groundwork for developing a system in which laboratory rats are used as lures for invading conspecifics. Shapira et al. (unpubl. data) caught a male Norway rat in a trap with a laboratory rat as live lure (Fig. 1). In our knowledge, this is the first example of a wild rat being trapped using the live lure method. The only previous record of using laboratory rats as live lures for wild rats that we could find is recorded in Wace (1986). However, this was attempted at a site that was found, retrospectively, to have not to had Norway rats present at the time of the experiment.

Figure 1. A male Norway rat caught with a snap trap placed inside a tracking tunnel leading to a caged male laboratory rat. Signs of rat activity were detected around the lure rat's cage (tunnel dug underneath the cage and tracks on the tracking cards). The traps were set and the animal in the photograph was caught the following night.

In a series of experiments following the first rat capture, we were able to demonstrate that in multiple scenarios, laboratory rats acted as better lures to invasive Norway rats than food baits (Shapira et al. 2013a, b). At one mainland site (Shakespear Open Sanctuary, Auckland (36°36′16.37″S, 174°49′32.24″E) with a high rat population density (Shapira et al. 2013a), laboratory rats attracted the same numbers of invasive Norway rats as food baits, but were more efficient lures in terms of trap/capture ratios (i.e. more captures per trap). Moreover, additional rat activity around the traps was observed only when live lures were present. At mainland sites with low rat population densities (Shapira et al. 2013b), live lures were significantly better attractants of wild Norway rats than food baits. At one of the sites (Matuku Reserve, Auckland (36°52′07.06″S, 174°28′31.79″E)), Norway rats were not trapped over 3 years prior to the experiment. During a 2-week period, three animals were trapped using live lures. At two sites with high rat population densities and abundance of food in the environment (Auckland Zoo in summer and Hamilton Zoo in autumn), significantly more wild Norway rats were caught using live lures than with food baits (11 v. 1 at Auckland Zoo, 9 v. 1 at Hamilton Zoo). In an additional rat control attempt at Auckland Zoo during winter, very low numbers of rats were trapped, with more animals caught with live lures than with food baits (4/2) (although this result was not statistically significant (Shapira et al. 2013b)).

In three manipulated island rat incursion scenarios at Browns Island (Motukorea) (36°49′50.21″S, 174°53′40.14″E), Auckland, Shapira et al. (2013b) separately released radio-collared male Norway rats onto the island and attempted to recapture them using both live lures and food-baited traps. The method was based on using radio detection to track the released rats (imitating in this case their detection in tracking tunnels or by any other non-lethal detection method) and placing traps in the area where they were detected. Both the number of replications and the placing of the lures were not ideal, as the experiment was subject to technical and permit limitations. Two of the male rats were caught with lure females within 1–5 days of the start of trapping. The third male rat lost its collar and avoided both food bait and live lures spread around the island. Furthermore, a rodent detection dog did not locate it during two separate searches (although, during an earlier trial on the same island, this dog found and killed a trial rat that had damaged its collar (Shapira et al. 2011)). Five to six weeks after the third rat released lost it collar, a Norway rat was caught in the existing (non-trial) trap grid. This was likely to be the third rat, although it was impossible to confirm this. While the first two rats demonstrated the power of conspecific attraction, the third rat demonstrated how elusive Norway rats can be, emphasising the need for multiple trapping/detecting methods to be used in responses to rat incursions.

Overall, during most of the tests, there was no significant difference in the attractiveness of male and female lure rats or the numbers of male and female rats trapped. In the Browns Island experiment, only males were released and, apart from the one that escaped, the other two were recaptured in traps with female lures. At two, the number of samples in this experiment is limited, so it cannot provide conclusive evidence regarding inter- and intra-sex attraction. In fact, over the course of the study, every possible combination of gender trappings was recorded—i.e. male and female invasive rats were caught in traps with both male and female lure rats. In absolute numbers, however, we caught more males than females and lure females attracted more invasive rats than lure males.

In all of the tests, it seemed that social attraction was either stronger than food attraction or exhibited at least the same efficacy, meaning that at least some animals will be more attracted to conspecifics than to food baits. As rat incursions are likely to continue and with more off-shore islands becoming rat free and serving as native fauna refuges, this additional trapping method might fill a gap in detection and capture systems that are presently based mainly on the attraction provided by food.

Shapira et al. (2013a, b) used laboratory and pet rats as lures. All domesticated rats are the descendants of the wild Norway rat, considered to be the same species (*Rattus norvegicus*), and were the principle target in the lure experiments. Ship rats (*R. rattus*) are strong interspecific competitors of Norway rats (Yom-Tov et al. 1999; Innes 2005a, b; King et al. 2011) and this is probably why they were not captured or detected with the laboratory (*R. norvegicus*) rat lure method. Recently, a ship rat was caught in a trap with a laboratory rat as a lure (M. Maitland, Auckland Council, pers. comm.). However, based on the amount of data gathered by Shapira et al. (2013a, b) it would probably be safe to argue that this case is an artefact and that in general, the luring method described here is not efficient for detecting and capturing ship rats. Using captive ship rats to lure their conspecifics is problematic for the following two reasons: (1) Being wild animals (without known domesticated counterparts), ship rats will be difficult to handle. (2) Being wild animals, small cages will probably put them in a state of constant stress, the effect of which on attraction is unknown. Some initial trials with ship rats as lures were conducted by Shapira and colleagues (unpubl data). These yielded nothing, but more thorough experiments should be carried out in order to better understand the applicability of this option.

2. Implications

2.1 Suggested uses for the live lure method

Currently, the Department of Conservation (DOC) is using various island biosecurity systems to cope with invasive species (Clapperton 2006; Broome 2007), employing both proactive and reactive approaches (Parkes & Murphy 2003). I suggest that the live lure method should be considered for both approaches as a potential aid to existing detection and capture methods. In the proactive approach, the live lure method might be used as a supplementary detecting tool. For example, Shapira et al. (2013a), using live lures, caught three Norway rats at Matuku Reserve, where the presence of this species had not been verified through trappings for more than 3 years prior to their trial. Since the deployment of live lures year-round is probably unrealistic, as live animals require higher levels of maintenance and can be more costly than other lures, and their use raises animal ethics issues, seasonal use is recommended. Live lures might be used in a similar way to rat detector dogs—by deploying live lure traps periodically for short periods of time to check for the presence of Norway rats.

In the reactive approach, the live lure method can be used after a rat incursion onto a rat-free island has been detected. It this case, multiple techniques are usually used in order to capture the invading animal(s), including reinforced trapping and bait stations and searches with dogs. The live lure traps can be used as an addition to the trapping effort, adding a social attraction aspect to the conventional methods.

In both proactive and reactive approaches, the use of live lures is subject to the needs of the specific situation. It is possible to spread cages within a large area and move them around or try to target the invading rat in a more specific area if signs of its activity can be detected. Based on the research done by Shapira et al. (2013 a, b) and discussed earlier, it is recommended that both male and female lures be used. It is important to stress, however, that at this stage of experimentation the distance that a wild rat will travel to a caged conspecific is not known. Having this information is crucial for being able to usefully apply the lure method and it is highly recommended that further research be conducted to enable it to be obtained.

2.2 Technique principle

The lure system, as tested by Shapira et al. (2013 a, b), does not reveal the specific mechanism of attraction. However, as olfactory communication (Cheal 1975) and vocalisations are both important aspects of *R. norvegicus* social behaviour (Barfield et al. 1979), a multi-modal form of signaling is probably present. The field implication of the social attraction is pretty straightforward, however; instead of food bait (Fig. 2A) it uses a live conspecific as the lure (Fig. 2B). Scent alone, as well as rat playback calls, will probably attract wild animals as well as live animals will. However, at this stage of experimentation their efficacy in comparison to live animals is unknown. As Norway rats are highly social, the social-based conspecific attraction is strong, regardless of motivation (sex-, intersexual relations- or hierarchy-driven).

2.3 Lure animals

There are two advantages for using laboratory rats over wild rats as lures. First, laboratory rats are tame, which makes them very easy to handle and maintain. Second, as opposed to wild rats they are accustomed to living in relatively small cages. A wild animal in a small cage will probably have high levels of stress, which might negatively affect conspecific attraction and can result in the premature death of the lure animal. Although the exact mechanism of attraction is

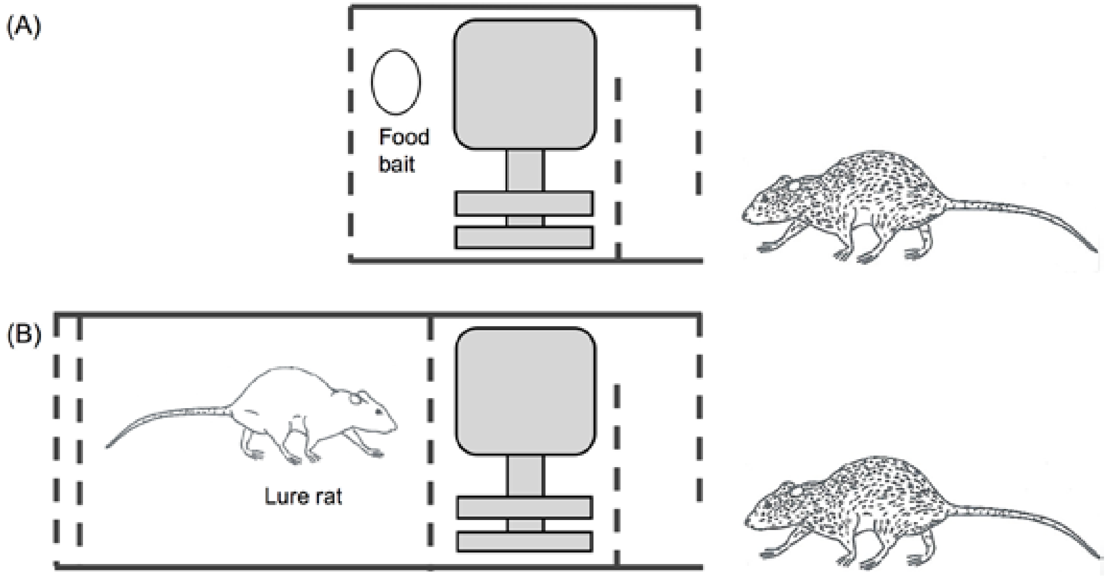

Figure 2. A—Schematic drawing of a standard DOC 200 trap using food as the bait. B—Schematic drawing of a modified DOC 200 trap design to house a laboratory rat as the lure. In both cases, the wild animal has to get through the kill trap in order to get to the food bait / lure rat.

largely unknown, sexual attraction (as well as territorial conflicts which can result in attraction) are probably strong factors (Barnett 1958). Therefore, it is recommended that sexually mature animals are used (rats can be sexually mature as early as 4–5 weeks of age, but it is probably advisable to use animals over 6 weeks old). As mentioned before, Shapira et al. (2013a, b) did not find significant differences between the attractiveness of male and female lures, although there was some evidence that females might be better attractants.

The possibility and consequences of lure animals escaping their cages will always need to be considered. This is especially true for females, because of the risk that they could breed. However, during all of the trials and experiments I carried out, the laboratory rats never tried to chew their way out of cages or attempt to jump out of a cage when the lid was lifted. Cages can be altered to make them escape proof. In particular, wooden parts can be covered with wire mesh and an additional mesh cover can be installed under the cage lid. In reality, the greatest threat is from the unauthorised release of animals by other people, which even locks (which were always used in the experiments reported here) cannot prevent. Daily monitoring of the cages is the only way to reduce this already low risk.

2.4 Lure devices

Lure devices should be designed so that the easiest way for target animals to approach the lure animal is through a trap. In their experiments, Shapira et al. (2013 a, b) used two types of lure devices. In the first one, the lure rat's cage was placed inside an enclosure with four trap (DOC 200) openings (Fig. 3 A–B). This design provides very efficient all-weather shelter for the lure animal and can potentially give protection for long periods of time. However, the device is relatively large and heavy and is not ideal for moving around. The second device is a modification of the standard DOC 200 trap box, in which a large compartment is attached to the trap (the two compartments are separated with mesh) to house the lure animal (Fig. 3 C–D). This design still provides good protection for the lure animal, but is relatively easy to carry and requires less space at trapping locations. Regardless of design, the principle remains the same: a cage housing a lure animal is attached to any kind of trap strong enough to efficiently hold and kill an adult Norway rat. The minimum recommended cage size for any apparatus design must correspond with the minimum floor area for an adult rat (Chave 2007), which is 25H × 25W × 50L cm (including an elevated nest box).-

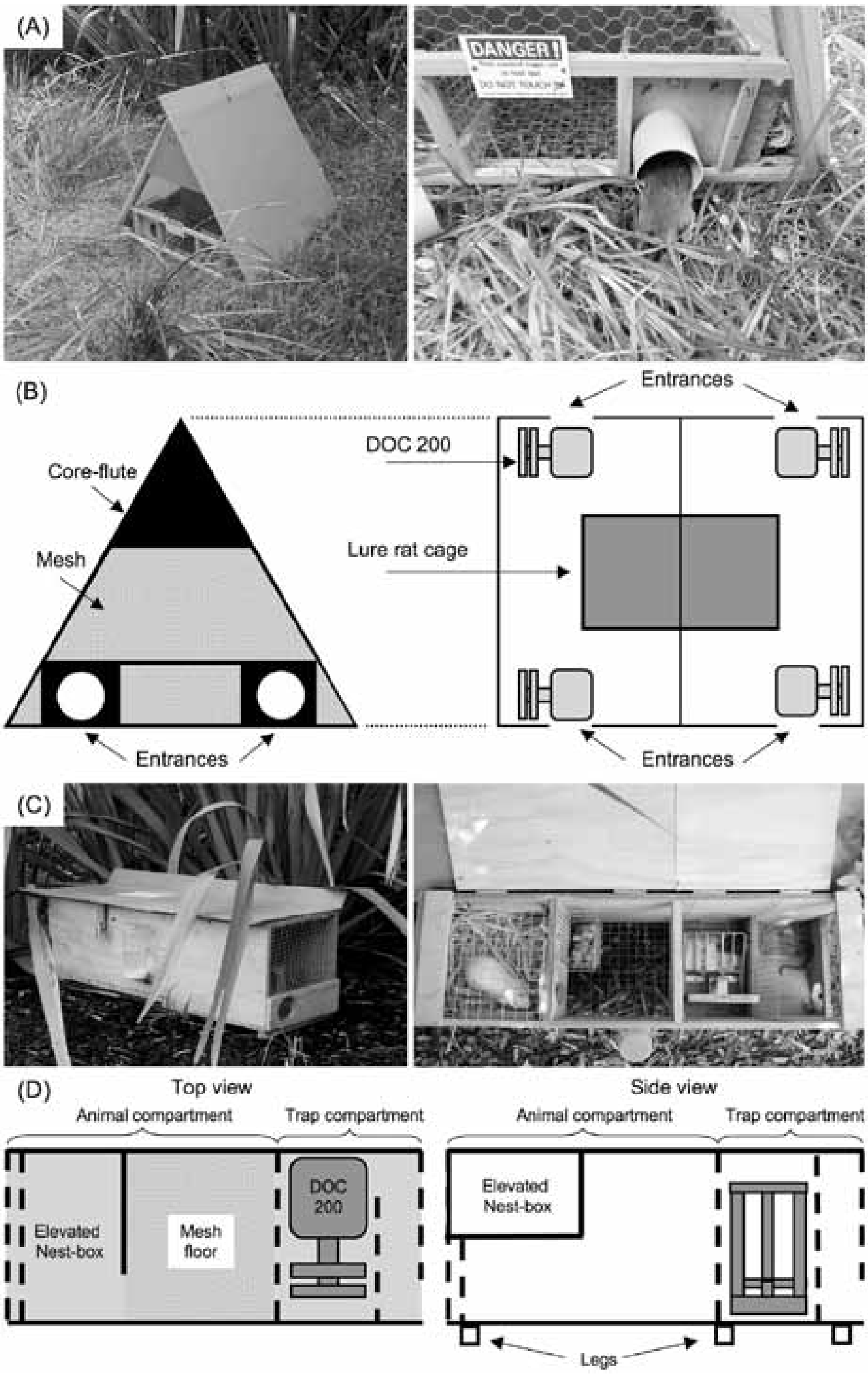

Figure 3. A—Enclosure housing a lure rat's cage and a rat caught at one entrance. B—Diagram of the enclosure apparatus. C—Modification of a DOC 200 trap box with two compartments, one housing the lure rat and one fitted with a DOC 200 trap showing a rat caught in the trap compartment and the lure rat it its nest box. (D) Diagram of the cage apparatus. Minimum cage dimensions should be for both cases 25H x 25W x 50L cm.

2.5 Field maintenance of laboratory rats

2.5.1 General

As a general rule, live animals require relatively high maintenance. As our trials were carried out under animal ethics procedures (Massey University Animal Ethics Committee), we had to visit the lure traps daily. Although this was more labour-intensive than maintaining food baits, we found that the actual maintenance of the lure rats was quite simple (Shapira et al. 2013a, b; unpubl. data). In any case, when a specific animal is being targeted in an incursion response situation, the usual procedure also requires daily visits to traditional traps (F. Buchanan, DOC, pers. comm.).

2.5.2 Getting the lure animals to the site

Ideally, the lure animals should be brought to the site already inside the lure + trap device. This way there is no need to move the lure rats between cages. Laboratory rats are tough animals and during our trials we transferred the traps with live lures inside motor vehicles, on board boats and on backpack carriers without harming the animals (Shapira et al. 2013a, b; unpubl. data). In general, live animals should be treated with extra care. Shaking and sudden movements should be kept, within the obvious limitations, to the absolute minimum possible.

2.5.3 Placing the lure devices

Lure devices should be placed on leveled ground. If possible, it is better to place them in a protected place, but this depends, of course, on availability. Shapira et al. (2013a, b; unpubl. data) deployed live lure traps in sheltered and open locations and during all weather conditions with no apparent harm to any of the lure animals.

2.5.4 Food and water

Lure animals should have an ad libitum supply of food and water. It is recommended that dry food (rodent pellets) is used, as the pellets last longer than fresh food and provide the animals with all the nutrition they require. If conditions are wet, food tends to become mouldy. If this occurs, it is advisable to provide the animals with relatively small quantities and to top them up as necessary.

2.6 Using live rats as lures for other invasive species

Rodents are prey for mustelids (*Mustela* spp.), another group of destructive alien mammals introduced to New Zealand which, like Norway rats, also pose reinvasion threats (Clapperton 2001; King et al. 2001). During our field experiments, we caught a stoat (*Mustela erminea*) and two weasels (*M. nivalis*) in the live lure rat traps (Shapira et al. unpubl. data). At the time of the experiment, no mustelids were caught with regular, meat-baited rat traps in the study area. Live laboratory rats have previously been tested as lures for stoats and found to be ineffective (Lawrence 1999). However, traps and lure cages were physically separated in Lawrence's (1999) study, so the true attractiveness of the rats might not have been displayed. That we caught only three mustelids during our trials probably reflects low population densities that have resulted from ongoing mustelid control at the study sites (J. Staniland, Forest & Bird, pers. comm.). Mustelids prey upon rats (McDonald et al. 2000; King et al. 2001) and are likely to be more attracted by live prey than food bait that rapidly loses freshness. Due to the difficulties encountered in the control of invasive mustelids (King & Moors 1979; King et al. 2009) and despite Lawrence's (1999) results, the use of laboratory rats as lures for invasive mustelids should be further investigated.

2.7 Animal ethics

Under the Animal Welfare Act (AWA) (1999), the manipulation of animals for research, testing or teaching requires approval from an Animal Ethics (AE) committee. This applies for practical as well as experimental usage. The AWA is mainly concerned with (1) 'obligations in relations to the physical, health, and behavioural needs of the animals', and (2) 'obligations to alleviate pain or distress of ill and injured animals'. Following the cage size and floor area recommendations and the feeding regimes suggested in this text should ensure compliance with (1). Daily visits to the cages for the purpose of checking the captive rat's condition, should minimise the chances of not meeting the requirements raised in (2). In some cases, iwi approval to use lure rats is also required. Both AE and iwi requirements can take time to organise, and to avoid delays, these issues should be addressed very early (if possible) in the planning process for field use of live lures.

3. Conclusions

Understanding the behavioural ecology of invasive species provides information that can be used to develop tools for conservation practices (Buchholz 2007). Shapira et al. (2013a, b; unpubl. data) used knowledge of the behavioural traits of the Norway rat to develop a novel method for detecting and capturing this invasive species. As discussed in section 1.4, the capability of rats to avoid detection highlights the need for flexible management responses when incursions occur (i.e. the use of a variety of detecting methods). Because of the severe negative consequences that may result from rat incursions onto rat-free islands or into mainland sanctuaries and the need for additional measures to detect survivors after eradication attempts, every method that proves efficient at attracting rats should be considered. The use of laboratory rats as live lures should be considered in future management plans, especially in island incursion scenarios where rapid response is crucial.

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