The Potential for Re-Invasion by Mammalian Pests at Maungatautari Ecological Island

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Trevor Allan Connolly

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Abstract

Mammalian pests are excluded from Maungatautari Ecological Island by an Xcluder™ pest-proof fence. Inevitably, the fence integrity will be compromised at some point by mechanisms such as treefall and flood-scour: such events could lead to pest re-invasion. Knowledge of pest activity directly outside the reserve would assist reserve managers in developing optimal breach-response procedures. This thesis described baseline data on the presence, timing of activity and behaviour of mammalian pest animals found directly at the Maungatautari fence. Two seasonal video studies investigated the effects of season (summer and winter), exterior habitat (forest and pasture) and simulated breach type ('tree-fall' and 'flood scour') on the number of pest sightings. Significantly more sightings were recorded in summer (788) than in winter (428), particularly for rodents. Rabbits were sighted significantly more often at pasture sites, but habitat type did not significantly affect sightings of any other species; nor did breach type affect sightings of any species. Ship rats were commonly sighted within the fence hood gutter. Overall, rodent, possum and cat sightings were very high, and mustelid sightings extremely low, in both seasons. Over 95% of non-lagomorph sightings were nocturnal, and the greatest threat of invasion was found to come nocturnally, from mice, and in the summer. A probability model showed that although the cumulative probability of a mammalian pest encountering a fence breach increases dramatically after dark, in reality there is always a threat of encounter, and this is always increasing with time. Over the same two studies, the behaviour of pest mammals sighted was also described. Pests were found to show interest in and enter summer breaches more often than winter breaches ($p < 0.001$). Simulated breaches were encountered by pests within the first 24 hours at a very high rate (95% summer, 92.5% winter), and most likely to enter a breach were rodents. Over 7 days, breaches were encountered and entered by increasing numbers of species and possibly by more individuals; all species were shown to be willing to enter. The threat of invasion by ship rats was probably underestimated because of their higher activity within the fence hood than at the fence base; mustelids may also offer a greater threat than the results suggest, because they almost always entered a breach. It was strongly recommended that when the fence integrity is compromised, physical response should be as quick as possible, especially at night. Future research was strongly encouraged, particularly to understand invasion behaviour of animals such as ship rats and stoats, and to describe pest behaviour at real breach events.

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CHAPTER 1

Literature Review

GENERAL INTRODUCTION

Introduced Mammals as Pests

In the 700-750 years since the first exotic mammals arrived in New Zealand with the colonising Polynesians (Hogg et al. 2003), up to 54 mammal species have progressively been introduced. Of these, 31 species have established wild or feral populations. At least 25 of these introductions are presently managed as pests in New Zealand (King 2005; Parkes & Murphy 2003). Some species, such as stoats (*Mustela erminea*) seriously threaten indigenous species (e.g. kiwi, *Apteryx* spp.) Other species that threaten conservation values may also be agricultural pests, as vectors of disease such as bovine tuberculosis (Tb) (e.g. brushtail possums (*Trichosurus vulpecula*), ferrets (*Mustela furo*), and red deer (*Cervus elaphus scoticus*)) or by damaging farmland directly (e.g. European rabbits (*Oryctolagus cuniculus cuniculus*)) (King, 2005).

The two strategic options to manage pest mammals are 1) sustained control, and 2) one-off control (e.g. eradication) (Parkes & Murphy 2003). The complete eradication of pest mammals over any substantial area of the New Zealand mainland has previously been thought impossible. Control techniques used in the past rarely detected every individual in a population, and this, combined with re-colonisation from neighbouring uncontrolled areas, has made eradication untenable.

Hence, the strategy most commonly used to manage mainland pest mammal populations is sustained control. This requires regular control operations, to be sustained in perpetuity, that aim to stop further damage by the target pest or pests (Parkes & Murphy 2003). In order to achieve maximum benefit, aspects such as frequency, intensity and spatial pattern of control must be optimised, and the most efficient, effective and environmentally safe methods must be used (Parkes & Murphy 2003). However, under this strategy, there will always be survivors, and eventually other individuals will disperse into a treated area. To avert further pest impacts (including extinctions), the Department of Conservation (DoC) has translocated vulnerable endemic species such as kakapo (*Strigops habroptilus*) to predator-free offshore islands (Powlesland et al. 1995; Saunders & Norton 2001).

Complete eradication of a pest species should be attempted only where the protection of a resource requires it, or where it is cheaper to eradicate than to undertake long-term sustained control (Parkes & Murphy 2003; Parkes 1990). In order for eradication to be successful, three strategic conditions must be met (Parkes 1990):

1. All individuals must be put at risk;
2. Re-colonisation must not be possible; and
3. Pests must be killed faster than they can replace their losses.

A fourth 'desirable' condition is that survivors must be detectable at low densities.

Offshore islands offer an opportunity for eradication because the surrounding sea prevents re-colonisation. Over the past 30 years, techniques that achieve the remaining two strategic conditions have been developed, largely through research on offshore islands.

Eradication on New Zealand's Offshore Islands

Attempts to eradicate pest mammals from New Zealand's offshore islands prior to the 1970s mostly targeted large mammals, e.g. feral goats (*Capra hircus*) on Kapiti Island (Parkes 1990). More recent successful eradications include feral cats (*Felis catus*) from Little Barrier Island in 1980 (Veitch 2001), and possums from Kapiti Island in 1986 (Brown & Sherley 2002; Cowan 1992). However, rodent eradication had only rarely been attempted before the 1970s, and never on islands larger than 1 hectare (1ha) (Moors 1985; Veitch & Bell 1990). The prevailing view of the time was that the possibility of "complete extermination on islands is remote, or at least a very, very difficult thing indeed" (Dingwall et al. 1978, p.273).

Rat eradication techniques were greatly improved by the arrival in the 1980s of second-generation anticoagulant poisons such as brodifacoum (Thomas & Taylor 2002). The new toxins and techniques allowed progressively larger islands to be cleared of rodents such as Norway rats (*Rattus norvegicus*) and/or Pacific rats (*Rattus exulans*), including Hawea (9ha) and Breaksea (170ha) Islands, Codfish (1396ha) and Kapiti (1965ha) Islands, and ultimately the largest offshore island to be cleared of rats thus far, sub-Antarctic Campbell Island (11,300ha), in 2001 (Empson & Miskelly 1999; McClelland 2002; Parkes & Murphy 2003; Taylor & Thomas 1989; Taylor & Thomas 1993; Thomas & Taylor 2002; Towns & Broome 2003). A DoC 'Island Eradication Advisory Group' now focuses on eradication research, skills development, review and audit (Cromarty et al. 2002).

DOC 'Mainland Islands'

The management techniques and experiences gained on offshore islands, complemented by a significant experimental multi-pest management programme at Mapara (Innes et al. 1999), have led to the establishment of six DoC 'Mainland Island' projects on the North and South Islands of New Zealand. Of these, three are 'habitat islands', (essentially, forest remnants surrounded by farmland: Trounson Kauri Park, Paengaroa Reserve, and Boundary Stream Reserve). The remaining three sites are 'habitat complexes' (core management areas inside a greater complex of similar habitats: Northern Te Urewera National Park, Rotoiti Nature Recovery Project and Hurunui River). The intention of the Mainland Island programme was to use some of the new multi-pest management practices to intensively manage the selected areas, with a focus on entire ecosystem restoration (Parkes & Murphy 2003; Saunders 2000; Saunders & Norton 2001).

Management of Mainland Islands clearly differs from that of offshore islands in that pest control must be ongoing, because there is no barrier preventing re-colonisation. With the strategic condition of eradication being compromised, complete pest eradication is impossible. Thus, pest control objectives at Mainland

Islands are generally to reduce pest population densities to, and maintain them at, levels low enough to allow ecological recovery (Saunders 2000).

PEST EXCLUSION FENCES

Background

Fences offer the potential to achieve permanent exclusion of pest mammals from areas of high conservation value, providing the fence design takes into account the physical abilities and behaviour of those animals it means to exclude (Clapperton & Day 2001). Exclusion fencing may be a cost-effective form of pest control for areas that are large relative to perimeter length. Additional benefits may include greater conservation outcomes than would be gained by a sustained control strategy (Clapperton & Day 2001).

Internationally, fences have been used for many years to restrict the movements of animals (McKillop & Silby 1988), with mixed results. Until the 1990s, little research had been done on fence design, except for rabbit exclusion fences in the United Kingdom (McKillop et al. 1998; McKillop & Silby 1988; McKillop & Wilson 1987; McKillop & Wilson 1999). Despite a long history of exclusion fencing in Australia targeting species such as rabbits, dingoes (*Canis lupus dingo*), foxes and cats, few designs have been scientifically tested, and guidelines to provide advice to conservation managers are scarce (Long & Robley 2004). Exclusion fences in New Zealand, prior to the 1990s, had also rarely been tested. Many fences were designed to exclude a small selection of pest species, rather than all species present (Aviss & Roberts 1994). Others have failed because of design faults, poor construction, or insufficient maintenance (Day & MacGibbon 2002; Day & MacGibbon 2007; Sanders et al. 2007).

With some overlap, most fence designs tested and constructed around the world fall into one of two categories: electric fences, and physical barrier fences.

Electric Fences

Electric fences aim to induce long-term behaviour modification in target animals by avoidance learning (McKillop & Silby 1988), and are therefore essentially psychological barriers (Day & MacGibbon 2007). Prolonged avoidance behaviour has been demonstrated in some species (e.g. pigs (*Sus scrofa*) (Hone & Atkinson 1983) and foxes (*Vulpes vulpes*) (Poole & McKillop 2002)), and electric fences have been shown to alter ranging behaviour in rabbits within a week of installation (McKillop & Wilson 1999). Mammals such as foxes, possums and rabbits will approach electric fences with caution, and then generally touch the wire with their un-insulated, highly innervated nose (Clapperton & Matthews 1996; McKillop & Wilson 1999; Poole & McKillop 2002). A typically mammalian response usually follows: quick withdrawal, often to a position of shelter. However, some individuals display atypical behaviour when shocked, such as charging or even chewing the fence (McKillop & Silby 1988; McKillop & Wilson 1999; Poole & McKillop 1999; Poole & McKillop 2002).

Avoidance may be learned after a single electric shock. However, when sufficiently motivated, many animals (e.g. mice, ship rats, stoats, cats, possums (Day & MacGibbon 2002; Day & MacGibbon 2007; Moseby & Read 2006), and deer (McKillop & Silby 1988)) have been seen to cross or force their way through electrified fences, some receiving multiple shocks in the process. Multiple electric shocks have also had the effect of inciting more vigorous escape behaviour in cats and possums confined within an experimental fence (Day & MacGibbon 2002; Day & MacGibbon 2007), although these animals were attempting to get out of an enclosure, rather than trying to get into an exclosure; an animal’s motivation to cross a fence may differ in each of these situations. Some animals may avoid shocks altogether if they touch a wire with their neck or back, which are less sensitive (McKillop & Silby 1988), or in the case of stoats, if they pass quickly through an electric fence between pulses (Day & MacGibbon 2002; Day & MacGibbon 2007). This is a major failing of electric fences: although they may partially restrict movement of smaller animals (Clapperton & Matthews 1996; Cowan & Rhodes 1992), they cannot completely exclude them.

Other problems include difficulties in construction. To avoid 'earthing' through immersion in sea water, an anti-fox fence erected across a small spit on the Sands of Forvie Nature Reserve in Aberdeenshire, Scotland, was extended only to high-tide mark at both ends. After initially visiting the fence in the central portion, foxes quickly learned the ends were open at low tide, and regularly entered the protected area (Forster 1975; Patterson 1977). A short-lived electric fence on Arapawa Island, in the Marlborough Sounds, was constantly shorted out by falling vegetation, allowing pigs and goats to walk through at will (Aviss & Roberts 1994). Similarly, possums, even after having learned avoidance behaviour, are capable of quickly detecting when the power supply has been cut, and passing through then (Clapperton & Matthews 1996; Cowan & Rhodes 1992). This has led to the failure of several electrified fences in New Zealand (e.g. the North Cape possum fence (Day & Flight 2002)).

For these reasons, the use of electric wires without an effective physical barrier is not recommended (Day & MacGibbon 2002; Day & MacGibbon 2007; Long & Robley 2004; Moseby & Read 2006). Over the last decade, research has been conducted in New Zealand with a focus on the design of physical barrier fences, capable of permanently excluding multiple pest species.

Physical Barrier Fences

In contrast to electric fences, physical barrier fences aim to exceed both the physical abilities and behavioural characteristics of targeted pest mammals, and are far more likely to achieve permanent pest exclusion (Day & MacGibbon 2007). Almost all barrier fences have targeted exclusion of either a single pest species (e.g. dingoes, pigs, goats, rabbits, or hedgehogs (*Erinaceus europaeus occidentalis*) (Aviss & Roberts 1994; Jackson 2001; McKillop & Wilson 1987; McKnight 1969)) or only a proportion of those present (e.g. feral foxes and cats (Moseby & Read 2006; Robley et al. 2007)), with varying degrees of success. A barrier fence designed to exclude multiple pest species must successfully combat many abilities and behaviours, including attempts to climb over, jump over, push through, chew through, and dig under fences (Day & MacGibbon 2002; Day &

MacGibbon 2007; Long & Robley 2004; Moseby & Read 2006; Robley et al. 2007). Exclusion can be achieved by using a buried 'skirt' (a horizontal extension of the fence mesh from the base of the fence; see Figs. 1 & 2) to prevent digging under a fence, a hood at the top of the fence to prevent climbing and jumping over, and the appropriate choice of mesh size and materials to prevent animals pushing or chewing through the fence. A successful possum barrier fence was designed and used for research purposes in 1979 (R. MacGibbon, pers. comm.), however the first New Zealand fence to be designed with the hope of excluding *all* mammalian pest species was tested and installed in the 1990s, at Karori Wildlife Sanctuary in Wellington (Campbell-Hunt 2002).

Karori Wildlife Sanctuary

The Karori Reservoir valley was the site of two water reservoirs for about 100 years, the last of which was decommissioned in 1998 (Campbell-Hunt 2002). The 225ha valley, now known as the Karori Wildlife Sanctuary, is encircled by an 8.6km pest-proof barrier fence, completed in 1999 (Karori Wildlife Sanctuary Trust 1999). The fence was designed to be capable of excluding all 14 pest mammals present: mice, ship rats, Norway rats, ferrets, stoats, weasels (*Mustela nivalis*), cats, dogs (*Canis familiaris*), hedgehogs, possums, rabbits, hares (*Lepus europaeus occidentalis*), goats and pigs (Karori Wildlife Sanctuary Trust 1997a).

Trials were conducted in 1993/94 to test the physical abilities and behavioural characteristics of pest mammals likely to be encountered (mouse, ship rat, weasel, stoat, ferret, cat and possum) (Aviss and Roberts, 1994). These trials led to the design of a series of fences, the best of which were built, on a small scale, within a purpose-built testing enclosure. Captive possums, feral cats, stoats and rats, previously recommended for further testing, were used to test the efficacy of each design. The design showing greatest effectiveness as a barrier was chosen (Fig.1), and construction of the fence was completed in 1999 (Campbell-Hunt 2002; Karori Reservoir Wildlife Sanctuary Steering Committee 1994; Karori Wildlife Sanctuary Trust 1997a; Karori Wildlife Sanctuary Trust 1997b).

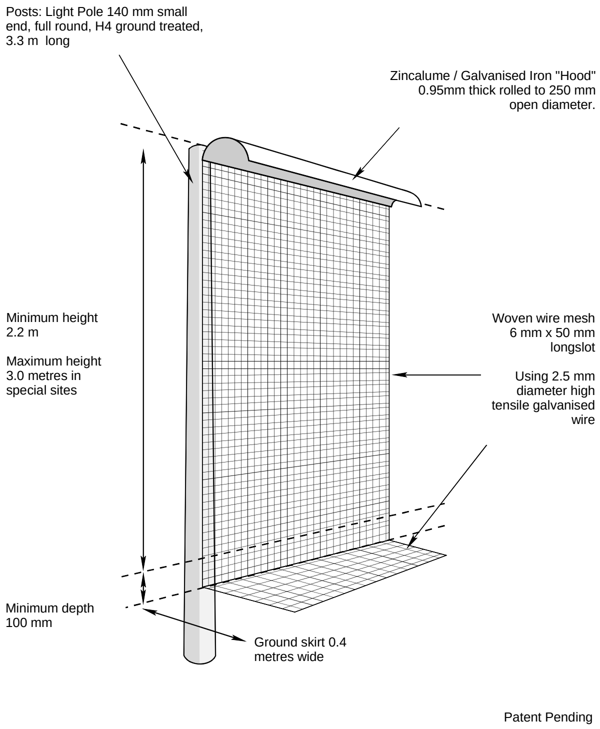

Figure 1. Design of the pest-proof fence at Karori Wildlife Sanctuary (Reproduced from the Karori Wildlife Sanctuary Management Plan (1997), with permission from K. Drayton, Karori Wildlife Sanctuary Trust). The ‘outside’ face of the fence is to the right.

An eradication campaign inside the finished fence, which began with possums in July 1999, expanded to target all pest mammals, and was declared successful in January 2000.

Within weeks, mice were thought to have re-invaded (Empson 2000; Karori Wildlife Sanctuary Trust 2000), although recent analysis of eradication attempts behind fences since 1999 suggests that at least one year with no evidence of mice is required to be confident that eradication has been successful (Speedy et al. 2007). The incursion was eventually attributed to flaws in the fence. Gaps were found between the ‘top hat’ and the wire mesh, which were large enough to allow a mouse to squeeze through. Although these were repaired, mice were able to re-invade through the wire mesh, as the 6mm gaps were not consistent in size (Karori Wildlife Sanctuary Trust 2001). Mice are yet to be re-eradicated from the reserve (Empson 2000). A single weasel was also detected in 2004, soon after a tree-fall crushed a section of the fence. The weasel was soon trapped and destroyed (Empson 2000). A further incursion by a weasel was detected in February 2008; this individual was also trapped and destroyed within a few days (McDonald, 2008).

The pest-proof fence at Karori Wildlife Sanctuary, though the first of its kind to be constructed in New Zealand, is not the only fence with the aim of excluding all mammalian pests present. In the mid-1990s, an independent fencing company was established in the Waikato: Xcluder™ Pest Proof Fence Company Limited.

XCLUDER™ PEST PROOF FENCE COMPANY

Background

The Xcluder™ Pest Proof Fence Company Limited was formed after the successful design, testing and construction of a prototype pest-proof fence, surrounding a privately-owned 16 ha valley (part of a property known as 'Warrenheip', owned by David and Juliette Wallace) at Karapiro, New Zealand. Design and testing began in 1996, with the aim of constructing a fence capable of excluding the entire suite of pest mammals present, including mice (Day & MacGibbon 2007). An experimental facility was constructed that allowed the testing of fence designs against mice, ship rats, Norway rats, ferrets, stoats, hedgehogs, rabbits, possums and cats (Day & MacGibbon 2002; Day & MacGibbon 2007).

Fence Designs

The first fence component to be tested was wire mesh. Minimum wire mesh size to be used on a fence is determined by the smallest targeted pest, and a captive population of wild-caught mice was used to evaluate mesh of different sizes. It was found that the smallest hole through which a juvenile mouse could pass was 7.1mm x 40mm, so a mesh size of 6mm x 25mm was chosen to provide a safety margin (Day & MacGibbon 2007). The mesh used in the fence efficacy trials was marine grade ("316") welded stainless steel mesh, and this is now standard for many Xcluder™ fences (Day & MacGibbon 2007).

Three main fence designs were tested for efficacy (Fig. 2). All incorporated a buried mesh 'skirt' to defeat digging animals. The first was an electric fence similar in design to that described by Clapperton and Matthews (1996), with minor modifications added during experiments (Day & MacGibbon 2002; Day & MacGibbon 2007). Long outriggers, one at 600mm height and one at the top of the fence, supported 5 wires (3 electric, 2 earth), with an output of 58 pulses per minute at 8500 volts (Day & MacGibbon 2002; Day & MacGibbon 2007).

The second design, now known as the Xcluder™ "Tui" fence, was also a wooden post and wire mesh fence. The design also incorporated flexible plastic netting, which extended at an angle above the fence, supported by fibreglass rods. The third design was the Xcluder™ "Kiwi" fence, which is now the mainstay of Xcluder's™ fence designs. This design includes a folded and rolled Colorsteel® hood attached to the top (Day & MacGibbon 2002; Day & MacGibbon 2007). Enclosures were built with the fence design facing inward, and animals were placed inside in a series of trials to see whether they could escape.

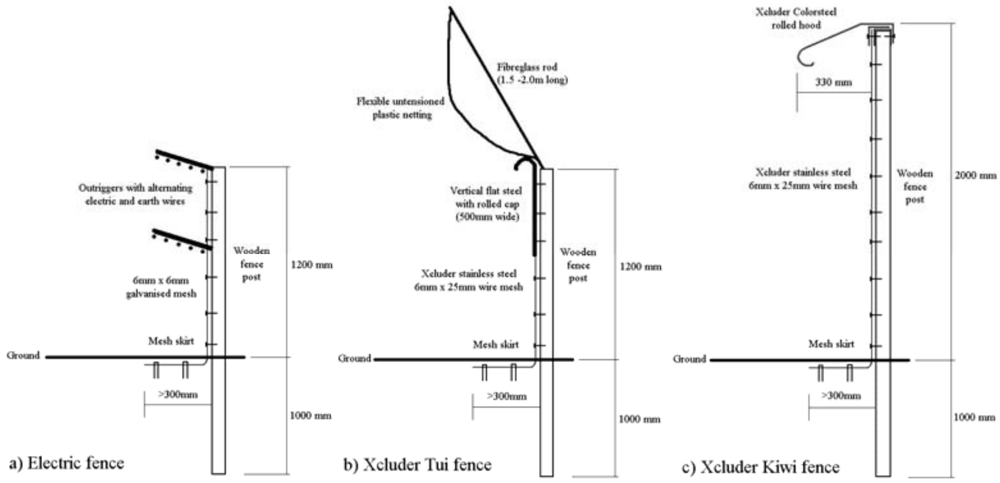

Figure 2. Fence designs built and tested in efficacy trials, by Xcluder Pest Proof Fencing Co. (adapted from Day and MacGibbon, 2007).

Interaction and Behaviour of Pest Mammals

Behaviours commonly seen in the trials included pushing, chewing (all species), digging, climbing and jumping (most species). The electric fence could not completely contain mice, ship rats, stoats, possums or cats. Mice and rats were often able to avoid the electric wires, stoats were quick enough to pass the wires between electric pulses, and possums and cats were able to jump to the top of the outriggers, often crossing even while receiving shocks (Day & MacGibbon 2002; Day & MacGibbon 2007). In contrast, both the “Tui” design and the “Kiwi” design were 100% successful in containing all animals. No pests were able to push through the mesh, dig under the skirt, or scale the flexible plastic netting of the “Tui” fence. Cats could jump to the top of the rolled hood (at the base of the flexible netting), but the unstable nature of the netting deterred them from climbing over, and the weight of larger cats caused the netting to sink towards ground level (Day & MacGibbon 2002; Day & MacGibbon 2007). The mesh and skirt were also successful on the “Kiwi” fence, and although pest animals often climbed to the top of the mesh (directly underneath the hood), none were able to reach around the hood, a reach distance of about 1m, in order to get to the top of the fence (Day & MacGibbon 2002; Day & MacGibbon 2007).

Corners of the fence, particularly inside corners, were subject to greater interest from animals. Most species moved along the fence base until a change in fence direction, at which point they would attempt escape. Often cats, stoats and possums would climb the mesh and try to jump back across tight (<120˚) corners, gaining more height (Day & MacGibbon 2002; Day & MacGibbon 2007). Animal learning by trial and error was evident, with a range of continually modified escape behaviours displayed before animals stopped trying to escape (Day & MacGibbon 2002; Day & MacGibbon 2007).

Fence trials have since taken place in Mauritius and Hawaii. Small modifications to fence design have resulted in 100% success against all pest species tested, including the Javan macaque (*Macaca fascicularis*) and Indian house shrew (*Suncus murinus*) in Mauritius, the Indian mongoose (*Herpestes javanicus*) in both Mauritius and Hawaii, and Mouflon sheep (*Ovis musimon*) in

Hawaii (Burgett et al. 2007; Day & MacGibbon 2002; Day & MacGibbon 2007). These experiments have confirmed that it is possible to completely exclude multiple pest species with barrier fences, as long as fence integrity is not compromised. In the eight years since the first Xcluder™ fence was erected, no pest animal has ever been known to cross an intact fence (Day & MacGibbon 2007).

Breaches and Monitoring

Long-term effectiveness of a fence requires the use of high-quality materials and exacting construction techniques, combined with a comprehensive maintenance and monitoring programme (Day & MacGibbon 2007). However, damage to fence integrity is thought to be inevitable at some stage in the life of a fence, because it is impossible to eliminate all chances of tree-falls or gates being left open. Xcluder™ have developed remote surveillance techniques to minimise the risk of re-invasion (Day & MacGibbon 2007). Fence integrity is monitored by an electrified wire suspended through a series of rings at the top of the fence, which ‘earths out’ when a branch or tree falls over the wire. The resulting voltage drop triggers an alarm signal, which is sent to a designated person by in-situ mobile phone-based devices, connected to the wire (Day 2007). The wire can be divided into sectors to allow a breach to be more easily found. Vehicle, pedestrian and water gates can be monitored in a similar way – where these are left open (or jammed open in the case of water gates), managers will know within seconds, and respond accordingly (Day 2007). In addition to these tools, physical inspection of the fence is recommended at least once a week.

To date, over 20 Xcluder™ fences (totalling over 65km) have been constructed, protecting over 4400ha from a range of pests (Day & MacGibbon 2007; Speedy et al. 2007). Data gathered from 18 of these sites has shown that pests re-invaded 9 sites, but only after fence integrity was compromised, and where response was not immediate (within 3 hours) (Day & MacGibbon 2007). The most comprehensive record of breach events, and responses, has come from the site with the longest fenceline and the largest area: Maungatautari Ecological Island, in the Waikato.

MAUNGATAUTARI ECOLOGICAL ISLAND

Background

Mt Maungatautari, an eroded andesitic volcanic cone, lies in the central Waikato, in the North Island of New Zealand (Clarkson 2002; Speedy et al. 2007). The mountain supports a dense mixed podocarp-broadleaf forest, covering approximately 3400ha, and is completely surrounded by farmland (MacGibbon 2001). The majority of the original native fauna present on the mountain is now absent, and the remaining flora has been intensely browsed for many years (McQueen 2004). The Maungatautari Ecological Island Trust (MEIT) was formed in the late 1990s, with the primary goal being to "restore the diversity, vitality and resilience of the ecosystems of Maungatautari, as close as possible to the original condition, to re-create self-sustaining communities of indigenous plants and animals" (McQueen 2004). The restoration project is entirely community-driven, and was initiated by Trust Chairman David Wallace, following on from the successful 'Warrenheip' experience (T. Day, P. de Monchy pers. comm.).

Pest Species Present at Maungatautari

A vital pre-requisite to achieving the primary goal of the MEIT is the permanent removal of all mammalian pests. Until the start of restoration, Maungatautari was home to mammalian pest species commonly seen elsewhere, including fallow deer (*Dama dama*), red deer, feral pigs, feral goats, feral cats, possums, feral ferrets, stoats, weasels, ship rats, mice, rabbits, hares and hedgehogs (McQueen 2004). The MEIT undertook to permanently exclude mammalian pests by encircling the entire mountain with an Xcluder™ 'Kiwi' fence, and then eradicating all 15 pest species within.

Two smaller enclosures were first constructed, as pilots for the main mountain area. The fences surrounding the 35ha northern enclosure (a 2.8km fence, at the end of Hicks Road, Maungatautari) and the 65ha southern enclosure (a 3.5km fence at Tari Road, Pukeatua) were completed early in 2004, and pest eradication campaigns in both took place in September/October the same year. Aerial spreading of 'Pestoff 20R' cereal pellets (containing 20ppm brodifacoum) was used as the main eradication tool for small mammals (Speedy et al. 2007). The methods used were similar to those developed on offshore islands: two bait applications, timed for late winter/early spring, when rodent populations are at their lowest and bait acceptance is highest (Gillies et al. 2003; Speedy et al. 2007). Small numbers of surviving pests (mice, ship rats and 1 hedgehog) were subsequently detected and removed using a network of tracking tunnels and cereal baits, but none have been detected in the northern enclosure since April 2005, and none in the southern enclosure since July 2006. Both enclosures are now considered to be completely free of pest mammals (Speedy et al. 2007).

The fence surrounding the main mountain was completed in August 2006, and again, pest eradication soon followed. Two aerial bait applications in late 2006 were followed by a third in November 2007, targeting residual mouse populations (Speedy et al. 2007). Localised baiting in tracking tunnels is ongoing, as mice are persistent in small pockets (P. de Monchy, pers. comm.). Intensive monitoring using tracking tunnels has failed to detect any other rodents, although as at December 2007, goats (<10) were thought to still be present, along with small numbers of rabbits and hares. These are all gradually being removed by ground hunters.

Fence Monitoring, Breaches and Responses

The MEIT has long recognised the need for regular inspection to ensure fence integrity. Daily physical inspections of the fenceline at the northern enclosure were carried out by volunteers using ATVs for many months, up until the fence surrounding the main mountain was finished and pest eradication efforts were undertaken in late 2006. From that point, volunteers carried out daily inspection of the entire 47km fenceline in a small 4WD vehicle. The first four sectors of the new electronic surveillance wire system were also installed in late 2006, covering the eastern side of the mountain, and by May 2007 this system was completed around the whole fenceline. By this time track conditions prevented even 4WD vehicles from circumnavigating the reserve, and with the new surveillance system complete, daily inspections were discontinued. At present, the remote surveillance system (comprised of the surveillance wire and vehicle, pedestrian and water gate alarms) is supplemented by physical inspection by staff twice per week in the winter, and once per week in the summer. Recently this has been augmented by volunteers who have each 'claimed' one fence sector, which they carefully inspect by walking, once per month. 17 out of 20 fence sectors are inspected in this way and it is anticipated that all 20 will be 'claimed' in time (P. de Monchy pers. comm.).

Currently, the Trust aims to get to the physical location of any breach within 90 minutes. Response to a breach begins with notification from the remote surveillance system (or a telephone call from a landowner) being received by a manager, by cellular telephone. The manager will then contact the appropriate person to inspect the breach, usually a Trust employee. Often, the problem turns out to be no more serious than a tree-fern frond leaning on the inside of the alarm wire after a period of high winds, which is easily removed. If extensive repairs are necessary (e.g. after a large tree-fall) the employee will call for assistance and return with appropriate equipment. If the breach occurs during daylight hours, Xcluder™ Pest Proof Fence Company can dispatch a repair crew within minutes to effect repairs. However, should a breach occur late at night, it may be necessary to erect a temporary fence until the morning. This consists of a length of vertically-mounted plastic netting that is erected across the breach (once any obstructions are cleared), and is attached to the intact fence ends. It is hoped that filling the gap created by a treefall will prevent animals exploiting a hole before more permanent repairs are completed the following day (T. Day, P. de Monchy pers. comm.). This system has so far worked very well, and no invasion has been detected provided the team responded within 3 hours.

In the 16 months to date of writing since completion of the main fence, there have been at least 12 significant breach events (Day & MacGibbon 2007, P. de Monchy pers. comm.). Of these, only three are known to have resulted in re-invasion by pest mammals, all by rodents and only where response time was greater than 3 hours (Speedy et al, 2007). At all sites, once the fence damage was repaired, a concentrated grid of tracking tunnels (including ink-cards and cereal-based brodifacoum pellets) was installed around the inside of the breach area to detect and destroy any potential invaders. Tunnels were checked regularly and in all cases, tracking ceased after a short period of time, indicating that eradication of the invader(s) had been successful (Speedy et al, 2007; P. de Monchy pers. comm.).

MAMMALIAN PEST BEHAVIOUR IN RELATION TO FENCED RESERVES

Linear Habitat Features

The effects of linear obstacles, particularly roads, on the ecology of nearby animals have been extensively studied (Spellerberg 1998). Roads have been found to inhibit movements of some forest mammals, regardless of traffic flow or road surface type (Burnett 1992; Oxley et al. 1974). However, road-edge habitat may also attract some animals. Mouse density in Pureora forest (North Island, New Zealand) was found to be greater at the road edge than the forest interior (King et al. 1996), and other rodent species (including ship rats) have also been found to occupy road edges in greater density than in the surrounding habitat (Adams & Geis 1983; Delgado et al. 2001; Garland & Bradley 1984; Meunier et al. 1999). Cane toads (*Bufo marinus*) and microtine rodents have used roads and grassy road-edges respectively as routes for dispersal into areas where they were previously unknown (Getz et al. 1978; Seabrook & Dettmann 1996). Both domestic and feral cats are known to spend a high proportion of time along linear habitat features such as roads, waterways and field edges (Fitzgerald & Karl 1986; Warner 1985), as are other predators such as ferrets, stoats (Alterio et al. 1998; Dilks et al. 1996; Murphy & Dowding 1994; Ragg & Clapperton 2004; Ragg & Moller 2000) and weasels (King et al. 1996a; King et al. 1996b).

A typical mammalian response to the discovery of an impermeable barrier is to continue moving alongside the barrier. Animals such as rats, mice, stoats, ferrets, foxes, cats and possums have all been observed responding in this way (Day & MacGibbon 2002; Moseby & Read 2006; Patterson 1977). At Maungatautari, animals encountered near the fence during the daytime have been observed to continue travelling along the fence base over distances of at least 1km (T. Day pers. comm.). In the case of roads and highways, this behaviour leads to the discovery and use of culverts and purpose-built underpasses, allowing animals such as rats, weasels, and cats to move across an otherwise dangerous barrier (Clevenger et al. 2001; Dodd et al. 2004; McDonald & St. Clair 2004a; McDonald & St. Clair 2004b; Ng et al. 2004; Yanes et al. 1995). A breach in a fence presents an opportunity comparable to a culvert under a road, and animal behaviour at these features may be similar. Detailed information about animal movements alongside a pest-proof fence, and their ability to locate and use holes in that fence, is important to managers of reserves such as at Maungatautari.

Activity Periods

Knowledge of animal activity periods is also important to reserve managers to help understand invasion risk. Pest mammals may be mostly nocturnal, e.g. mice, ship rats, hedgehogs, possums and ferrets (Alterio & Moller 1997; Cowan 2005; Hooker & Innes 1995; Innes 2005; Ruscoe & Murphy 2005; Tempero et al. 2007), mostly diurnal, e.g. stoats (Alterio & Moller 1997; Tempero et al. 2007), or indifferent, e.g. cats, rabbits and hares (Alterio & Moller 1997; Konecny 1987; Norbury & Flux 2005; Norbury & Reddiex 2005; Tempero et al. 2007). Other environmental factors such as rainfall are known to influence the activity levels of some animals, e.g. cats (Harper 2007).

Previous Studies at NZ Pest-Proof Fences

The potential for re-invasion through a pest-proof fence by mammalian pests has been tested during preliminary studies at Maungatautari (Day 2006; Speedy et al. 2007). In order to quantify detection and use of breaches by pest mammals, 50 experimental breaches (holes and ramps) were created along a 10km section of the fence. Ink tracking-cards were placed at each breach, and remained over a period of four weeks. Within the first 24 hours, 8% of breaches had been used, and after three days, this had risen to 22%. A total of 71% of breaches were used by the end of the four week period. Mice and rats used the mesh holes, and possums, cats and rats used the ramps. Mustelids were observed and trapped along the fenceline during the experiment, but none were detected at the simulated breaches (Day 2006; Speedy et al. 2007).

A related experiment investigated the behaviour of an invading ship rat in a simulated invasion event at a fenced reserve. Six individual male rats were sequentially live-trapped alongside the pest-proof fence, fitted with radio-collars, and then released at point of capture into the southern exclosure at Maungatautari. Only one rat was present at any time within the exclosure. Two of the six died after eating brodifacoum bait laid for mice, one after 31 days inside the exclosure. The remaining four climbed out of the exclosure within 7 days of release. The rats travelled up to 1km from the point of release, but usually stayed within 100m of their release point for the first three days. This suggests that a quick breach response and intensive targeting of rodents close to the point of entry is desirable (Speedy et al. 2007). The experiment was intended to be the first of a series that will further investigate the behaviour of invading ship rats, with other possible scenarios including female invaders, multiple invaders and alternative species (J. Innes pers. comm.).

Importance of Increasing Knowledge of Pest Activity and Behaviour

The MEIT currently attempts to physically respond to a breach within 90 minutes of the breach happening. However, there may be times when this is not possible, e.g. where weather and track conditions make a night response dangerous. Knowledge of pest activity and behaviour at the fence may allow fence managers to answer the question "Can we reliably find and fix a potential breach before a pest finds and uses it?" Understanding which mammalian pest species are most likely to locate and enter a breach, and how quickly they may do so, will assist in the development of optimal breach response procedures, and minimise invasion risk. For the purposes of this thesis, the term “risk” refers to the potential for a pest mammal to encounter and exploit a fence breach. In order to quantify the risks posed by potential invaders, it is necessary to gather data through research.

AIMS AND STRUCTURE

The purpose of this thesis is to provide baseline data for future studies by assessing the potential for reinvasion by pest mammals through the pest-proof fence at Maungatautari Ecological Island. My main aims were to:

1. Describe baseline data on activity levels and behaviour of mammalian pests directly adjacent to the pest-proof fence;
2. Test for the effects of exterior habitat type, breach type and season on mammalian pest activity levels directly at the fence;
3. Determine how quickly pest mammals may locate a fence breach, and how likely they are to exploit it; and
4. Develop a predictive model that may be used to help assess the risk of re-invasion if response to a fence breach is delayed.

The thesis is structured as follows:

Chapter 1 reviews and describes literature on the progress made in recent decades in methods of eradicating mammalian pests from New Zealand’s offshore islands, the limited application of these methods on the mainland, and the design and testing of fences (both electric and physical barrier fences) as tools to exclude mammals from mainland sites. Relevant background information is provided for Maungatautari Ecological Island, and Xcluder™ Pest Proof Fencing Ltd.

Chapter 2 describes data gathered at Maungatautari with respect to pest mammal presence, number of sightings for each species, and the effects of 3 factors (season, habitat type and breach type) on numbers of sightings. Timing of pest sightings is also described, as are sightings of mammals within the fence hood. A descriptive probability model is presented that calculates the cumulative probability of at least 1 pest mammal encountering a simulated breach within 24 hours.

Chapter 3 examines the behaviour of mammalian pests that were sighted during the study described in Chapter 2. Particular attention is paid to pest behaviour in relation to the simulated breaches: whether they appear to show interest in and/or enter the breach, or show no interest at all. The rate at which simulated breaches are encountered by at least one pest mammal (and whether interest is shown) is described, and general observations are made on the behavioural traits each species commonly exhibited.

Chapter 4, the final chapter, discusses the conclusions on the number and timing of pest sightings, probability of encounter and behaviour of mammalian pests at simulated breaches. The significance of these results and the implications for management of the reserve are discussed, and recommendations are made for response to fence breaches, and directions of future research.

Chapters 2 and 3 in this thesis have been written as stand-alone manuscripts, each including an abstract, full introduction, methods, results, discussion and references relevant to that chapter. While this means that some content (particularly introductory and methodology material) is repeated in each of those chapters, it will significantly aid the future publication of this research in peer-reviewed journals.

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CHAPTER 2

Activity of Mammalian Pests Outside a Pest-Proof Fence at Maungatautari Ecological Island

ABSTRACT

Mammalian pests are excluded from Maungatautari Ecological Island by a pest-proof fence. Inevitably, the fence integrity will be compromised at some point by such mechanisms as treefall and flood-scour: such events could lead to pest re-invasion. Knowledge of pest activity directly outside the reserve would therefore assist reserve managers in developing optimal breach-response procedures. A video study was conducted at 20 simulated fence breaches over summer 2006/07 and winter 2007, to gather data on pest activity periods, and to determine the significance of season (summer and winter), exterior habitat (forest and pasture) and breach type ('tree-fall' and 'flood scour') on number of sightings. In the summer, 788 sightings were recorded in 157 days (95.4% nocturnal); in winter, sightings totalled 428 in 160 days (86.2% nocturnal). Sightings of possums, hedgehogs and cats were high in both seasons, for mice and rats high in summer, and for hares, high in winter. The effect of season on overall sightings of each species was significant, particularly for mice. Habitat type was significant only for rabbit sightings (mostly seen at pasture sites), and breach type was not significant at all. Only 7 mustelid sightings were recorded over both seasons. The fence faces greatest pressure from pests during the hours of darkness, especially in summer: mean encounters (± SEM) per 100 hole-nights (HN) were 493 ± 65.1 in the summer, and 267 ± 48.9 in the winter. Video footage (recorded in December 2007/January 2008) found ship rat activity to be much higher inside the fence

hood than on the ground. A probability model suggested that the probability of at least one pest mammal encountering a breach within 24 hours was 99% in summer, and 85% in winter; cumulative probability increases greatly after dusk. Further research on the abundance, movements, home range and invasion behaviour of mammalian pests is recommended, particularly for mustelids, cats and ship rats.

INTRODUCTION

Mt Maungatautari, an eroded andesitic volcanic cone, lies in the central Waikato, in the North Island of New Zealand (Clarkson 2002; Speedy et al. 2007). The mountain supports a dense mixed podocarp-broadleaf forest, covering approximately 3400ha, and is completely surrounded by farmland (MacGibbon 2001). The majority of the original native fauna present on the mountain is now absent, and the remaining flora has been intensely browsed for many years (McQueen 2004). The Maungatautari Ecological Island Trust (MEIT) was formed in the late 1990s, with the primary goal being to "restore the diversity, vitality and resilience of the ecosystems of Maungatautari, as close as possible to the original condition, to re-create self-sustaining communities of indigenous plants and animals" (McQueen, 2004).

A vital pre-requisite to achieving the primary goal of the MEIT is the permanent removal of all mammalian pests. To this end, a 47km Xcluder™ pest-proof fence was completed in 2006, which completely encircles the mountain. An eradication campaign then began, to remove mammalian pest species from within the exclosure (including fallow deer (*Dama dama*), red deer (*Cervus elaphus scoticus*), feral pigs (*Sus scrofa*), feral goats (*Capra hircus*), feral cats (*Felis catus*), possums (*Trichosurus vulpecula*), feral ferrets (*Mustela furo*), stoats (*Mustela erminea*), weasels (*Mustela nivalis*), ship rats (*Rattus rattus*), mice (*Mus musculus*), rabbits (*Oryctolagus cuniculus*), hares (*Lepus europaeus occidentalis*) and hedgehogs (*Erinaceus europaeus occidentalis*)). By January 2008, the only pest mammals known to be present within the reserve were isolated pockets of mice, up to 10 goats, and a small number of lagomorphs (P. de Monchy pers. comm.). These are being targeted in ongoing operations.

Long-term effectiveness of a pest-proof fence requires the use of high-quality materials and exacting construction techniques, combined with a comprehensive maintenance and monitoring programme (Day & MacGibbon 2007). Damage to fence integrity is accepted as inevitable at some stage in the life of a fence, because it is impossible to eliminate all chance of tree-falls or gates being left open. Xcluder™ Pest Proof Fencing Company have developed remote surveillance techniques to minimise the risk of pest re-invasion (Day & MacGibbon 2007). An alarm system monitors the integrity of the fence, including vehicle, pedestrian and water gates. Managers are notified by mobile phone immediately an alarm is triggered, and respond accordingly (Day 2007).

The MEIT currently attempts to physically respond to notification of a breach within 90 minutes. However, there may be times when this is not possible, e.g. when weather and track conditions make a night response dangerous. Knowledge of pest activity outside the fence may assist fence managers to answer the question "Can we reliably find and fix a potential breach before a pest finds and uses it?" Knowing which mammalian pest species are present directly outside the fence at Maungatautari, and their periods of activity, will assist in the development of optimal breach response procedures, and minimise invasion risk. Pest mammals may be mostly nocturnal, e.g. mice, ship rats, hedgehogs, possums and ferrets (Alterio & Moller 1997; Cowan 2005; Hooker & Innes 1995; Innes 2005; Ruscoe & Murphy 2005; Tempero et al. 2007), mostly diurnal, e.g. stoats (Alterio & Moller 1997), or indifferent, e.g. cats, rabbits and hares (Alterio & Moller 1997; Konecny 1987; Norbury & Flux 2005; Norbury & Reddiex 2005; Tempero et al. 2007). Other environmental factors such as rainfall are known to influence the activity levels of some animals, e.g. cats (Harper 2007). A high level of invertebrate activity has been observed directly at the fence (pers. obs.). Invertebrates are commonly eaten by ship rats and mice (Innes 1979; Miller & Miller 1995; Ruscoe & Murphy 2005), and high invertebrate activity levels may attract rodents to the fenceline.

The potential for re-invasion through a pest-proof fence by mammalian pests has been tested during a preliminary study at Maungatautari (Day 2006; Speedy et al. 2007). Prior to the completion of the fence, two breach types were simulated by cutting a series of holes in the fence mesh, and installing ramps at some sites to simulate branch falls. Ink tracking-cards were placed at each breach, and remained over a period of four weeks. Within the first 24 hours, 8% of breaches had been used, and after three days, this had risen to 22%. A total of 71% of breaches had been used by the end of the four week period. Mice and rats used the mesh holes, and possums, cats and rats used the ramps. Mustelids were observed and trapped along the fenceline during the experiment, but none were detected at the simulated breaches (Day 2006; Speedy et al. 2007). Detailed temporal data could not be gathered as part of this study.

The use of video recording allows recording of temporal data as well as images, and also allows conclusive identification of species. Time-lapse video recording systems have been used to study predation at nests (Brown et al. 1998; Innes et al. 1994; Morgan et al. 2006), and these studies have shown that continuous monitoring of the activity and behaviour of cryptic nocturnal animals is possible. Although expensive and labour-intensive, video footage was chosen as the method that would provide the required data on pest presence at a simulated fence breach.

This study was conducted with the following aims:

1. To describe baseline data on levels of presence, number of sightings and activity periods of mammalian pests directly outside the Maungatautari pest-proof fence.
2. To test for the effects of exterior habitat type, breach type, and season on number of mammalian pest sightings.
3. To create a probability model, that might indicate cumulative probability of at least one mammalian pest encountering a breach, according to time of day and season the breach happens, and speed of response.

METHODS

Study Site

Maungatautari Ecological Island (38°03’26”S, 175°33’40”W) is 16km south-east of Cambridge, New Zealand (Figs. 1 & 2). A 4m-wide compacted metal service road runs along the outside of the 47km pest-proof exclusion fence. The habitat on the opposite side of the road is mostly grazed pasture, interspersed with small (≤0.25ha) pockets of indigenous mixed podocarp-broadleaf forest, dominated by rimu (*Dacrydium cupressinum*) and tawa (*Beilschmiedia tawa*). The section of fenceline chosen for the study was on the southern (Pukeatua) side of the reserve, beginning at the end of Tari Road and stretching approximately 7km towards the east (Fig. 3). The study site was chosen because the adjacent habitat offered a good representation of habitat found elsewhere on the reserve’s perimeter, and access by 4WD vehicle was relatively easy.

Figure 1. Location of Maungatuatari Ecological Island (indicated by the arrow).

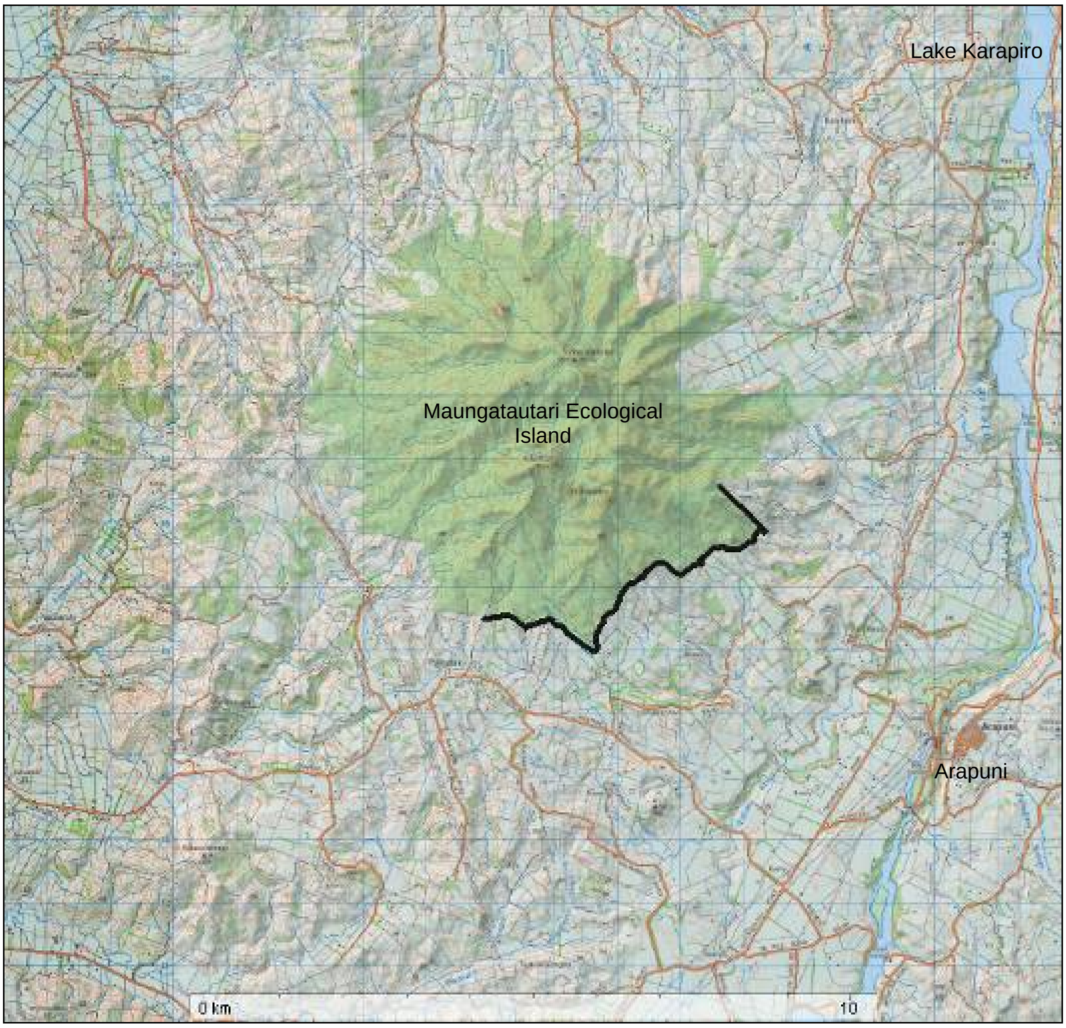


Figure 2. Location of Maungatautari Ecological Island, in relation to Arapuni and Lake Karapiro. The section of fenceline used in the study is highlighted black.

Fence Breaches

Twenty sites along the 7km stretch of fenceline were chosen at which to simulate fence breaches. The habitat next to the service road was determined to be either 'Pasture' (no trees present) or 'Forest' (at least 20 trees present, >5m in height). Along sections of the fence opposite blocks of each of these habitats, 10 sites were selected, to test for the effects of adjacent habitat on pest sightings. Sites were separated by a minimum of 150m, with most separated by 200m or more.

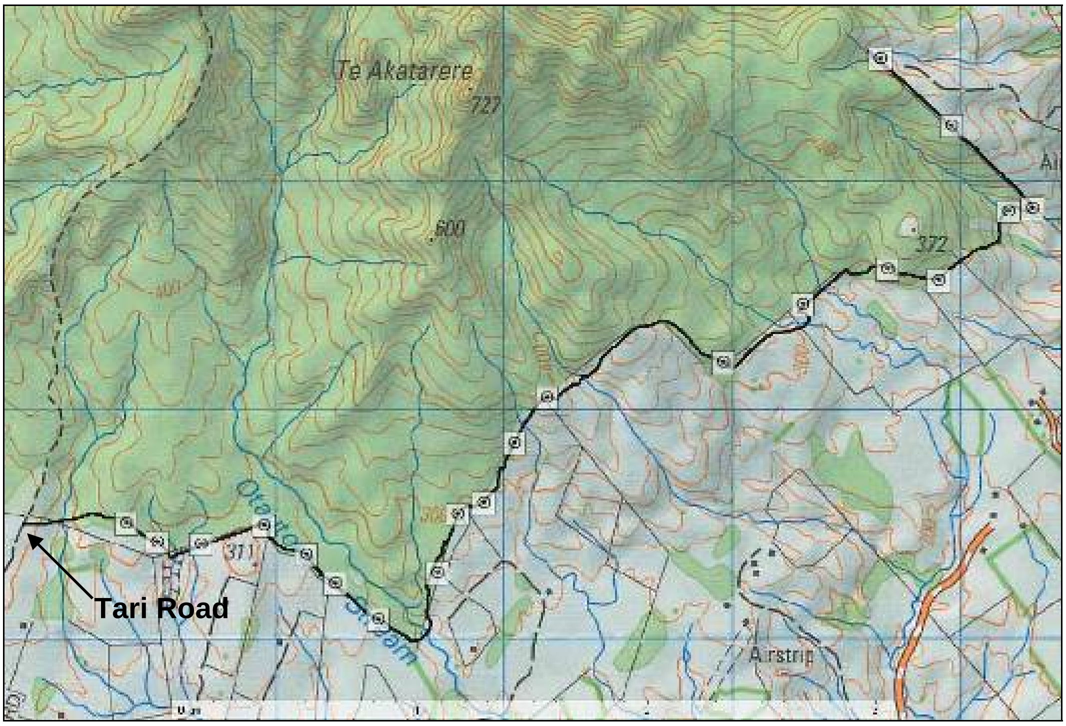


Figure 3. Sites of the 20 simulated breaches.

The 150m spacing between observation sites was chosen as a compromise between ensuring independence among sites for some pests (rodents, rabbits), and minimising travel distance and time spent along the steep, fragile service road (see 'data analysis' section for further comment). At each site, a 750mm long x 600mm wide x 600mm high wire mesh cage was installed on the inside of the exclusion fence at ground level. Each cage was covered on five sides with Xcluder's™ 6mm x 25mm stainless steel mesh (all cage materials are standard on Xcluder™ Pest Proof Fence Company's 'Kiwi' fence design (Fig. 4)). The open 600mm x 600mm face was butted hard against the inside of the fence mesh, and galvanised steel battens were screwed into the wooden cage frames from the outside of the mesh, effectively sealing the sixth side of the cage. A hole measuring 250mm x 250mm was then cut in the fence mesh within the cage frame at ground level (Fig. 4). This was deemed a large enough hole to allow any likely mammalian pest animal to enter. A temporary 600mm x 600mm mesh cover was attached to the face of the cage to prevent entry until each hole was filmed.

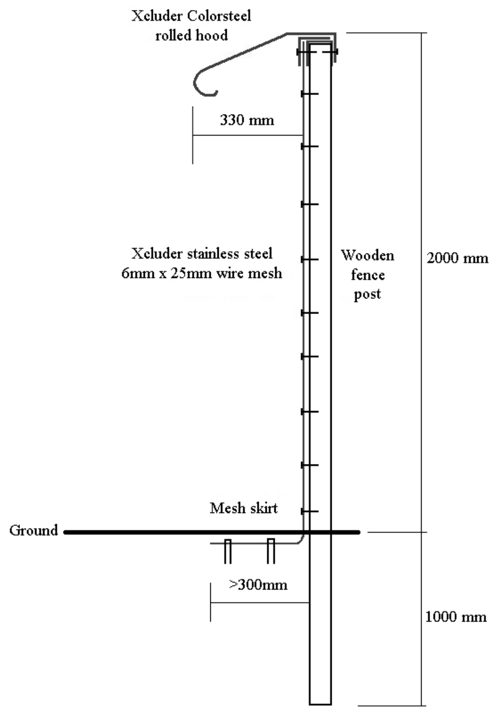


Figure 4. Schematic diagram of the Xcluder^{TM} 'Kiwi' fence design, as erected at Maungatautari. The rolled Colorsteel® hood is at top (adapted from Day & MacGibbon, 2007).

The cages in effect formed a ballooning of the fence, and while animals could exploit the hole, they were unable to go any further than the cage allowed, and fence integrity was maintained. During each trial, two breach types were simulated. The 'flood-scour' type was intended to simulate a breach that would not trigger the monitored alarm, and which might remain undiscovered for up to a week (Fig. 5), so was installed for a 7-day period. On day 1, the temporary mesh face was removed and the ground surface at the hole disturbed. The hole was filmed 24 hours a day for 7 days, to gather data on mammalian pest species present, number of sightings, and time periods most active. On day 7 the hole was re-sealed.

Figure 5. A cage as installed at the fence. The temporary mesh cover has been removed and the simulated 'flood-scour' breach is open.

The 'tree-fall' breach type was filmed for 24 hours (Fig. 6). This was meant to simulate an event that would trigger the alarm and be discovered within 24 hours. A three-metre long branch (no more than 75mm diameter) was laid across the road, with the end inside the opened hole. In addition, to simulate a 'break' in the mesh (to block animals that might move *along* the mesh itself) a length of Colorsteel® (500mm wide) was attached to the fence above the hole, up to the top of the fence. An object was also placed inside the rolled fence hood gutter, to block animals (particularly ship rats) which have been seen moving along inside. This arrangement was as close an imitation of a tree-fall event as it was possible to simulate while maintaining fence integrity.

Each breach type was filmed at each site, with an interval of at least 2 weeks between. To survey differences in pest sightings between seasons, two video trials of equal length were recorded to represent both summer and winter.

The hood gutter potentially provides an extensive, easily-travelled habitat for ship rats. Invertebrate activity inside the hood has been seen to be high (T. Day pers. comm.). Stoats have been sighted inside the hood on occasion (T. Day pers. comm.), but only during daylight. Ferrets are poor climbers (Clapperton & Byrom 2005), and are unlikely to be seen inside the hood. Nocturnally, the fence hood is likely to be an attractive, and potentially predator-free above-ground habitat for ship rats. A third set of observations was therefore designed to test the possibility that ship rats may be more active inside the hood than at the fence base.

Figure 6. A 'tree-fall' hole, with cover removed. This breach type was open for 24 hours at a time.

Recording Equipment

Initially, a single black and white CCD video camera (Jaycar model QC3310) with zoom lens (Jaycar QC3394) was used at each site. The cameras were mounted in weatherproof housings, and fitted to a tripod. Infra-red spotlights (Jaycar QC3650, wavelength 850NM) were attached to the housings for illumination during the hours of darkness. The cameras were set up on the far side of the service road, facing the holes (Figs. 7 & 8).

The video cameras were connected to 12V time-lapse VCRs (Panasonic AG-1070DC, AG-6730, AG-TL550; Sanyo TLS-1600P) via a waterproof 'pelican' case. The VCRs were set to record in 24hr time-lapse mode, recording approximately 3 frames per second, sufficient to capture clear images of animals as small as mice moving across the field of view. All equipment was powered by 12V 40Ah sealed lead acid batteries which, along with the video tapes, required daily changes. The summer filming required 31 visits over 31 consecutive days.

Winter filming required changes due to site access issues during inclement weather. Over the course of the summer study, it became obvious that after even brief rain, the service road was impassable at some points. Daily battery and video tape changes often required access through neighbouring farms, and constant 4WD vehicle traffic damaged the service road at some sites. Winter rainfall is relatively high on the mountain (T. Day pers. comm.), and this meant that daily 4WD vehicle access was not going to be possible for the winter study. Even an all-terrain vehicle (ATV), if used daily, would still cause too much track damage. It was decided that if a winter study were to take place, it could be done only by using video equipment that didn't require daily visits.

Therefore, for the winter study I used six Archos 504 personal media players (high storage capacity digital video recorders (DVRs) with low power consumption) in place of the VCRs. These devices (the size of a pocket calculator) have an internal 160GB hard-drive, and record video at 25 frames per second. If set at medium video resolution (similar in quality to the VCR recording used in summer), more than 8 days of continuous video footage can be recorded and stored. Power consumption (~35mA) is minimal compared to a 12V VCR (~800mA). I built weatherproof pelican cases to the same specifications as those used for the VCRs, and used one 12V 65Ah battery connected in parallel to four 12V 12Ah batteries to power each system. Testing confirmed that this setup would be sufficient to power a DVR, video camera and infra-red spotlight for more than a week.

During the fence hood observations, two camera units were set up at each site. The first used the same cameras as before, arranged in the same way as previously, on the opposite side of the road, facing the fence breach. The second camera was a weatherproof, miniature video camera with in-built infra-red LEDs (Jaycar AVC307R). This was fitted to the underside of the Colorsteel® fence hood, facing towards the rolled gutter, and connected to a second DVR placed at the base of the fence, but 20m along the fenceline. In this way, simultaneous recording of both the fence base and the hood gutter at each site was completed.

Filming Schedule: Summer

For the summer study, between February 24th and March 26th, 2007, up to six sites were filmed at any one time. Of these, up to five sites were ‘flood-scour’ sites (7 days duration), and one a ‘tree-fall’ site (24 hours duration). At all times, both ‘forest’ and ‘pasture’ sites were filmed simultaneously. Sites were scheduled for filming in rotation, and no more than every second cage along the fenceline was used at any one time, meaning that cameras were separated by at least 300m.

Figure 7. A video camera, infra-red light and video recorder (in black case), set up opposite a simulated breach.

Figure 8. An illustration of camera position in relation to a simulated breach, summer study.

Filming Schedule: Winter

Winter filming was completed between between August 3rd and September 21st, 2007. It was no longer possible to carry out daily visits over a long period; this practical consideration dictated the nature and frequency of recording during the winter study. All the 'tree-fall' holes in a block were filmed together at the start of the winter session, by allocating five cameras to them over four nights, to complete the 20 breach simulations. Then, filming of the 'flood-scour' holes started. Camera and DVR units were shifted around the hole sites as for the summer study, and again, both 'forest' and 'pasture' sites were filmed simultaneously at all times. After filming of the first block of 'flood-scour' holes was completed, only one to two visits per week were required over the winter study, which reduced track damage considerably.

Filming Schedule: Inside the Fence Hood

The third block of filming, with cameras focussed inside the fence hood gutter, was achieved with DVRs between December 2007 and January 2008. It was hypothesised, based on anecdotal evidence, that ship rats may be more active inside the hood than at the fence base. The aim was to make initial observations of ship rats inside the hood, and compare the results with ship rat sightings recorded simultaneously at the same sites but along the fence base. Four breach sites were filmed for a week each, two at a time.

Data Analysis

The video recordings were watched and each sighting of a mammalian pest was recorded by species, along with time of encounter. The intention was to analyse and describe the overall number of sightings for each pest species at each site, and no attempt was made to identify or count the number of individual animals recorded (except for ship rats in the hood study). A generalised linear mixed model (GLMM) was used to test for significance of season, habitat type and breach type on number of sightings per hole/night. GLMM was used rather than ANOVA because of the non-normality of the count data. This analysis was completed assuming Poisson distribution, with a blocking structure that recognised ‘season’, ‘habitat’ and ‘breach type’ as random factors. The 150 m minimum distance between sites (and 300m between any two sites filmed simultaneously) was considered enough to allow independence to be assumed for mice, ship rats and rabbits, as home range lengths for these species have been found to be smaller than this distance (Fitzgerald et al. 1981; Gibb et al. 1978; Hooker & Innes 1995). For all other species, the assumption of independence between sites may have been violated; GLMM analyses were still completed for these data, however results should be treated with caution. Non-independence in the data could have had the effect of overestimating the number of degrees of freedom in the analyses for those species, which may mean a result is viewed as being significant, when in fact it is not.

For analysis of 'breach type', data from the first 24 hours of the 'flood-scour' holes were compared with data from the 'tree-fall' holes (for which only 24 hours of data were recorded). Linear regression and ANOVA were used to test for trends of increasing or decreasing visits per day, per species at the 7-day 'tree-fall' holes. Spearman's rank correlation coefficient was used to test for association of species counts with rainfall and mean and minimum nightly temperature. Rainfall and temperature data were retrieved from the NIWA National Climate Database (http://cliflo.niwa.co.nz/, 15/12/2007).

Probability of Pest Encounter

A simple probability model was constructed to illustrate the cumulative probability of at least one mammalian pest encountering a fence breach within 24 hours, according to the time of day and season the breach happens. The results of the model are intended to be viewed as probability estimates only, and may provide a useful (though non-statistical) illustration of what the data suggests.

As the model was intended to illustrate probability of encounter within 24 hours according to *time of day*, all data were used, despite the majority (140 of 160 days total) being recorded between 25 hours and 168 hours post-breach. The data were divided into 24 hourly periods of the day for each season. Each hour was deemed to consist of 60 1-minute "trials", in each of which could be observed either "encounter" (success) or "no encounter" (failure). For each season, the mean number of encounters per hour of the day across all sites was calculated (e.g. mean number of encounters between 21:00 – 21:59). The probability of pest encounter, p, per minute of that hour equals –

$$p = \frac{\text{Mean Number of Sightings}}{60}$$

The probability of no pest encounter (p_n) over a period of N minutes then equals –

$$p_n = (1 - p)^N$$

Therefore, probability of pest encounter (p_e) for a period of N minutes equals –

$$p_e = 1 - (1 - p)^N$$

These formula were used to calculate the probability of pest encounter for each hour of the day, in each season. For example, if the mean number of summer pest encounters between 21:00 – 21:59 (across 157 days) was found to be 0.637, then $p = \frac{0.637}{60} = 0.0106$; p_n over one hour = $(1 - 0.0106)^{60} = 0.5271$; and p_e over one hour = $1 - (1 - 0.0106)^{60} = 0.4729$. Therefore on average, if a breach happens at 21:00 in the summer, the probability of at least one pest encountering that breach between 21:00 – 21:59 is 0.4729, or 47.29%.

The cumulative probability of pest encounter for the following 24 hour period was then calculated by multiplying this initial probability with the 23 subsequent probability figures (e.g. for a breach occurring at 21:00, p_e within hour 1 = 0.4729; p_e within 2 hours = 0.4729 x p_e2; p_e within 3 hours = 0.4729 x p_e2 x p_e3; etc). This series of calculations was completed 24 times, each starting in a different hour, so that the cumulative probability of pest encounter was calculated over the first 24 hours post-breach, according to time of day the breach happens. The results were graphed to display cumulative probability curves.

RESULTS

Animals Sighted

In the summer study, a total of 788 sightings was captured on video over 157 hole-nights (HN) (three nights of footage were lost through battery failure). Animals most often encountered in the summer study were possums (212 sightings averaging 134 ± 13.2 per 100HN) and mice (201 sightings averaging 128 ± 14.0 per 100HN) (Table 1, Fig. 9). Ship rats were sighted 99 times (51 ± 10.3 per 100HN). Cats, in contrast, were encountered 116 times (73 ± 7.5 per 100HN). Pelage markings distinguished some cats as individuals, including at least 7 different cats sighted in each season. Mustelids were very rarely sighted, only 6 encounters in total. Mean sightings per 100 hole-nights totalled 493 ± 65.1 across all species. A selection of still images taken from video can be seen in Figure 15.

Altogether, 428 animal encounters were recorded over 160HN over the winter study (Table 1). In contrast to the summer, mice were sighted only 30 times (19 ± 5.4 per 100HN), while hares (89 sightings, 55 ± 8.3 per 100HN), possums (86 sightings, 54 ± 7.4 per 100HN) and cats (80 sightings, 50 ± 8.0 per 100HN) were most often seen. Mustelids were again rare, with only a single stoat sighting, and no ferrets.

Significance of Season, Habitat and Hole Type

Significantly higher overall numbers of pest sightings were recorded in summer than in winter ($p < 0.001$[*], Table 1). Summer sightings were significantly higher for mice ($p < 0.001$), ship rats ($p = 0.004$), cats ($p = 0.05$*), rabbits ($p < 0.001$) and possums ($p = 0.006$*), whereas the greater number of hare sightings in winter was only marginally insignificant ($p = 0.06$*). No seasonal difference was found for any other species.

The effects of habitat were not significant for the overall distribution of pest sightings ($p = 0.95$*), but significantly more rabbit sightings were recorded at pasture sites than forest sites ($p < 0.001$). Habitat did not significantly affect sightings of any other species.

Similarly, hole type did not have a significant effect on overall sightings ($p = 0.87$*), nor did it affect sightings of any individual species – although the higher number of rat sightings at 'tree-fall' holes was only marginally insignificant ($p = 0.06$).

[*] Result should be viewed with caution due to possible lack of independence between sites.

Table 1. Total number of sightings per season, and significance values.

Species	Number of Sightings and % of Total				Per 100 HN (± SEM)		Significance of Season (p-value)
	Summer		Winter		Summer	Winter	
Mouse	201	25.5%	30	7.0%	128 ± 14.0	19 ± 5.4	<0.001
Ship Rat	83	10.5%	42	9.8%	51 ± 10.3	26 ± 6.4	0.004
Hedgehog	99	12.6%	63	14.7%	62 ± 8.2	39 ± 6.9	0.43*
Possum	212	26.9%	86	20.1%	134 ± 13.2	54 ± 7.4	0.006*
Rabbit	46	5.8%	37	8.6%	28 ± 5.9	23 ± 5.4	<0.001
Hare	25	3.2%	89	20.8%	13 ± 3.4	55 ± 8.3	0.06*
Cat	116	14.7%	80	18.7%	73 ± 7.5	50 ± 8.0	0.05*
Ferret	5	0.6%	-	-	3 ± 1.4	-	N/A
Stoat	1	0.1%	1	0.2%	0.6 ± 0.6	0.6 ± 0.6	N/A
TOTAL	788	100%	428	100%	493 ± 65.1	267 ± 48.9	<0.001*

[*] Result should be viewed with caution due to possible lack of independence between sites. This applies to Tables 2 and 3 also.

Table 2. Total number of sightings at holes opposite each habitat type, and significance values.

Species	Summer Sightings		Winter Sightings		Significance of Habitat (p-value)
	Forest	Pasture	Forest	Pasture	
Mouse	95	106	19	11	0.94
Ship Rat	61	22	18	24	0.88
Hedgehog	44	55	32	31	0.98*
Possum	97	115	41	45	0.78*
Rabbit	15	31	10	27	<0.001
Hare	16	9	54	35	0.77*
Cat	52	64	29	51	0.39*
Ferret	2	2	-	-	N/A
Stoat	-	1	-	1	N/A
TOTAL	382	406	203	225	0.95*

Table 3. Total number of sightings at each breach type, and significance Values.

Species	Summer Sightings		Winter Sightings		Significance of hole-type (p-value)
	Tree-fall	Flood-scour (1st day only)	Tree-fall	Flood-scour (1st day only)	
Mouse	21	29	6	8	0.40
Ship Rat	25	8	4	7	0.06
Hedgehog	12	16	6	13	0.28*
Possum	26	21	6	10	0.90*
Rabbit	15	5	1	4	0.43
Hare	4	4	19	3	0.13*
Cat	11	16	9	7	0.49*
Ferret	1	2	-	-	N/A
Stoat	1	-	-	-	N/A
TOTAL	116	101	51	52	0.87*

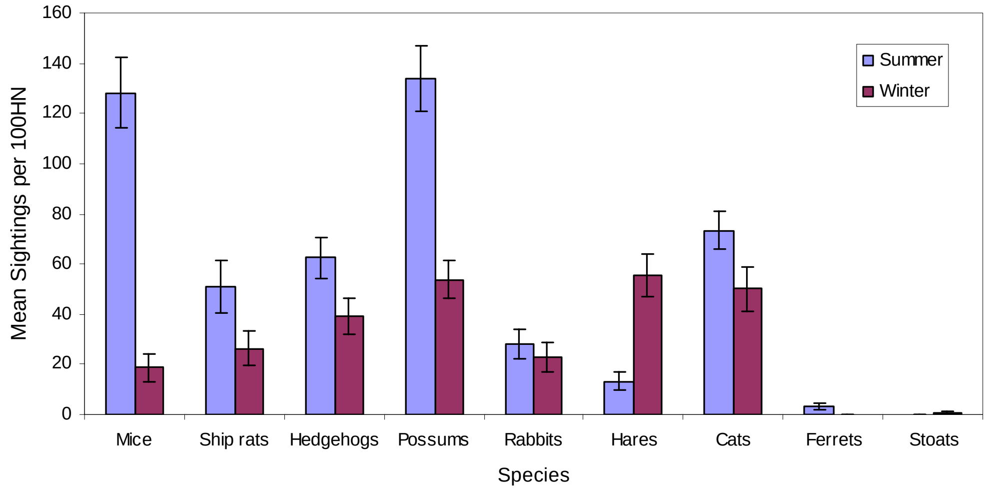


Figure 9. Mean sightings per 100 hole-nights, per species, by season (± SEM).

Timing of Pest Activity

Pest mammal sightings, when arranged according to hour of the day, appear to follow distinctive patterns in timing (although this has not been statistically tested). A total of 95.4% of overall sightings were nocturnal[†] in the summer, compared with 86.2% in the winter. Sightings of mice, ship rats, possums and hedgehogs[‡] were 100% nocturnal, regardless of season (Figs. 10 and 11), and cat sightings were 92.2% nocturnal in the summer, and 93.8% nocturnal in the winter. If lagomorphs are discounted (as these species are possibly of least concern to reserve managers), summer sightings were 98.6% nocturnal, and winter sightings 98.0% nocturnal. Sightings over summer in particular began, for many species, almost immediately after end of civil twilight (Fig. 11).

A number of trends were observed in the distribution of pest activity over 24-hour periods. Mouse sightings in the summer peaked between 8-11 pm, and

[†] For the purposes of this thesis, the term 'nocturnal' refers to the period between civil twilight end in the evening, and civil twilight start the following morning. Civil twilight is defined to be the time period when the sun's centre is no more than 6 degrees below the horizon before sunrise, or after sunset (King, 2005, p.473).

[‡] One exception – a single hedgehog was seen between 9-10am, in the winter. This individual was in very poor condition and appeared to be unwell, which may have prompted atypical behaviour (Jones & Sanders, 2005).

remained high until about 4 am. The number of winter mouse sightings was very low, following no discernible pattern. Ship rat sightings followed a similar pattern to those of mice in the summer, except the peak in sightings began approximately an hour later. In the winter, number of ship rat sightings was constant between 7 pm and midnight, but reduced steadily through to about 5 am, when sightings ceased. Possum sightings in the summer peaked between 8-10 pm, but were consistently high between dusk and 4 am, and winter sightings followed a similar pattern. Hedgehogs appeared to have two well-defined periods where sightings were high in both seasons, especially in the summer. The first period was between 7 pm and 1 am, which was followed by an hour of relative inactivity. A second period then spanned 2-6 am. Cat sightings peaked in the summer between 7-11 pm (overlapping the periods of greatest mouse and rat sightings), and tailed off through to 7 am. Rabbits were recorded between 4 pm and 9 am regardless of season. In the summer, daily rabbit sightings appeared to peak three times - at dusk, again around midnight, and finally at dawn. Hare sightings appeared distinctly bimodal in the winter, with most around dawn (continuing for approximately 3 hours), and with another period at dusk. Summer sightings followed a similar pattern, but were less frequent. Again, these are observed trends only, and have not been statistically validated.

Mouse sightings were positively correlated with rainfall ($r_s = 0.563$, $p < 0.001$) in the summer, but summer possum sightings were negatively correlated with rainfall ($r_s = -0.395$, $p = 0.028$). No further correlations were found for summer sightings. In the winter, ship rat sightings were positively correlated with rainfall ($r_s = 0.459$, $p = 0.003$), while sightings of hares were negatively correlated with both mean nightly temperature ($r_s = 0.337$, $p = 0.034$) and minimum temperature ($r_s = 0.410$, $p = 0.009$).

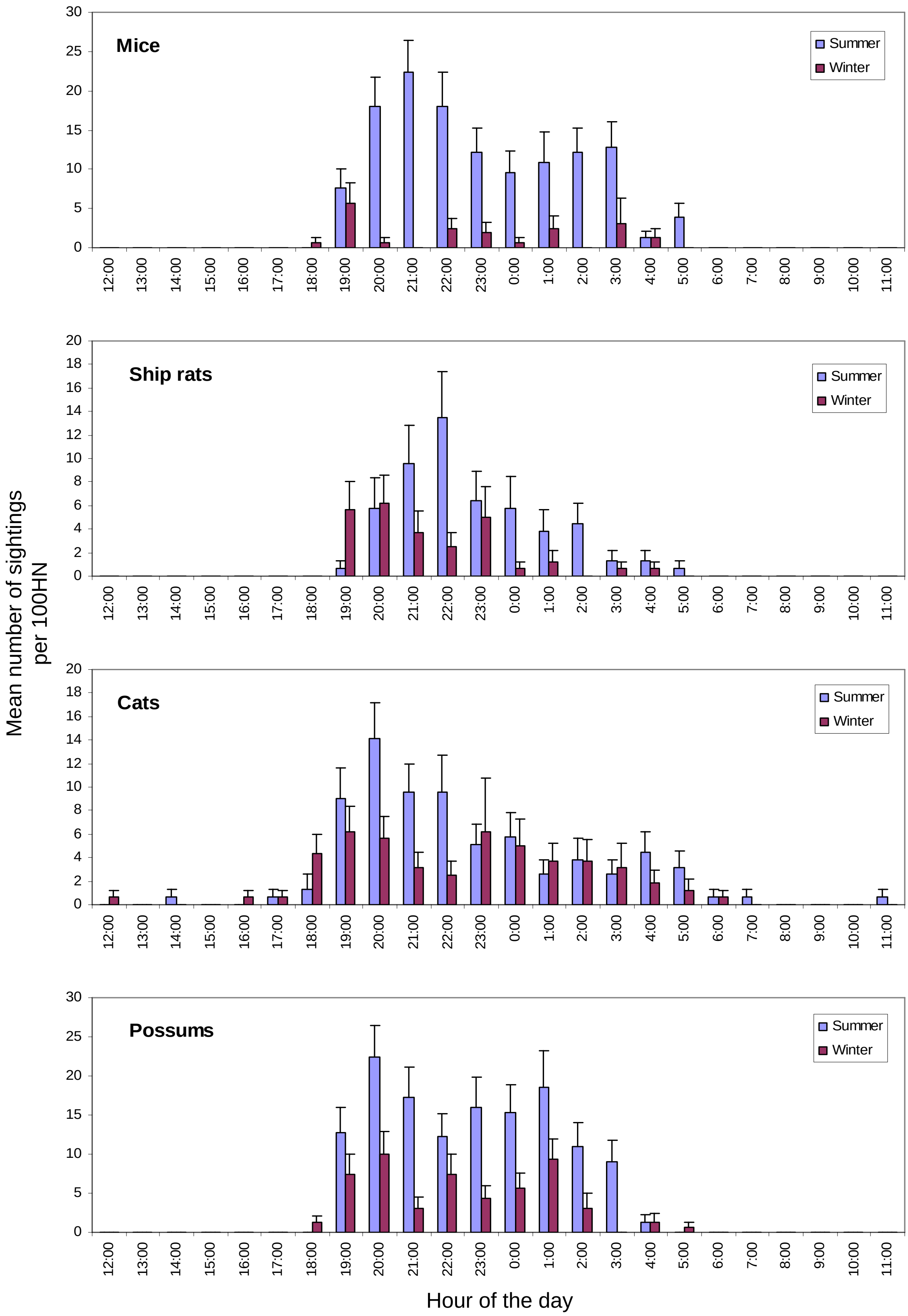


Figure 10. Mean (+ SEM) number of sightings per hour of the day, per species, by season. Summer times are corrected for New Zealand Summer Time.

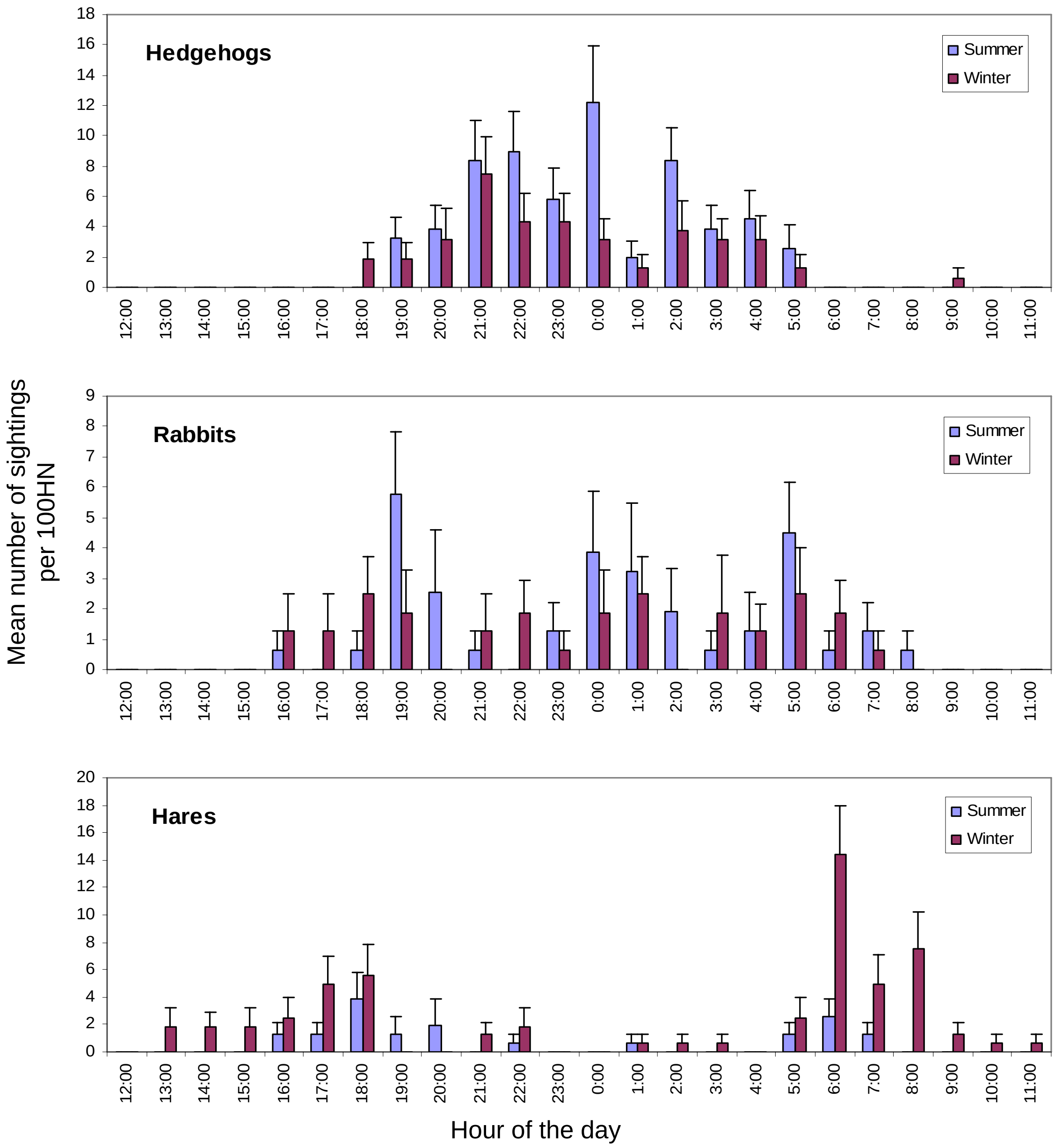
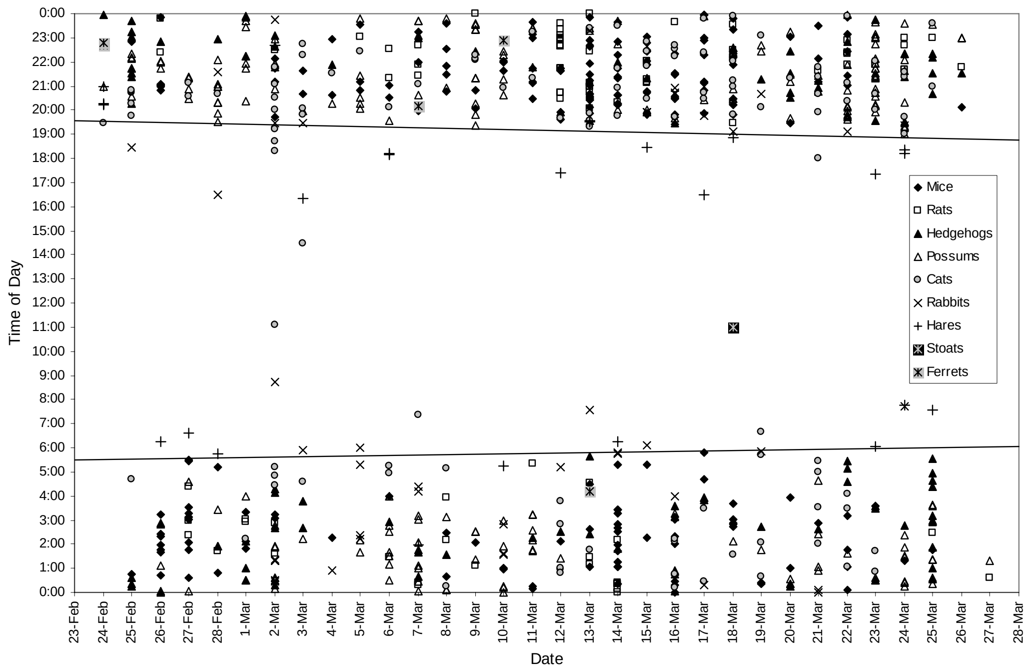


Figure 10 (Cont.). Mean (+ SEM) number of sightings per hour of the day, per species, by season. Summer times are corrected for New Zealand Summer Time.



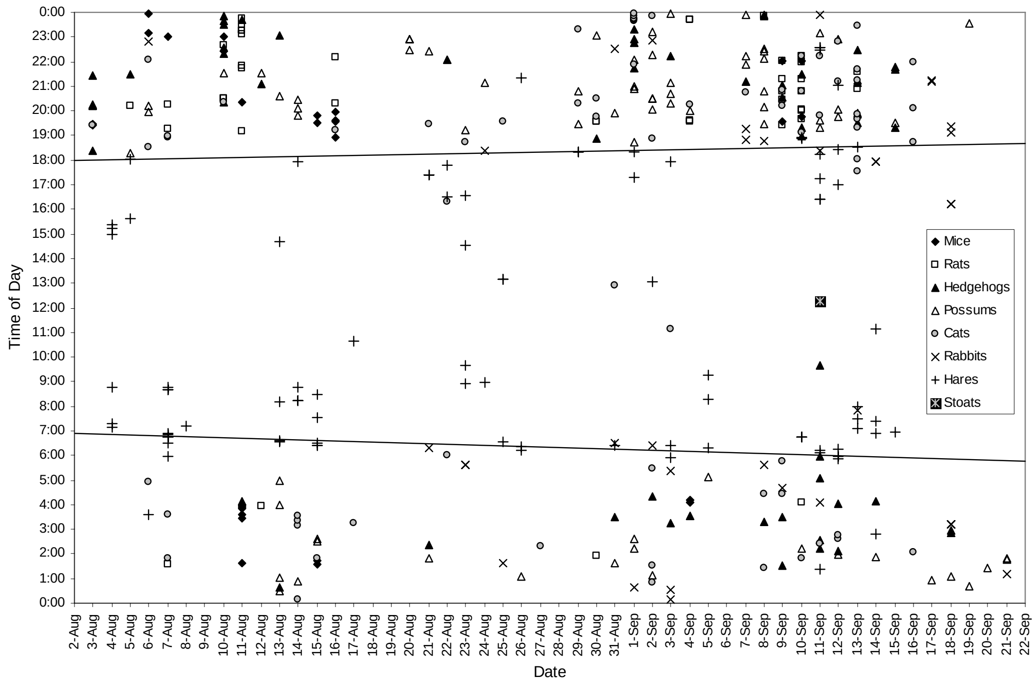


Figure 11. Time of sightings for all species in summer (above, corrected for NZ Summer Time) and winter (below). Upper line, civil twilight end; lower line, civil twilight start.

Pest Sightings in the First 24 Hours

Altogether, 39 out of 40 holes (97.5%) were encountered by at least one pest mammal within the first 24 hours of a hole being opened in the summer. In the winter, this figure was 37 out of 40 (92.5%). Mean number of *sightings* per hole (± SEM) in the first 24 hours was 5.4 ± 0.5 in the summer, and 2.6 ± 0.4 in the winter. The mean number of *species sighted* per hole (representing an absolute minimum mean number of *individual animals* encountered) in the first 24 hours was 2.8 ± 0.2 in the summer and 1.4 ± 0.1 in the winter.

Pest Sightings Over 7 Days

In the summer, total mean cumulative sightings per week-long hole (± SEM) increased from 5.05 ± 0.6 after Day 1, to 33.6 ± 2.4 after Day 7 (Fig. 12). Winter sightings increased from 2.6 ± 0.6 after Day 1, to 18.9 ± 2.0 after Day 7. No trend of increasing or decreasing number of encounters per day (per species, over a 7-day period) was found (t=-0.94, p=0.35), in either season. Mean (± SEM) cumulative number of *species* encountered per hole by Day 7 was 5.7 ± 0.25 in the summer, and in the winter, 4.9 ± 0.2.

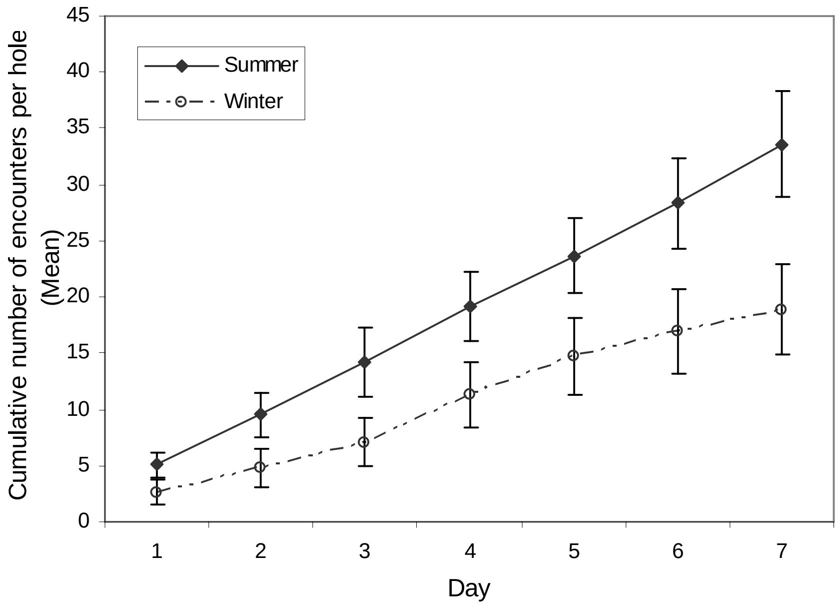


Figure 12. Mean (± SEM) cumulative number of sightings at 'flood-scour' breaches, over a 7 day period.

Hood Observations

Because recording of an entire week failed at one of the four sites, video from only three sites could be watched and summarised. One single night of recording (the 7th night) at one of the three remaining sites was also lost. This reduced the total number of nights observed from 28 down to 20 nights. Altogether, 187 ship rat sightings were recorded inside the hood over the 20 nights of observation. Over the same period and at the same sites, only 4 ship rat sightings were recorded at the fence base. A mean (± SEM) of 9.35 ± 1.5 ship rat sightings per HN were recorded within the hood. The highest number of sightings on a single hole-night was 23, and at least one rat sighting was recorded on all 20 nights. No other mammalian species were recorded using the fence hood, although invertebrate activity was very high. Again, still images taken from video can be seen in Figure 15.

Timing of ship rat sightings followed that found in the main summer study (Fig. 13). Sightings peaked between 8pm and midnight, but remained constant until about 5am.

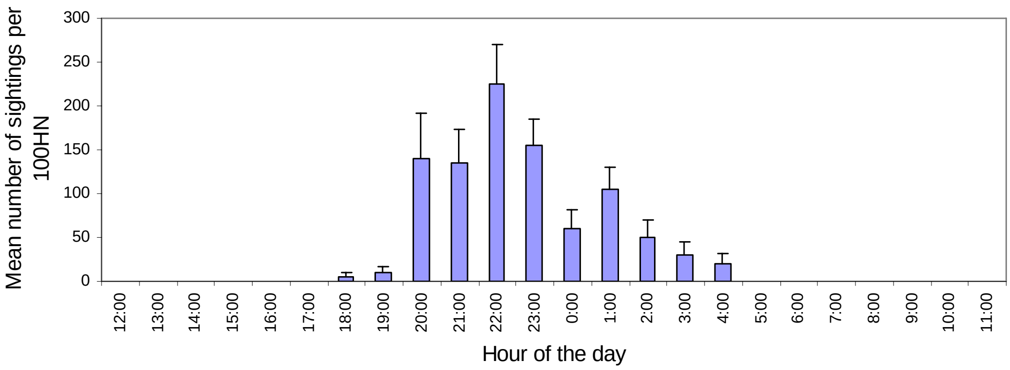


Figure 13. Mean number of ship rat fence-hood sightings per 100HN (+ SEM) according to time of day. Times are corrected for New Zealand Summer Time.

Probability Model: Cumulative Probability of At Least One Pest Encounter

Probability curves representing cumulative probability of at least one mammalian pest encountering a breach, according to time of day and season, are displayed in Figure 14. In summer, the model shows that cumulative probability of at least one pest encountering a breach increases much faster nocturnally than diurnally (Fig. 14a). For example, if a breach should happen at 6 pm in the summer, there is a 30% probability that a pest will encounter the breach within 3 hours. This rises to 90% by midnight, and 99% by 6 am if the breach has not been attended to. In contrast, if the fence is breached at 6 am, the probability of mammalian pest encounter within 3 hours is 1%; this increases to 12% by 6 pm, but is 99% by 6 am the following day.

Probability of encounter by mammalian pests in winter follows a similar pattern to that of summer, but at a lower probability level (Fig. 14b). Again, probability increases at a much faster rate nocturnally. At a 6 pm breach, probability of pest encounter within 3 hours is 45% (higher than in summer, because of the earlier onset of dusk in the winter), and by 6 am this figure rises to 84%. By 6 pm the following evening probability is up to 85%. Probability of a pest encounter at a morning (6 am) breach within 3 hours is <1%, and this rises to 4% by 6pm. By 6 am the next morning, probability is 85% that at least one pest has encountered the breach.

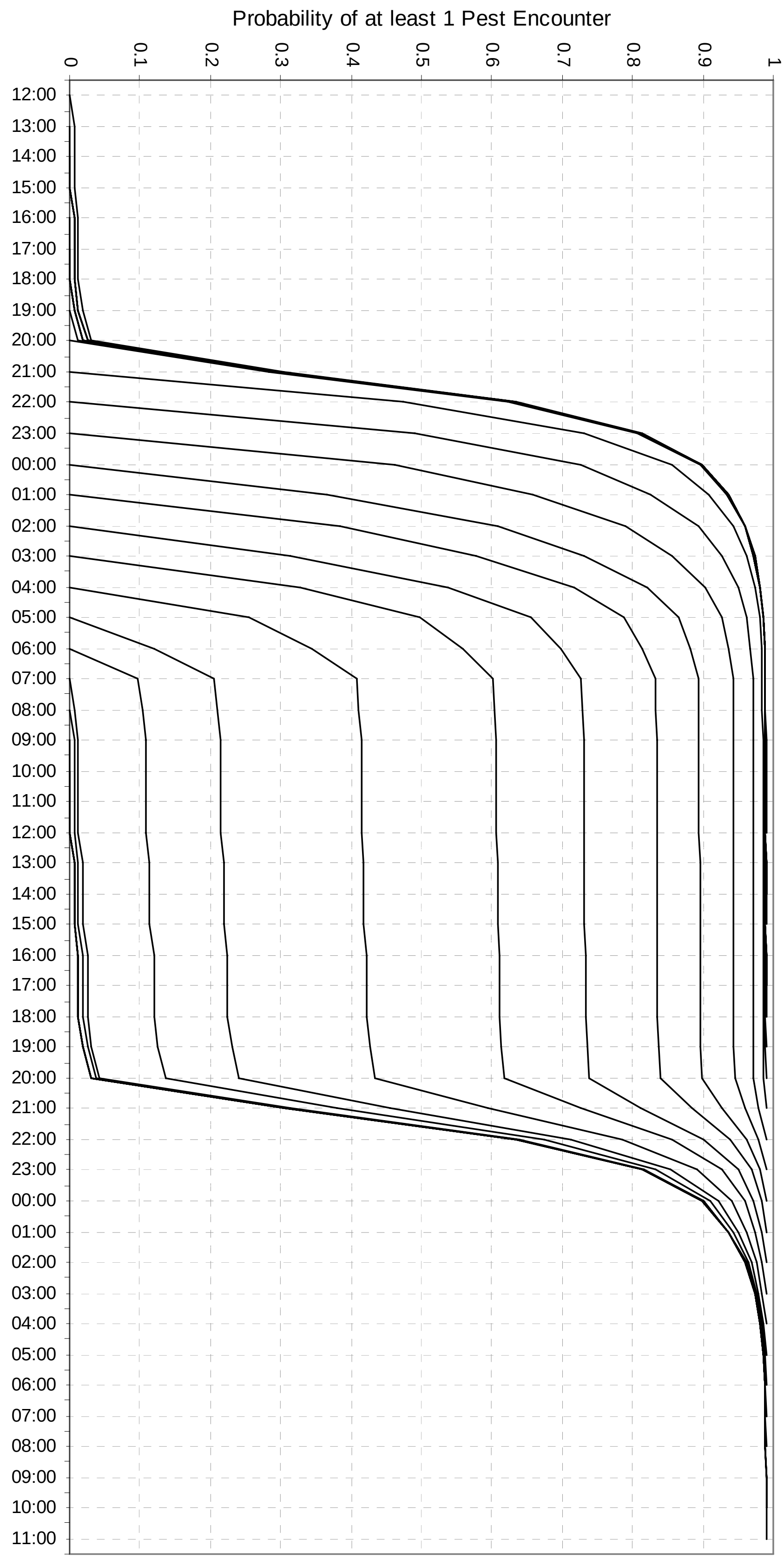


Figure 14a. Graph displaying cumulative probability curves for Summer. Each curve represents the cumulative probability of at least one pest mammal encounter over the 24 hours immediately post-breach, according to the time of day a breach happens. Times are to New Zealand Summer Time.

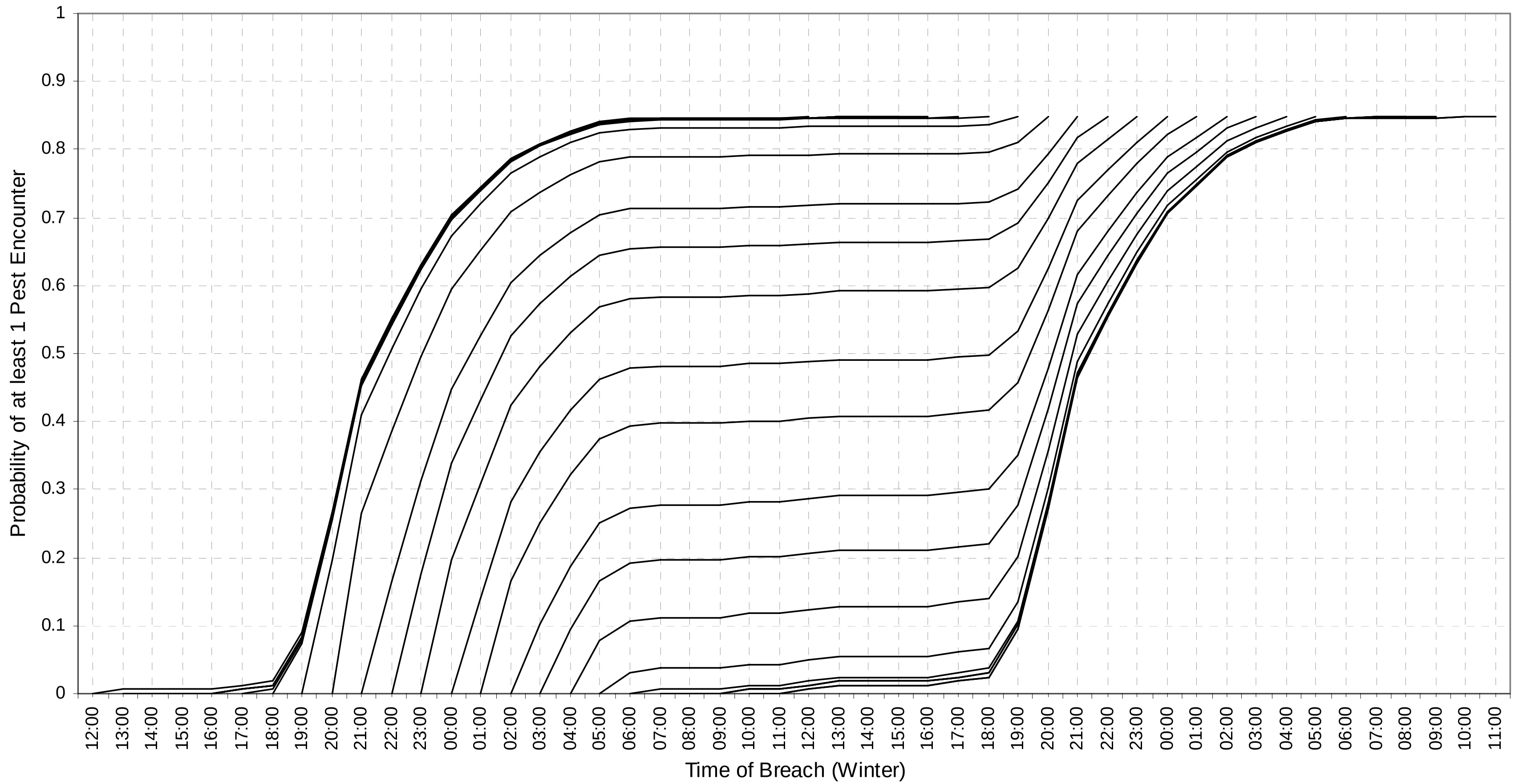


Figure 14b. Graph displaying cumulative probability curves for Winter. Each curve represents the cumulative probability of at least one pest mammal encounter over the 24 hours immediately post-breach, according to the time of day a breach happens. Times are to New Zealand Standard Time.

Figure 15. A selection of still images taken from the summer and winter video footage. Top row, cat and two kittens (2 images); 2nd row, ferret (L) and stoat (R); 3rd row, possum and ship rat; bottom row, rabbit (L) and hare (R).

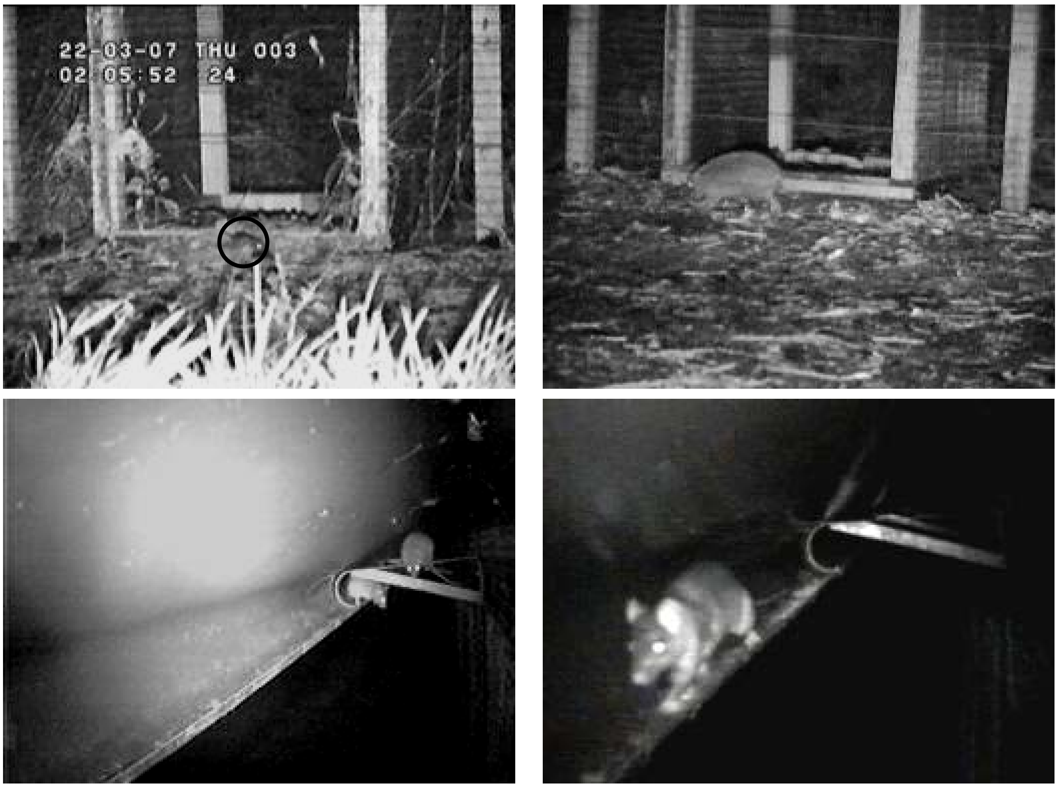


Figure 15 (cont.). Further still images. Top left, mouse (circled); top right, hedgehog; bottom left, two ship rats inside the fence hood, looking at the ground; bottom right, ship rat inside the hood, in a hurry.

DISCUSSION

Numbers of Sightings

The proportion of total sightings contributed by each species was much as expected, with three exceptions.

(1) Ship rats are widespread on the New Zealand mainland (Innes 2005), and anecdotal evidence suggested that, as they were the species most often seen by people at the fence, they would also be most often seen on video. This was not the case, and in the summer, more mouse, possum, hedgehog and even cat sightings were recorded than ship rats. This paucity of ship rat sightings at the base of the fence suggests that ship rats may have been using the fence in other ways, such as within the Colorsteel® fence hood gutter.

(2) The rate of cat sightings (73 ± 7.5 per 100HN summer, 50 ± 8.0 per 100HN winter) was much higher than expected. Within 1km of the fence, there are farmhouses and farm utility buildings at regular intervals. This proximity to houses, the high number of sightings and the high number of individual cats seen suggests that some individuals may be farm or even domestic cats, rather than feral. Cats are known to spend a high proportion of time along linear habitat features such as roads, waterways and field edges (Fitzgerald & Karl 1986), and these results suggest that at least some of these individuals routinely travel and inspect the Maungatautari fenceline.

(3) The low level of recorded mustelid sightings, though not entirely unexpected, is also worth noting. Stoats have previously been sighted hunting along the fenceline (T. Day pers. comm.), and mustelids are also known to spend much time following linear habitat features (Alterio et al. 1998; King et al. 1996; Murphy & Dowding 1994). The summer study took place over the period of juvenile dispersal for stoats and ferrets (Byrom 2002; King & Murphy 2005), and because of the high numbers of sightings of prey species (rodents, possums and lagomorphs), a higher number of mustelid sightings might have been expected.

One possible explanation for the lack of sightings may be that as the base of the fence offers no cover, mustelids mostly move along the far side of the road, in or nearby vegetation. If they did, they would avoid detection by the video cameras. They may not move parallel to the fenceline at all, but simply visit the fence intermittently. Mustelids may also have been deterred by human scent, or the presence of the camera equipment. For example, the mainly nocturnal ferrets might have been deterred by the infra-red lighting used. Newbold (2007) found evidence that some ferrets were capable of seeing infra-red light at a wavelength of 870NM, on the supposedly invisible side of the 850NM wavelength for lighting used in this study. Further study is recommended to investigate in more detail the interaction of mustelids with the fence at Maungatautari, particularly movements and proportion of time spent at or near the fence.

Seasonal Differences

Although this study did not include any direct measure of pest abundance, individual activity levels or density, changes in number of sightings between seasons for most species followed similar patterns to previous abundance studies, as follows.

1. Rodent sightings in general (and mice in particular) significantly declined from summer to winter. Both mouse and ship rat populations are known to follow this general pattern in environments that are not dominated by mast-seeding events (Badan 1979; Daniel 1978; Harper 2002; Innes et al. 2001; Murphy 1989), although annual density fluctuations may be higher than seasonal (Daniel, 1978; Innes et al, 2001).
2. The higher number of summer possum sightings, though possibly not statistically significant (see Methods) also concurs with previous findings on density, as possum abundance is generally highest in late summer, and lowest in spring (Brockie et al. 1981).
3. Hedgehog sightings did not significantly drop in the winter. The severity of the winter influences the proportion of a hedgehog population that will take the risk of entering hibernation (Jones & Sanders 2005), so the

relatively mild central Waikato winter of 2007 may have permitted many to avoid it.

4. Rabbit density is lowest in areas of high rainfall (Gibb et al. 1978), such as at Maungatautari. Rainfall at the reserve in 2007 increased from 85mm in March to 126mm in August, which may have discouraged rabbit activity in the winter.
5. Hares were seen more often in September. Although this increase was not statistically significant, it corresponds with the intense breeding behaviour exhibited by hares at this time (Norbury & Flux 2005).
6. Mustelids were very rarely observed, and no seasonal trends in activity could be seen.

The change in rate of sightings between seasons for any species may be caused by a change in size of the population. However this is not the only possibility. It may simply mean that a similar number of animals are still present, but each individual is more or less active. It may also be caused by a change in habitat usage, brought on by a change in food availability, e.g. mice eating more plant material in winter, and more invertebrates in summer (Fitzgerald et al. 1996). A combination of any or all of these factors is likely to cause a change in rate of sightings.

Habitat Effects

The results suggest that the habitat adjacent to the service road at Maungatautari does not significantly influence sightings of any species except rabbits. Rabbits are known to inhabit areas of closely-grazed grass (Gibb et al. 1978), and it was no surprise to see the significantly higher number of sightings at pasture sites than at forest sites. Otherwise, pressure on the fence is not significantly increased by the close presence of discrete pockets of habitat such as indigenous forest, and no habitat 'hotspots' have been found that may require particular vigilance. Again, possible non-independence between sites means caution is advised for hedgehog, possum, hare and cat results. However, individual cats were often observed at more than one site in a single night, and appear to patrol the service road regardless of habitat directly alongside.

The lack of habitat effect is not altogether surprising. The study did not investigate habitat use by mammals in the vicinity of the fenceline, nor were movements of individuals recorded (with the partial exception of some cats). However it seems likely that while some species may den in certain habitats (e.g. ship rats and possums in forest fragments), once on the service road (or on the fence itself) they range widely. The service road offers a surface that is free of obstacles, is easily travelled and is relatively dry in inclement weather; prey (invertebrates, rodents, lagomorphs) is also present at the fence or on the road for many species. Because the habitat opposite the fenceline is mosaic in nature, it is unlikely to greatly affect the probability of a pest encounter; if it were more uniform (e.g. 10 km of unbroken forest followed by 10 km of unbroken pasture), there might well be an effect.

Breach Types

No species was sighted more often at either breach type, and a fence breach seems as likely to be encountered by a pest mammal whether a branch has fallen across the road or not. Ship rats were sighted more often at ‘tree-fall’ breaches in the summer, and although this was not statistically significant, it suggests that more research may be required to investigate the detailed effects of fallen branches and large tree-falls. The physical nature of the breaches used in-situ in this study was always going to be limited by the need to maintain fence integrity at the research site. A purpose-built exclosure would be required for more rigorous testing of breach types (e.g. large tree-falls) that completely destroy sections of fence.

Timing of Activity

Night-time (between civil twilight end and civil twilight start) pest sightings were far more frequent, which was not unexpected. Mice are known to be mostly nocturnal, except where numbers are high and food is limited (Rowe 1981). Ship rats (Innes 2005), possums (Paterson et al. 1995) and hedgehogs (Jones & Sanders 2005) are also mostly nocturnal. Cat activity has previously been found to vary according to season (Langham 1992), but these results found few diurnal sightings in either season. Thus, a breach during the hours of darkness, and the first half of the night in particular, is of greatest concern to reserve managers.

The positive correlation between mouse and rat sightings and rainfall may add to this concern, and suggests that if a tree falls over the fence during a rain storm in the hours of darkness, a quick response is most needed at the very time when it is least likely (because of access difficulty in wet conditions). The negative correlation of possum sightings with rainfall (Ward 1978) may mean that the fence is least at risk from possums during the same event.

Pest mammals were sighted by the video cameras within the first 24 hours of a breach opening at a much higher rate than they were detected at a breach by footprint tunnels by Speedy et al (2007), although this comparison is not entirely valid because of the different methods used. Speedy et al's (2007) ink-cards were placed directly inside the breach (or on ramps) to indicate whether animals had exploited the simulated breach, but could not spot 'near misses', in which animals may have been present but did not exploit a breach. Video cameras could record sightings of animals at a breach, whether they exploited the breach or not. The nature and rate of breach exploitation by pest mammal species seen in this study is to be published in a future paper.

Rats in the Hood

Observations inside the hood provided firm evidence that rats travel and forage extensively in this artificial but highly acceptable above-ground habitat, much more often and possibly in much higher numbers than on the ground. Although it is not appropriate to directly relate the fence hood observations to the previous summer and winter results, they do suggest that the two seasons' data on ship rat sightings gathered from the ground alone, as reported above, were underestimates of the real potential for invasion of a breach by rats. Further studies are urgently needed on ship rat abundance, distances travelled and proportion of active time spent within the hood gutter.

Probability of Pest Encounter

The probability model suggests that based on these data, there is a 99% probability of *at least one* pest mammal encountering a breach within 24 hours in the summer, and an 85% probability in the winter. Cumulative probability of encounter increases massively after dusk, but increases at a slower rate in daylight. This is of huge concern to reserve managers, and again suggests that a quick response particularly to night-time breaches is vital. However, it must also be emphasised that regardless of time of day, there is *always* a risk of pest encounter and invasion after "time zero"; and that this risk is *always increasing* with time.

The results of the probability model are alarming for reserve managers. However, these data should possibly also be considered as conservative, as only pests that were present directly at the base of the fence were recorded. It is unreasonable to assume that these were the only pests present in the vicinity, and more are likely to be present nearby, e.g. in forest fragments, on farmland or inside the fence hood. Conversely, it should also be remembered that these data represent only two seasons, in a single year of research; large annual fluctuations in density of species such as ship rats are known (Daniel 1978, Innes et al 2001), and may affect probability of breach encounter. The rarity of stoat sightings was surprising (two in 319 days of observation), and true diurnal probability of pest encounter may be much higher. Similarly, ship rats within the fence hood are likely to increase the nocturnal probability of encounter; again, further research on presence, abundance and movements of these species in relation to the fence is strongly recommended.

Independence Between Sites

The distance between breach sites was sufficient to assume independence between sites for individual mice, ship rats and rabbits. Ideally, the distance should also have allowed this assumption to hold for all other pest species, to enable more robust statistical analysis (except for mustelids, due to small sample size). Over the summer study, VCRs were used for recording, and required daily battery and video tape changes. Up to six sites had to be visited every day for 31 days. Visiting all sites over 7 km of steep, winding terrain in a 4WD vehicle (in low gear ratio) took most of the day, and increasing distances would have made daily servicing impractical. The decision on distances between sites was made as a compromise between statistical robustness (for species other than rodents and rabbits) and practicability. While the p-values reported for comparisons in this research should be interpreted carefully for some species, the trends described from the data remain clear.

If DVRs had been available in the summer, distances could have been much greater, as only weekly visits would be required. A 1 km gap between sites may then have been possible, and sites could have been split between the northern and southern sides of the mountain. This 1 km distance would then have allowed the assumption of independence to hold for hedgehogs (Jones and Sanders 2005), and possibly also for possums, stoats, ferrets and cats, although these species are all known to range over large distances (Green 1984, Gillies & Fitzgerald 2005, King & Murphy 2005, Clapperton & Byrom 2005). However, the DVRs became available only after the summer study, and it was necessary to use the same sites in the winter as used in the summer, to allow a seasonal comparison.

Conclusion

This chapter has documented the temporal and seasonal pattern of sightings for mammalian pests recorded at a 7 km representative sample of the Maungatautari fenceline. The fence faces greatest pressure from pest mammals during the hours of darkness, in both summer and winter. Number of sightings for mice, ship rats, possums, rabbits and cats are significantly higher in summer than in winter. These data cannot tell whether there were higher numbers of individuals or the same number of more active individuals, but as indices of abundance of unmarked populations they generally follow those seen elsewhere. Overall number of sightings was generally not affected by adjacent habitat type, or type of breach. The high levels of nocturnal pest sightings (particularly cats) directly at the base of the fence is of concern, and should be taken into account when considering the most appropriate response to a fence breach. Ship rat activity inside the fence hood is extremely high and likely to present the single most severe threat of invasion, especially during a rain storm at night. The true probability of a pest encountering a breach may be higher than the probability model suggests, and further study into the abundance, movements, home range and invasion behaviour of pest mammals at Maungatautari Ecological Island is strongly recommended.

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CHAPTER 3

Behaviour of Mammalian Pests at Simulated Breaches in a Pest-Proof Fence

ABSTRACT

Mammalian pests are excluded from Maungatautari Ecological Island by an Xcluder™ pest-proof fence that excludes every individual unless the fence integrity is compromised. Inevitably, the fence will be breached on occasion by mechanisms such as treefall and flood-scour. Knowledge of pest behaviour in relation to fence breach events would assist reserve managers in developing optimal breach-response procedures. A video study was conducted at 20 simulated fence breaches over summer 2006/07, winter 2007 and summer 2007/08 to gather data on rates of mammalian pest interest and entry into fence breaches, and to test whether the risk of invasion varies significantly with season (summer and winter), exterior habitat (forest and pasture) and breach type ('tree-fall' and 'flood scour'). The number of breaches encountered by pests within 24 hours was high in both seasons (95% summer, 92.5% winter), but pests showed interest in, and subsequently entered, more summer breaches than winter breaches ($p < 0.001$). Similarly, high rates of encounter were found at 7-day breaches, with 100% of breaches encountered by pests within the week in both seasons. Increasing numbers of encounters, and of species, were recorded at each breach over a 7-day period. Mice, when sighted, were more likely to show interest in and/or enter breaches than any other species. The behaviour of ship rats, the species next most likely to enter breaches at ground level, was probably underestimated because many rats moved along the fence inside the hood, invisible to the ground-level cameras. Possums, cats and hedgehogs showed less

interest than rodents. Cats showed a willingness to follow prey into breaches, and possums often scent-marked holes before moving on or entering. Although seasonal differences in interest were found for rodents, hedgehogs and rabbits, none was found for cats or possums. Ship rats ($p = 0.014$) and hares ($p < 0.001$) showed significantly more interest in 'tree-fall' holes than in 'flood-scour' holes, but habitat type did not affect rates of interest or entry for any species.

INTRODUCTION

Mt Maungatautari, an eroded andesitic volcanic cone, lies in the central Waikato, in the North Island of New Zealand (Clarkson 2002; Speedy et al. 2007). The mountain supports a dense mixed podocarp-broadleaf forest, covering approximately 3400ha, and is completely surrounded by farmland (MacGibbon 2001). The majority of the original native fauna present on the mountain is now absent, and the remaining flora has been intensely browsed for many years (McQueen 2004). The Maungatautari Ecological Island Trust (MEIT) was formed in the late 1990s. Their primary aim is to "restore the diversity, vitality and resilience of the ecosystems of Maungatautari, as close as possible to the original condition, to re-create self-sustaining communities of indigenous plants and animals" (McQueen 2004).

A vital pre-requisite to achieving the primary goal of the MEIT is the permanent removal of all mammalian pests. To this end, a 47km Xcluder™ pest-proof fence was completed in 2006, which completely encircles the 3363 ha of forest clothing the mountain top, at an average of 475 m elevation below the summit (252 m asl). This fence design has been proven experimentally and in-situ to exclude 100% of the pest mammals that encounter it, unless the integrity of the fence is compromised (Day & MacGibbon, 2007). An eradication campaign then began, to remove mammalian pest species within the exclosure (including fallow deer (*Dama dama*), red deer (*Cervus elaphus scoticus*), feral pigs (*Sus scrofa*), feral goats (*Capra hircus*), feral cats (*Felis catus*), possums (*Trichosurus vulpecula*), feral ferrets (*Mustela furo*), stoats (*Mustela erminea*), weasels

(*Mustela nivalis*), ship rats (*Rattus rattus*), mice (*Mus musculus*), rabbits (*Oryctolagus cuniculus*), hares (*Lepus europaeus occidentalis*) and hedgehogs (*Erinaceus europaeus occidentalis*)). By January 2008, the only pest mammals known to have survived within the reserve were isolated pockets of mice, up to 10 goats, and small numbers of lagomorphs (P. de Monchy pers. comm.). The mice are not thought to be invaders, as most are many hundreds of metres from the nearest boundary point. All are being targeted in ongoing operations.

Damage to fence integrity is thought to be inevitable at some stage in the life of a fence, because it is impossible to eliminate all chances of tree-falls or gates being left open. Xcluder™ Pest Proof Fencing Company have developed remote surveillance techniques to minimise the risk of pest re-invasion (Day & MacGibbon 2007). An alarm system monitors the integrity of the fence, including vehicle, pedestrian and water gates. Managers are notified by mobile phone immediately an alarm is triggered, and respond accordingly (Day 2007).

The MEIT currently attempts to physically respond to a breach within 90 minutes of notification of a breach. However, there may be times when this is not possible, e.g. where weather and track conditions make a night response dangerous. More than 95% of pest activity at Maungatautari is known to take place nocturnally (see Chapter 2). Knowledge of the behaviour of pests that encounter a breach (in particular, whether pests seem interested in the breach, and whether they will exploit it) will assist in the development of optimal breach response procedures, and minimise invasion risk.

The potential for re-invasion through a pest-proof fence by mammalian pests was tested during a preliminary study at Maungatautari (Day 2006; Speedy et al. 2007). Prior to the completion of the fence, breaches were simulated by cutting a series of holes in the fence mesh at some sites, and installing ramps at some of these to simulate branch falls. Ink tracking-cards were placed at each breach, and remained over a period of four weeks. No measurement was made of pest movement or investigation outside breaches, so only breach *use* events were recorded. Within the first 24 hours, 8% of breaches had been used, and after three days, this figure had risen to 22%. A total of 71% of breaches had been used by the end of the four week period. Mice and rats used the mesh holes, and possums, cats and rats used the ramps. Mustelids were observed and trapped along the fenceline during the experiment, but none were detected at the simulated breaches (Day 2006; Speedy et al. 2007).

The use of video recording allows both conclusive identification of species, and recording of behavioural data. Time-lapse video recording systems have been used to study predation at nests (Brown et al. 1998; Morgan et al. 2006), and these studies have shown that continuous monitoring of the activity and behaviour of cryptic nocturnal animals is possible. Although expensive and labour-intensive, video footage was chosen as the method that would provide the required data on pest behaviour at a simulated fence breach.

This study was conducted with the following aims:

1. To describe baseline data on levels of mammalian pest encounter, interest and entry at simulated breaches along the Maungatautari pest-proof fence.
2. To test for the effects of exterior habitat type, breach type, and season on levels of pest interest and levels of pest entry to simulated breaches.

METHODS

Study Site

Maungatautari Ecological Island (38°03'26"S, 175°33'40"W) is 16km south-east of Cambridge, New Zealand (Fig. 1). A 4m-wide compacted metal service road runs along the outside of the 47km exclusion fence. The habitat on the opposite side of the road is mostly grazed pasture, interspersed with small (≤0.25ha) pockets of indigenous mixed podocarp-broadleaf forest, dominated by rimu (*Dacrydium cupressinum*) and tawa (*Beilschmiedia tawa*). The section of fenceline chosen for the study was on the southern (Pukeatua) side of the reserve, beginning at the end of Tari Road and stretching approximately 7km towards the east (Fig. 2). The study site was chosen because the adjacent habitat offered a good representation of habitat found elsewhere on the reserve's perimeter, and access by 4WD vehicle was relatively easy.

Figure 1. Location of Maungatuatari Ecological Island (indicated by the arrow).

Fence Breaches

Twenty sites along the 7km stretch of fenceline were chosen at which to simulate fence breaches. The habitat next to the service road was determined to be either 'Pasture' (no trees present) or 'Forest' (at least 20 trees present, >5m in height). Along sections of the fence opposite blocks of each of these habitats, 10 sites were selected, to test for the effects of adjacent habitat on pest activity. Sites were separated by a minimum of 150m (see 'Data Analysis' below).

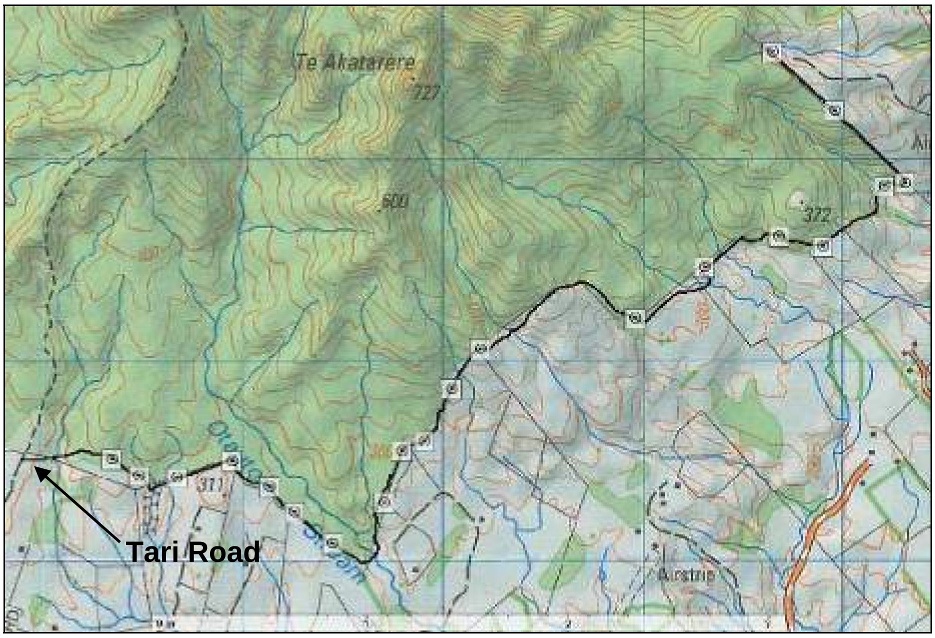


Figure 2. Sites of the 20 simulated breaches.

At each site, a 750mm long x 600mm wide x 600mm high wire mesh cage was installed on the inside of the exclusion fence at ground level. A hole measuring 250mm x 250mm was then cut in the fence mesh within the cage frame at ground level (Fig. 3). A temporary 600mm x 600mm mesh cover was attached to the face of the cage to prevent entry until each hole was filmed.

During each trial, two breach types were simulated. The 'flood-scour' type lasted 7 days, and was intended to simulate a breach that would not trigger the monitored alarm, and which might remain undiscovered for up to a week (Fig. 3).

Figure 1

Figure 3. A cage as installed at the fence. The temporary mesh cover has been removed and the simulated 'flood-scour' breach is open.

The 'tree-fall' breach type was filmed for 24 hours. This was meant to simulate an event that would trigger the alarm and be discovered within 24 hours. A three-metre long branch (no more than 75mm diameter) was laid across the road, with the end inside the opened hole. In addition, to simulate a 'break' in the mesh (to block animals that might move *along* the mesh itself) a length of Colorsteel® (500mm wide) was attached to the fence above the hole, up to the top of the fence. An object was also placed inside the rolled fence hood gutter, to block animals (particularly ship rats) moving along inside (see below). This arrangement was as close an imitation of a tree-fall event as it was possible to simulate while maintaining fence integrity.

The hood gutter (Fig. 4) provides an extensive, easily-travelled habitat for ship rats. Initial observations indicated that invertebrate activity within the hood was high. Stoats have been sighted inside the hood on occasion (T. Day pers. comm.), but only during daylight. Ferrets are poor climbers (Clapperton & Byrom 2005), and are unlikely to reach the inside of the hood. Nocturnally, the fence hood is likely to be an attractive, and possibly predator-free above-ground habitat for ship rats. A third set of observations was therefore designed to test the possibility that ship rats may be more active inside the hood than at the fence base.

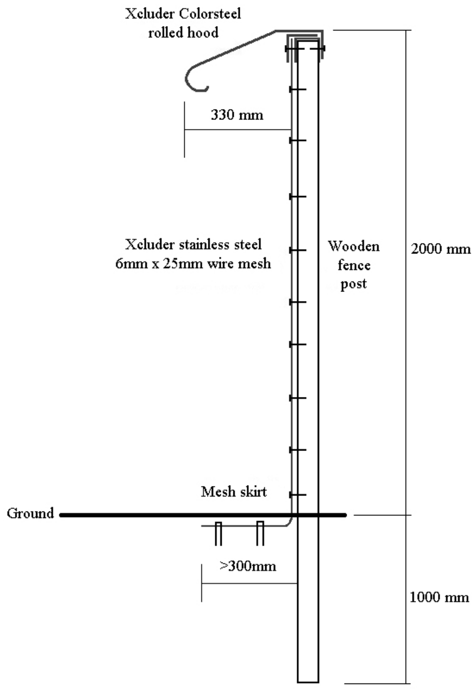


Figure 4. Schematic diagram of the Xcluder^{TM} 'Kiwi' fence design, as erected at Maungatautari. The rolled Colorsteel® hood is at top (adapted from Day & MacGibbon, 2007).

Recording Equipment

Each breach type was filmed at each site, with an interval of at least 2 weeks between. To survey differences in pest behaviour between seasons, it was intended that two video trials of equal length would take place to represent both summer and winter.

During the summer study, black and white CCD video cameras were set up at each site. Infra-red spotlights (wavelength 850NM) were set up for illumination during the hours of darkness. The cameras were set up on the far side of the service road, facing the holes. The video cameras were connected to 12V time-lapse VCRs via a waterproof 'pelican' case. The VCRs were set to record in 24hr time-lapse mode, and required daily battery and video tape changes.

Winter filming was more difficult to organise, for logistical reasons. Over the course of the summer study, it became obvious that after even brief rain, the service road was impassable at some points. It was decided that if a winter study were to take place, it could be done only by using six Archos 504 personal media players (high storage capacity digital video recorders (DVR) with low power consumption) in place of the VCRs. Testing confirmed that these devices were capable of recording and storing more than a week of video at 25 frames per second.

During the fence hood observations, two camera units were set up at each site. The first used the same cameras as before, arranged in the same way as previously, on the opposite side of the road, facing the fence breach. The second camera was a weatherproof miniature video camera with in-built infra-red LEDs, fitted to the underside of the Colorsteel® fence hood, facing towards the rolled gutter and connected to a second DVR placed at the base of the fence 20m along the fenceline. In this way, simultaneous recording of both the fence base and the hood gutter at each site was completed.

Filming Schedule: Summer

For the summer study, between February 24th and March 26th, 2007, up to six sites were filmed at any one time. Of these, up to five sites were 'flood-scour' sites (7 days duration), and one a 'tree-fall' site (24 hours duration). At all times, both 'forest' and 'pasture' sites were filmed simultaneously. Sites were scheduled for filming in rotation, and no more than every second cage along the fenceline was used at any one time, meaning that cameras were separated by at least 300m (see 'Data Analysis' below). Cameras were set up to record a total of 160 days of footage.

Filming Schedule: Winter

Winter filming was completed between between August 3rd and September 21st, 2007. Because it was no longer possible to carry out daily visits over a long period, the order in which each breach type was filmed had to be changed. All the 'tree-fall' holes in a block were filmed together at the start of the winter session, by allocating five cameras to them over four nights, to complete the 20 breach simulations. Then, filming of the ‘flood-scour’ holes started. Camera and DVR units were shifted around the hole sites as for the summer study, and again, both ‘forest’ and ‘pasture’ sites were filmed simultaneously at all times. After filming of the first block of ‘flood-scour’ holes was completed, only one to two visits per week were required over the winter study. Again, 160 days of recording were recorded in total.

Filming Schedule: Inside the Fence Hood

The third block of filming, with cameras focussed inside the fence hood gutter, was achieved with DVRs between December 2007 and January 2008. The aim was to make initial observations of ship rat activity inside the hood, and compare the results with the activity recorded simultaneously at the same sites but along the fence base. Four breach sites were filmed for a week each, two at a time.

Data Analysis

Cameras were in place over an equal number of days (160) in each season, but battery failure caused the loss of three days of footage in the summer. This difference was adjusted for in the data analysis.

All video was watched, and recorded pest mammal encounters were classed into two main and two sub-categories:

1) *Encounter* – a pest mammal is observed, but does not display any behaviour that indicates interest in the simulated breach.
2) *Interest* – the animal displays behaviour indicating interest in the simulated breach. This includes such behaviour as looking at, approaching, sniffing, and/or scent marking the hole in the mesh.
    a. *No Entry* – the animal subsequently does not enter the breach.
    b. *Entry* – the animal enters the breach. At least half the animal’s body must have passed through the hole in the mesh to be classed as entering.

Where 'Interest' was analysed, data from both sub-categories ('no entry' and 'entry') were included. These were combined to quantify the rate of discovery for a breach, regardless of whether an animal subsequently entered. 'Entry' was also analysed separately. Non-parametric methods (χ^2 contingency tables, Fisher's Exact Test) were used to test for an association between season and the observed rates of breach 'interest' and 'entry'. A generalised linear mixed model (GLMM) was used to test for significance of breach type and habitat on 'interest' behaviour. GLMM was used rather than ANOVA because the count data were not normally distributed. This analysis was completed assuming Poisson distribution, with a blocking structure that recognised 'season', 'habitat' and 'breach type' as random factors. The 150m minimum distance between sites (and 300m between any two sites filmed simultaneously) was considered enough to allow independence to be assumed for mice, ship rats and rabbits, as home range lengths for these species have been found to be smaller than this distance (Fitzgerald et al. 1981; Gibb et al. 1978; Hooker & Innes 1995). For all other species, the assumption of independence between sites may have been violated; GLMM analyses were still completed for these data, however results of both this and the non-parametric testing should be treated with caution. Non-independence in the data could have had the effect of overestimating the number of degrees of freedom in the analyses for those species, which may mean a result is viewed as being significant, when in fact it is not.

RESULTS

Behaviour in the First 24 Hours

In the summer study, 39 out of 40 (95%) breaches were encountered by at least one pest mammal within the first 24 hours, and 29 (72.5%) were entered by a pest mammal in the same period. At a further 5 holes, pest mammals showed interest but did not enter; thus, pests at least showed interest in 85% of summer breaches within the first 24 hours. Mean (± SEM) number of *entry* events within the first 24 hours was 2.0 ± 0.3 per day over the summer, and mean number of events where *interest* was shown was 3.3 ± 0.4 per day.

Because identification of individual animals was impossible for most species, number of *species* encountered at each breach can be used to represent the absolute minimum number of individual animals seen. In the summer, a mean of 2.8 ± 0.2 species were sighted at each breach. A mean of 1 ± 0.1 species entered each breach, and altogether, a mean of 1.9 ± 0.2 species were seen to show interest in the first 24 hours of a summer breach.

Altogether, 37 (92.5%) of 40 winter breaches were encountered by at least one pest mammal within the first 24 hours. A total of 11 (27.5%) were entered, and pest interest was shown at 19 breaches (47.5%). Mean (± SEM) number of winter *entry* events was 0.3 ± 0.08, and a mean of 0.85 ± 0.2 winter *interest* events were recorded per day.

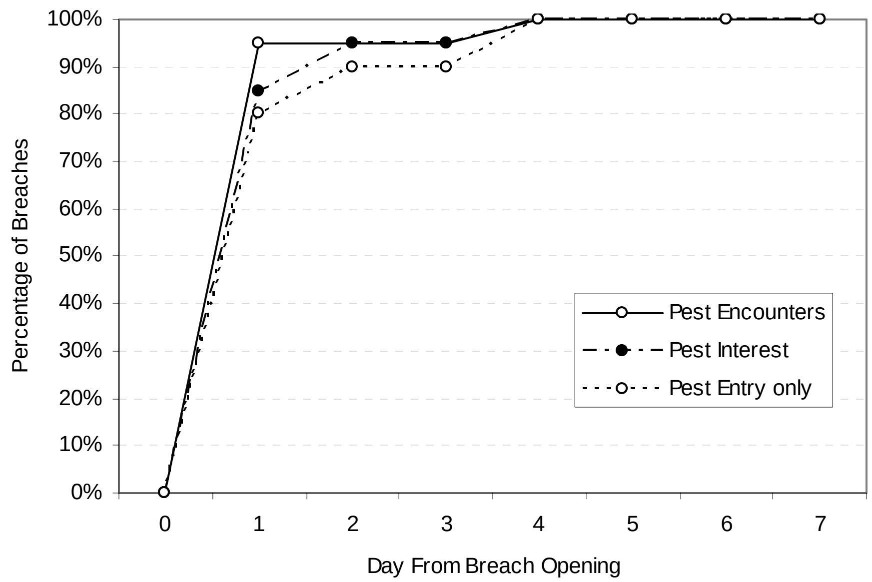
The mean number of *species* sighted in the first 24 hours of each winter breach (again, representing the absolute minimum number of individual animals) was 1.4 ± 0.1. Mean number of species seen to show *interest* in the first 24 hours was 0.58 ± 0.1, while the mean number of species to *enter* a breach was 0.28 ± 0.1.

Behaviour Over 7 Days

In the summer study, interest was shown by pests at 85% of 7-day flood-scour breaches after day 1. Pests had entered 90% of breaches within 2 days of opening, and after 4 days all breaches had been entered (Fig. 5a). Mean (± SEM) cumulative number of sightings was 5.05 ± 0.6 after day 1, and this increased to 33.6 ± 2.4 after day 7 (Fig. 6a). The mean cumulative number of breach *entries* increased from 2 ± 0.4 after day 1, to 13.05 ± 1.7 after day 7, and altogether, the mean cumulative number of summer sightings where *interest* was shown increased from 2.9 ± 0.5 after day 1, to 18 ± 1.7 after day 7. Over the course of a week, mean cumulative number of *species* sighted was 5.7 ± 0.3. Mean cumulative number of species seen to *show interest* in a breach by day 7 was 3.4 ± 0.3, while the mean number of species to *enter* a breach by day 7 was 3.35 ± 0.3.

At winter breaches, pest mammals were sighted at 90% of breaches in the first 24 hours (Fig. 5b). Pests had shown interest in 80% of winter breaches after 4 days, and had entered 60% of breaches after 5 days. Mean (± SEM) cumulative number of *sightings* per breach was 2.6 ± 0.6 after day 1, and 18.9 ± 2 after day 7 (Fig. 6b). Pests had shown *interest* in breaches a mean of 0.55 ± 0.2 times after the first day, and this figure increased to 4.1 ± 0.7 after 7 days. Pests had *entered* breaches a mean of 0.15 ± 0.1 times per breach after day 1, which increased to 2 ± 0.5 times after the 7th day. After 7 days, mean cumulative number of *species* sighted at winter 'tree-fall' breaches was 4.9 ± 0.2. Mean cumulative number of species to have *shown interest* after a week was 2.2 ± 0.3, while the mean cumulative number of species to *enter* after 7 days was 1.32 ± 0.3.

(a) Summer



(b) Winter

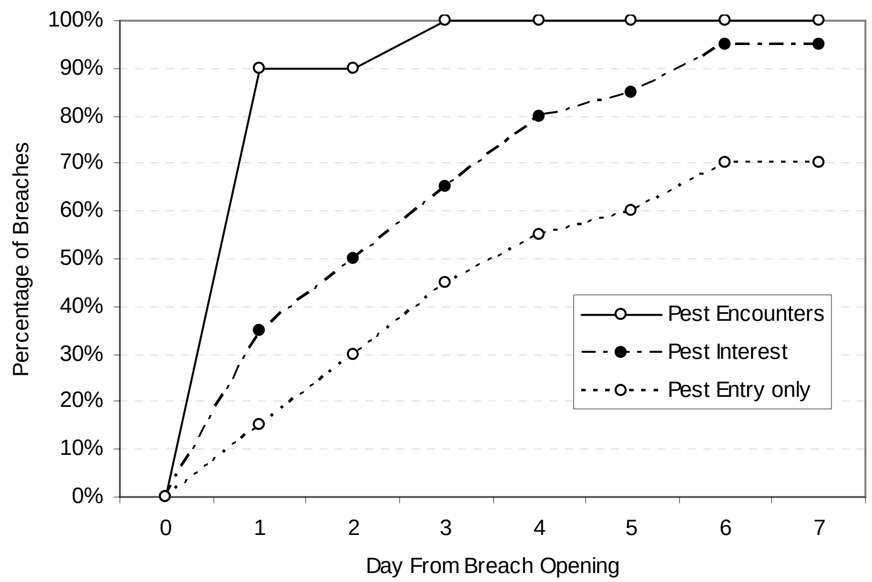
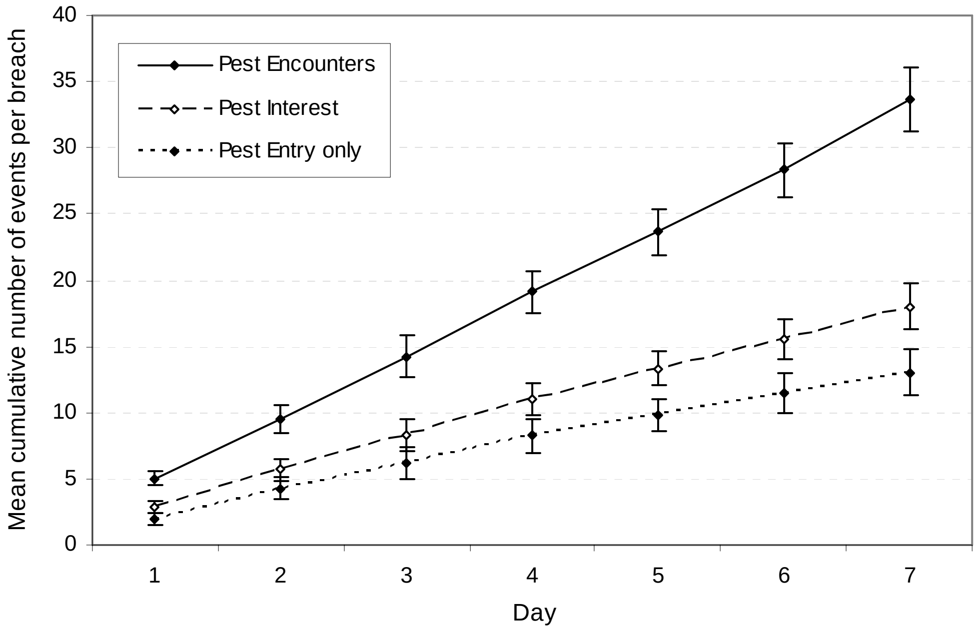


Figure 5. Percentage of breaches at which pests had been sighted, had shown interest or had entered, over 7 days in Summer (a) and in Winter (b).

(a) Summer



(b) Winter

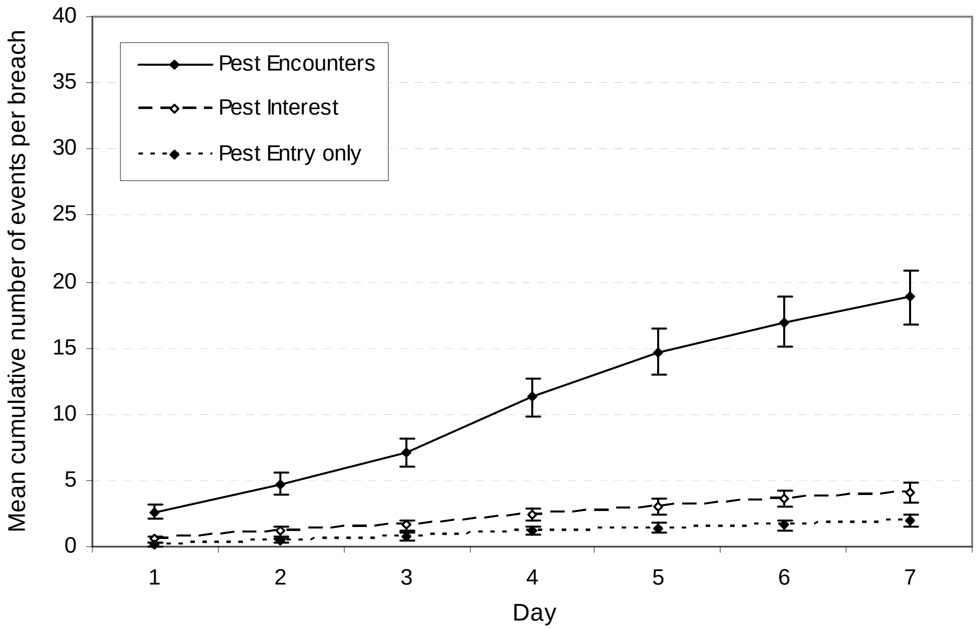


Figure 6. Mean (± SEM) cumulative number of times pests had been sighted at, had showed interest in or had entered 7-day breaches in Summer (a), and in Winter (b).

Number of Sightings

A total of 788 individual pest mammal sightings were recorded over the summer study, and of these, 38% resulted in entry to a simulated breach (Table 1). Pests were deemed to show interest in but not enter a breach in a further 17% of sightings, and thus in 55% of sightings, a mammalian pest showed interest in a breach. In the remaining 45% of sightings, pests were deemed to be showing no interest at all.

The total number of sightings recorded in winter was 428 (Table 2), and breaches were entered on only 49 occasions (11%). Pests showed interest in, but did not enter a breach in another 56 sightings, and altogether, breach interest was shown in 25% of winter sightings.

Pest Behaviour at Breaches

Mice entered summer breaches more often than any other species (174 times, 87% of mouse sightings, Fig. 7). Altogether, mice showed breach interest in 89% of encounters. Mice were significantly more likely to enter a breach when sighted than ship rats ($\chi^2 = 12.6$, $p < 0.001$), the species next most commonly seen to enter. Ship rats entered summer breaches 62 times (75% of ship rat sightings), and showed interest in breaches in a total of 82% of sightings (but see below for observations recorded inside the fence hood). Although collectively rodent sightings comprised only 36% of total pest sightings (n = 788), 78% of all summer breach entries (n = 302) were by rodents (Table 3).

Possums entered summer breaches on only 22 occasions (10% of possum sightings). However, possums showed interest in, but did not enter breaches on a further 65 occasions (31% of possum sightings), and showed breach interest in 41% of sightings in total. Similarly, hedgehogs entered breaches 19 times (19%) and showed interest in breaches but did not enter another 21 times (21%), totalling 40 occasions of interest (40%).

Cats entered breaches rarely (5 occasions, 4% of sightings), but appeared interested without entering on a further 26 occasions (22%), for a total of 27% of sightings. In both summer and in winter, at least 7 individual cats were recorded, and some of these were sighted at multiple sites in a single night. Most were regularly seen along stretches of fenceline up to approximately 2 km in length.

Mustelids were rarely seen, but in all sightings at least showed interest in a breach, and actually entered during 5 of 6 summer sightings.

Only 37% of winter mouse sightings resulted in breach entry, and 43% of ship rats (Fig. 8). Overall, rodents were still responsible for 59% of all breach entries, despite comprising only 17% of total winter sightings.

Possum sightings resulted in winter breach entry on 8% of occasions. However, possums showed interest in 37% of sightings altogether. Winter cat sightings resulted in breach entry in 6% of sightings, and altogether cats showed breach interest in 14% of sightings. Only 1 mustelid was sighted in the winter (a stoat), which entered a breach.

Table 1. Summary of mammalian pest behaviour in relation to simulated breaches, in the Summer.

Species	Entered Breach	Did Not Enter Breach		Total Sightings Summer
		Interested in Breach	Not Interested in Breach	
Mouse	174	4	23	201
Ship Rat	62	6	15	83
Hedgehog	19	21	59	99
Possum	22	65	125	212
Rabbit	13	6	27	46
Hare	2	4	19	25
Cat	5	26	85	116
Ferret	4	1	-	5
Stoat	1	-	-	1
TOTAL	302	133	353	788

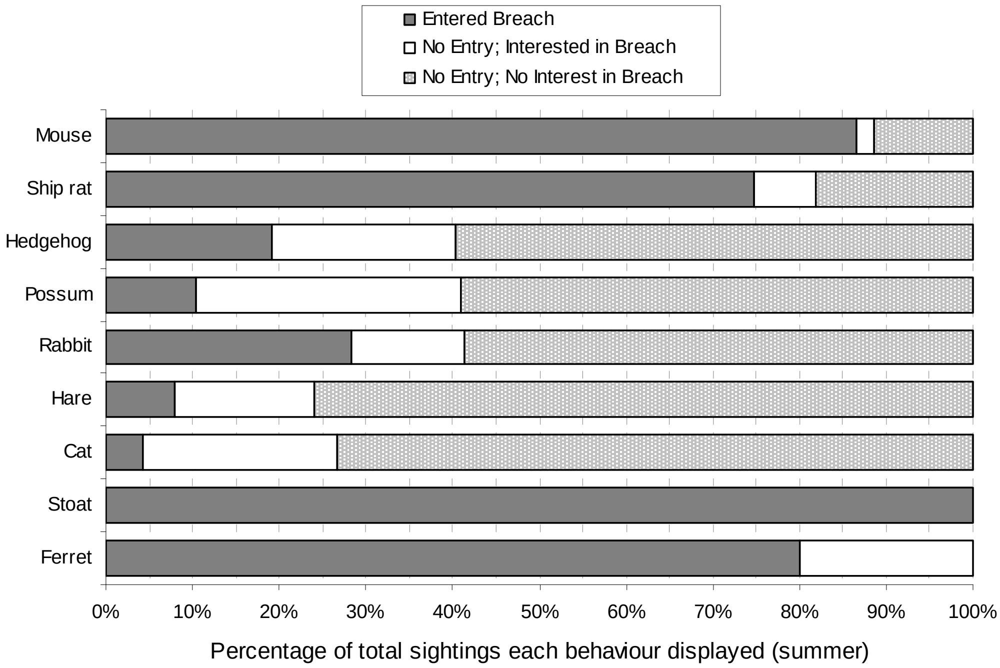


Figure 7. Percentage of total summer sightings that resulted in each of the three behaviours, per species.

Table 2. Summary of mammalian pest behaviour in relation to simulated breaches, in the Winter.

Species	Entered Breach	Did Not Enter Breach		Total Sightings Winter
		Interested in Breach	Not Interested in Breach	
Mouse	11	4	15	30
Ship Rat	18	3	21	42
Hedgehog	4	6	53	63
Possum	7	25	54	86
Rabbit	2	2	33	37
Hare	1	10	78	89
Cat	5	6	69	80
Ferret	-	-	-	-
Stoat	1	-	-	1
TOTAL	49	56	323	428

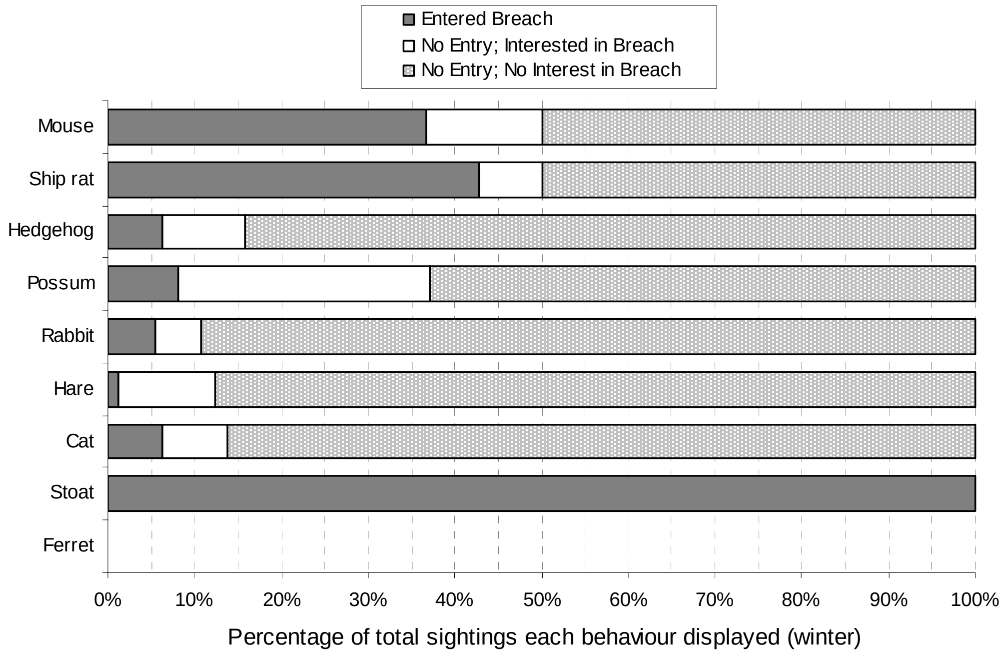


Figure 8. Percentage of total winter sightings that resulted in each of the three behaviours, per species.

Table 3. Percentage of total sightings each species comprised, compared with percentage of breach entries each species comprised, for both seasons.

Species	Summer		Winter	
	% of Total Sightings	% of Total Breach Entries	% of Total Sightings	% of Total Breach Entries
Mouse	26%	58%	7%	22%
Ship Rat	11%	21%	10%	37%
Hedgehog	13%	4%	15%	8%
Possum	27%	7%	20%	14%
Rabbit	6%	4%	9%	4%
Hare	3%	1%	21%	2%
Cat	15%	2%	19%	10%
Ferret	0.6%	1%	-	-
Stoat	0.1%	0.3%	0.2%	2%

Seasonal Difference in Behaviour

A very significant higher overall level of breach interest (i.e. when sighted, showing interest in and/or entering) was found in summer than in winter (χ^2 = 43.9, p < 0.001*). Summer interest was greater in mouse (χ^2 = 23.46, p < 0.001), ship rat (χ^2 = 6.82, p = 0.009), hedgehog (χ^2 = 11.64, p < 0.001*) and rabbit (Fisher's Exact, p = 0.0018) sightings. No seasonal difference in breach interest was found for possums (χ^2 = 0.37, p = 0.54*) or cats (χ^2 = 2.75, p = 0.097*).

Similarly, the greater rate of summer entry to breaches was highly significant for mice (χ^2 = 34.11, p < 0.001), and was significant also for ship rats (χ^2 = 5.63, p = 0.018), hedgehogs (Fisher's Exact, p = 0.022*) and rabbits (Fisher's Exact, p = 0.006), but again, not for possums (χ^2 = 0.35, p = 0.555*) or cats (χ^2 = 0.37, p = 0.544*).

Effect of Breach Type and Habitat on Behaviour

When sighted, ship rats showed significantly more interest in 'tree-fall' breaches than 'flood scour', regardless of season (Wald 6.08, p = 0.014), as did hares (Wald 141.66, p < 0.001*). In contrast, hedgehogs showed significantly greater interest in 'flood-scour' holes in either season (Wald 50.76, p < 0.001*). Habitat type had no significant effect on pests showing interest in or entering breaches.

* Result should be viewed with caution due to possible lack of independence between sites.

Hood Observations

Altogether, 187 ship rat sightings were recorded within the fence hood over 20 nights (mean 9.35 ± 1.5 SEM per night). Of these, only 1 sighting resulted in a rat running down the fence mesh to ground level within the field of view of the ground camera, and none resulted in breach entry. Rats often stopped directly above the simulated breach, and spent a few seconds looking down towards the ground. They were seen to capture and eat invertebrates on up to 10 occasions, and invertebrate activity was very high within the hood. No other mammalian species were observed at any time.

General Observations of Behaviour

A selection of still images taken from video clips can be seen in Fig. 9. Mice were almost always sighted moving at a steady pace, and always directly at the base of the fence; they were very rarely sighted on the fence mesh. In contrast, ship rats were regularly seen on the fence mesh (30% of sightings in summer, 40% winter), moving up or down, or even across the fence. When on the ground, ship rats were most often sighted directly at the fence base, but also used the nearest wheel rut to the fence on the roadway. Hedgehogs also moved along the fence base in the majority of sightings, but used both wheel ruts also. All other species were sighted most often moving along the wheel ruts, in particular the rut nearest the fence; only very rarely were any animals seen coming into the field of view from behind the camera.

When rodents entered a breach, most remained inside for at least 60 seconds; in this time they moved at speed over every internal surface, including the mesh and the wooden framework. Corners received particular attention, and often the animal would remain out of sight for some time as they investigated the ceiling of the cage. Possums often moved directly to the rear of the cage on entry, standing on their hind legs as they investigated the back face of the cage. Although some possums remained within the cage for more than 30 seconds, most departed within 20 seconds. Cats entered only when prey was sighted, and were twice seen catching a mouse within the cage. One cat that attempted to reach some ducklings on the inside of the mesh stayed inside the cage for more than 30 minutes, watching the 'just-out-of-reach' prey.

Rats tended to find and walk along branches at 'tree-fall' breaches, often right into the cage. Hedgehogs tended to walk around branches at 'tree-fall' holes, and on a few occasions were seen to stop and eat invertebrates including weta (*Hemideina* sp.). Possums would often scent-mark either the mesh or a fence-post next to a breach, while cats occasionally sprayed the same areas with urine. One cat was sighted with 2 kittens, on more than one occasion. Cats sometimes looked directly at the camera once they were within the field of view; but pests of any species only very rarely inspected the cameras at close range (at least visibly) and/or knocked the cameras.

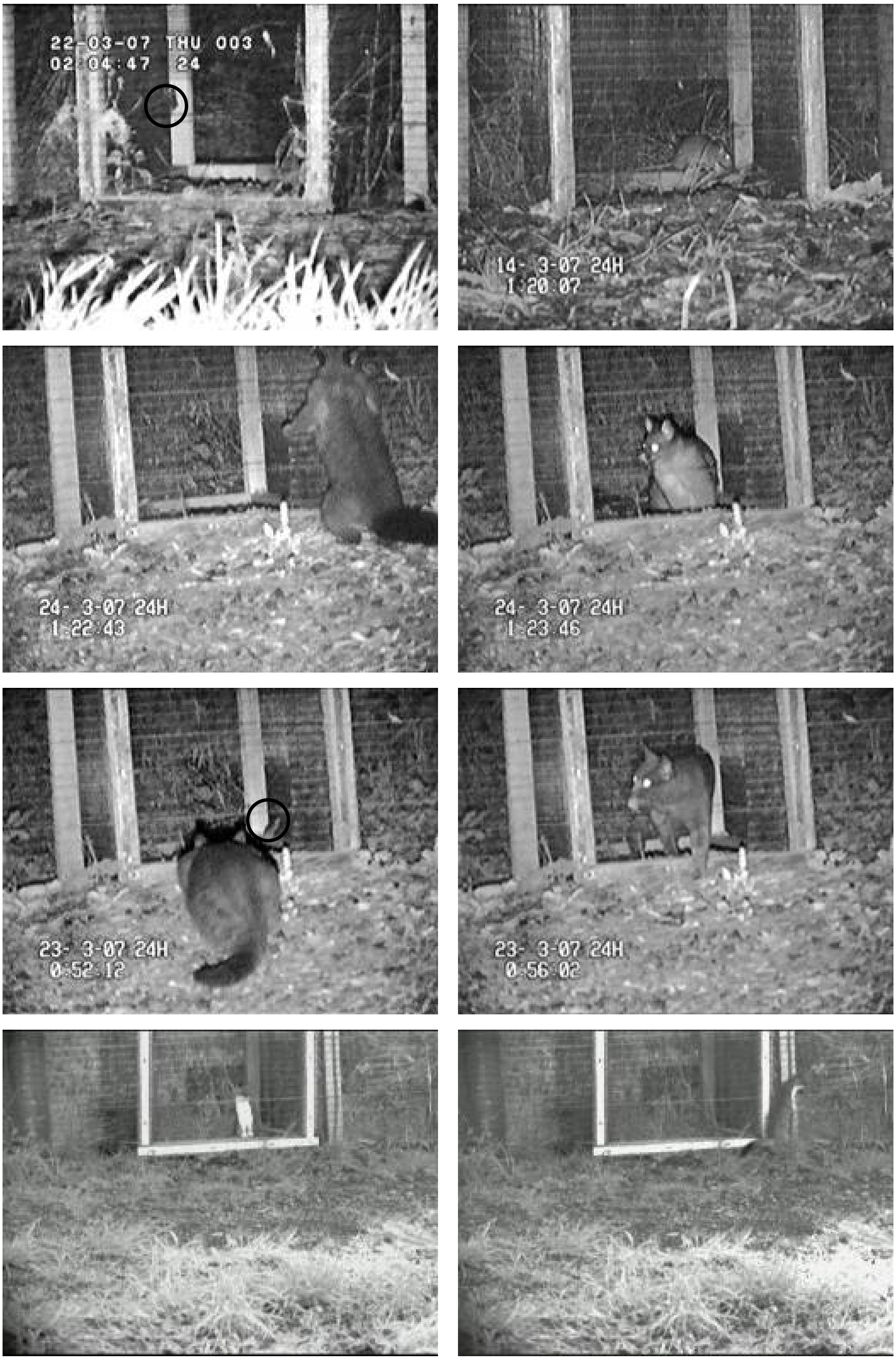


Figure 9. A selection of still images taken from video. Top row: mouse (L, circled), ship rat (R). 2nd row: possum scent-marking the cage (L), before entering (R). 3rd row: mouse (circled) inside cage, with cat closely observing (L), cat then catches the mouse inside cage (R). bottom row: a handsome stoat investigates the cage interior (L), then prepares to climb the mesh (R).

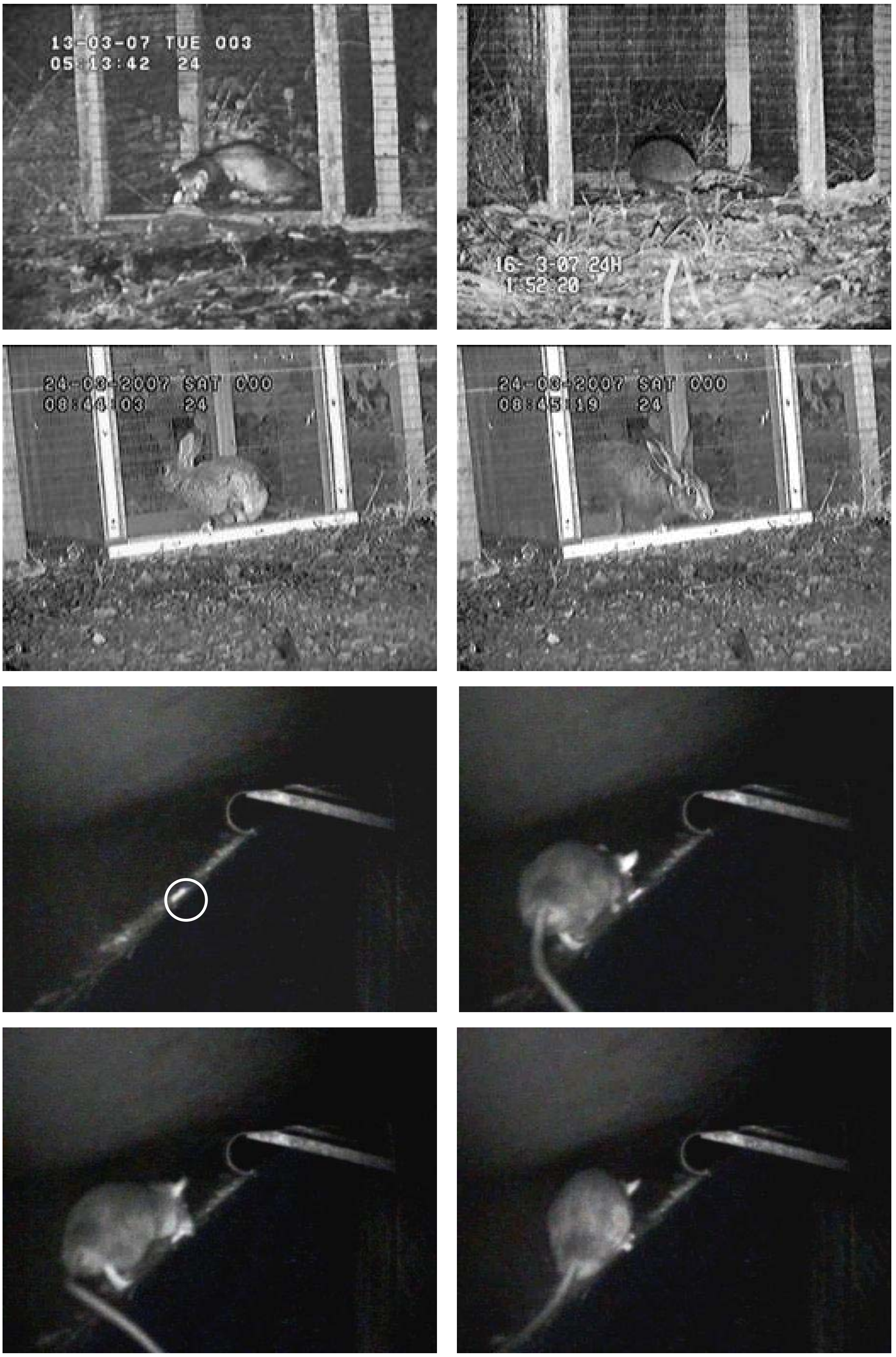


Figure 9 (cont.). More still images. Top row, ferret (L); hedgehog (R). 2nd row, rabbit (L), replaced within a few seconds by a hare (R). 3rd row, moth (L, circled) inside the fence hood gutter, discovered by a ship rat (R). Bottom row, the ship rat catches the moth (L) and eats it (R).

DISCUSSION

Breach Encounters

These results strongly emphasise the need for quick response to a breach in the fence, regardless of season.

Altogether, 95% of summer breaches were encountered by a pest mammal within 24 hours, and pests showed interest in 85% of breaches in the same period. Over 95% of Maungatautari pest mammal activity (excluding lagomorphs) takes place during the hours of darkness (see Chapter 2), and these results indicate that exploitation of summer breaches by multiple individuals of multiple pest species is highly likely on the first night even though summer nights were short (~10 hours) when filming was done. Not unexpectedly, summer breaches are likely to be encountered and exploited by increasing numbers of species (and possibly increasing numbers of individuals) over the course of a week.

The high rate of pest encounters with winter breaches (92.5%) suggests that a winter breach is almost as likely to be encountered within 24 hours as a summer breach. Fewer individuals of fewer species may do so, and of those, fewer are likely to exploit the breach, even though they have more time (~13 hours in August). Rates of encounter and exploitation are still high however, and exploitation on the first night is still very likely. Again, over the course of a week, increasing numbers of species and individuals are likely to encounter and possibly exploit a breach.

The physical nature of the simulated breaches is likely to have influenced the entry behaviour of larger species such as cats and possums in particular. If individuals of these species were able to perceive the experimental breach as being 'no-exit', they may have been more reluctant to enter the cages. In contrast, mustelids showed no reluctance to enter, even if they perceived the cages as being fully enclosed. As they have evolved to hunt in confined spaces such as rabbit and rat burrows it is possible these species may be more likely to enter a confined space than cats or possums.

No valid comparison can be made between these data and those reported by Speedy et al (2007), who found that only 8% of 50 artificial breaches had been exploited within 24 hours. At the time Speedy et al (2007) conducted their study, the fence had yet to be completed, and eradication of pests within the reserve had not yet been undertaken. Pests presumably still maintained territories directly inside the fence, which were detectable by animals outside the reserve. Many individuals may therefore have been deterred from attempting to invade another territory. More significantly, the methods used were different; Speedy et al (2007) used ink tracking-cards rather than video, and simulated both holes in the fence (not backed with cages) and realistic ramps. Further, the holes in the fence were too small to comfortably allow the passage of possums or cats, so these species were not effectively monitored.

Pest Behaviour at Breaches

The proportion of breaches *entered* by a pest within the first 24 hours (72.5% of breaches in the summer, 27.5% in the winter) was very high. Rodents, and in particular mice, were by far the most likely mammals to encounter and exploit a fence breach in either season. In the summer, mice were almost certain to both encounter and enter a breach on any given night. Winter mouse encounters were significantly fewer, and mice were also less likely to enter a breach when seen, but mice still accounted for 22.4% of winter breach entries. No mice were seen within the fence hood.

Although summer ship rat encounters and entries were fewer than for mice in this study, levels were still high. The short fence hood study in the summer of 2007/08 also suggests that the ground-level breach encounter results massively under-represent total ship rat activity along the fence, and thus also the potential for ship rat invasion to the reserve. The hood itself represents just one of a range of micro-habitats at the fenceline. It seems unlikely that the fence hood habitat contributes significantly to any increase (or decrease) in the ship rat population at the fenceline; however, particularly during large tree-fall events, it is possible that the fence hood gutter may lead ship rats that are active within the hood directly to the point of breach, where fence integrity has been compromised. Ship rats were significantly more likely to enter a simulated tree-fall breach in this study. At these sites, ship rats were often observed to move along the ground parallel to the fence, until they came across the branch laid perpendicular to the breach, whereupon they would walk along the top of the branch into the breach. The possibility of much higher ship rat activity within the favourable hood gutter, together with their arboreal tendencies (Hooker & Innes 1995), suggests that ship rats may potentially find and exploit a tree-fall breach more quickly, and possibly in greater numbers, than any other species. More extensive research into ship rat abundance, movements and behaviour at the fence is strongly recommended.

Possums entered simulated breaches on relatively few occasions, in either season. However, they showed interest in a breach in approximately 40% of sightings. On the 'interest' occasions where they didn't enter, the possums usually approached the hole, peered through, and either moved on or scent marked the hole surrounds. Possums are well-known to scent mark trees by rubbing the trunk with a gland, often the chin or the sternal gland (Biggins 1984). One reason they may have been reluctant to enter the breach is that they were deterred by the presence and/or size of the cage, in the same way some animals are reluctant to enter traps; had the cages been far larger (or absent entirely), possums may have perceived the breach differently, and entered more often. They may also have been able to perceive the infra-red lighting used by the cameras. Vanstone (2006) found that some possums were capable of detecting infra-red light at 870nm wavelength, and it is possible that at least some of the Maungatautari possums were deterred by the pool of light trained on the breach. Conversely, it is possible that infra-red light may have attracted possums. Regardless, in a high proportion of sightings, possums displayed awareness of and interest in simulated breaches. This result should possibly be considered as conservative: it is not possible to tell whether possums that showed no interest at all had a) failed to perceive the breach, or b) perceived it, but have chosen to ignore it.. Further research is recommended to assess whether possums would be more likely to show interest in or enter a breach if there were no cage on the other side of the fence.

Similarly, cats rarely entered simulated breaches, but often showed interest. Overall, cats behaved in a similar way to possums towards a breach, in that where interest was shown (but no entry), cats would approach the breach, sniff the surrounds, and occasionally urinate on the cage entry. On two occasions cats approached a breach, stopped directly in front of it and then lay down for more than 15 minutes, seeming to show no interest in the breach. Cats entered breaches only where a) they detected prey within the cage itself (e.g. mice, on 2 occasions) or b) they detected prey (ducklings) on the other side of the fence, next to a simulated breach. Ducklings (both paradise ducks, *Tadorna variegata* and mallards, *Anas platyrhynchos*), and young pheasants (*Phasianus colchicus*) were commonly seen on the inside of the fence, often separated from their parents by the fence itself. One cat was seen to attempt to catch an adult duck on the outside, and when unsuccessful, tried to dig under the fence to catch the duckings; after this, the cat entered the cage and remained within for more than 30 minutes, intent on the ducklings that were only a few centimetres away. A different cat on the outside of the fence was also seen chasing a duckling along the inside of the mesh.

Again, for those cats that showed no interest, it is impossible to know whether they a) failed to perceive the breach, or b) perceived it, but chose to ignore it, or were actually deterred by it. It seems likely that cats were able to perceive the cages as being fully enclosed beyond the hole in the mesh, and were reluctant to enter because of this (except where prey was inside). Cats were also observed to turn their heads as they walked past, and look directly at the camera and infra-red lighting unit. It is likely that they could perceive the dull-red glow of the infra-red diodes (visible to humans also). It may also be possible that they can perceive infra-red light around 870NM wavelength, as can some possums (Vanstone 2006) and some ferrets (Newbold 2007), but this is unknown. Regardless, an alarming number of overall cat sightings and individual cats were recorded in this study, along with a moderate level of interest in breaches. Video footage has shown their willingness to enter simulated breaches where prey is sighted on the inside of the breach, and multiple individuals have been seen 'patrolling' laterally along the fenceline itself. This wide-ranging hunting behaviour directly at the fenceline is highly likely to lead to coincidental discovery of breach events by cats. Whether feral or not, cats are of concern to reserve managers, and further research is recommended on their movements and behaviour at Maungatautari; particular focus should be on behaviour at breaches (particularly tree-fall), and behaviour once a breach has been exploited.

Hedgehogs showed a similar level of breach interest to possums and cats, and were more likely to enter, particularly in the summer. The greater interest in simulated 'flood-scour' breaches is likely to be due to the absence of a branch being laid across the road at these sites. Hedgehogs were seen to struggle to climb across the branches, and often opted to walk around the branch, on the opposite side of the road to the fence. This may mean that there is less potential for invasion in the event of a tree-fall, although they are considered excellent climbers (Jones & Sanders 2005). Hedgehogs are possibly of less concern to reserve managers than other species, but they are commonly seen at Maungatautari, and are certainly willing to enter simulated breaches.

Stoat and ferret sightings were rare in either season, particularly winter. All of those that were seen at least showed interest in a breach, and all except one ferret entered. This is of no surprise, as stoats and particularly ferrets hunt very actively down holes (Moors 1983; Robson 1993). However, a higher number of mustelid sightings might have been expected, because 1) mustelids are known to spend much time following linear habitat features (Alterio et al. 1998; King et al. 1996; Murphy & Dowding 1994); 2) the summer study took place over the period of juvenile dispersal for stoats and ferrets (Byrom 2002; King & Murphy 2005); and 3) high numbers of sightings of prey species (rodents, possums and lagomorphs) were recorded. Mustelids are often sighted at the fenceline (T. Day pers. comm.), and despite the low numbers recorded on video, this study has shown that when seen they are very capable of locating and exploiting a breach. Research into the movements and behaviour of mustelids in relation to the fence is strongly recommended.

Conclusion

Fences act to channel the movements of wild animals in predictable directions. This study has confirmed, and in greater detail, preliminary observations showing that fence breaches are almost certain to be encountered by at least one and possibly more than one pest mammal within the first 24 hours in either season. Once encountered, exploitation is highly likely, particularly in summer. If left open for 7 days, breaches are encountered and exploited by increasing numbers of pests. Rodents are likely to be the first to encounter and enter a breach at ground level in both summer and winter; ship rats encounter and enter ground-level breaches at a rate only slightly lower than that of mice, but rat activity within the fence hood is probably much greater than on the ground, so it is very likely that ship rats present a much greater threat of invasion than these results suggest. Further monitoring in other seasons could well show that, for every rat approaching the fence at ground level, there could be several more in the hood. Possums, cats and hedgehogs all show interest in and enter fence breaches, at a lower rate than rodents; cats will readily follow prey into a breach, and mustelids, though rarely seen, will always at least show interest in a fence breach.

For all these reasons, response to a breach should be made as quickly as possible, especially at night in any season, and especially in the summer. Further research is strongly recommended on the abundance and movements of ship rats, possums, cats and mustelids in relation to the fenceline; and for these same species, more rigorous investigation into their behaviour (both on discovery of breaches, and after invasion) is also strongly recommended.

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CHAPTER 4

General Discussion

PRIMARY AIMS

The purpose of this thesis was to provide baseline data for future studies and to assess the potential for reinvasion by pest mammals through the pest-proof fence at the Maungatautari Ecological Island. Two seasonal studies were undertaken in order to: (1) describe baseline data on the periods of pest activity and behaviour of mammalian pests directly adjacent to the pest-proof fence; (2) test for the effects of exterior habitat type, breach type and season on mammalian pest sightings directly at the fence; (3) determine how quickly pest mammals may locate a fence breach, and how likely they are to exploit it; and (4) develop a predictive model that may be used to help assess the probability of a pest encountering a breach if response to a fence breach is delayed.

STUDY FINDINGS

This study confirms and emphasises the constant threat that the pest-proof fence faces from mammalian pests. Pests are very common directly outside the fence, and within 24 hours there is a very high likelihood that a fence breach will be located and exploited, possibly by multiple pest mammals. Not unexpectedly, the greatest threat of re-invasion comes a) nocturnally, b) from rodents, and c) in the summer; however, these results also confirm that there is constant risk from multiple pest species, regardless of time of day or season.

The results complement and expand on the findings of Speedy et al. (2007), who found that mice, rats, hedgehogs and rabbits made use of holes at the base of the fence, while mice, rats, possums and cats made use of artificial ramps.

Although no ramps were used in this study, these and other species were consistently present at the fence base, and their willingness to exploit fence holes (particularly for mice and rats) was confirmed. This study has provided significant new detail about the timing of pest sightings at the fence, and how quickly these animals might locate and exploit a breach.

This study may have underestimated the actual likelihood of pest encounter and breach exploitation due to methodological limitations. The video cameras could not record the presence of any animals out of view (e.g. behind the cameras), and it is highly probable that many more pest animals are active very near to the fence roadway than the cameras recorded. Ship rat activity within the fence hood was not filmed simultaneously with the fence base in the two seasonal studies, and overall activity is likely to have been much higher than fence base observations suggested. Also, mustelids were rarely sighted on video, but are commonly sighted in the vicinity of the fence; it is likely that mustelids were present at the time of the study, but perhaps did not routinely move along the base of the fence. When sighted they always located holes, and showed little hesitation in entering. The actual threat of breach encounter and exploitation by mustelids is therefore potentially higher than that found in this study, both nocturnally (by ferrets) and diurnally (by stoats and weasels).

Cat activity was very high along the fence, and this is also of concern. Individual cats regularly moved and on occasions were observed hunting along the fenceline. Cats often showed interest in a breach, especially if given a chance to follow prey through a hole in the mesh. It is possible that some of the cats seen were domestic or farm cats, but this is unknown; either can be just as damaging to wildlife. Regardless, it is highly likely that a fence breach will be encountered by a cat within 24 hours, particularly between dusk and dawn. Whether it will enter may depend on the physical nature of the breach itself; however this study confirms that they are willing and able to do so at ground level.

Invasion Behaviour

It is one thing to determine how likely a pest mammal is to discover a fence breach and enter the reserve; it is something else to determine whether the invader will stay once inside the protected area. When Speedy et al. (2007) experimentally released six male ship rats into the 65 ha pest-free southern exclosure at the Maungatautari Ecological Island by, four had climbed back out within a week. The Xcluder™ exclusion fence in this case was designed to prevent entry, but not exit, of animals from the reserve. This self-exporting behaviour was to some extent unexpected: the environment within the exclosure might have been considered ideal for an invading ship rat, with a plentiful food supply and no competitors for food resources or territories. However, the absence of conspecifics, and the close proximity of their original home range, probably enticed them to leave. It is unknown whether the same behaviour could be expected of an invasion propagule consisting of e.g. multiple ship rats, dispersing juveniles or a single pregnant female. Mice have been seen to be reluctant to jump between Xcluder's™ fence hood brackets (at the top of the fence), and the fence hood gutter, some 150mm away (T. Day pers. comm.). It seems unlikely that mice which have entered the reserve, and become 'cut off' by the fence being repaired, would be willing to jump from the top of the fence to the ground (a vertical drop of 2m), to exit the exclosure. The potential invasion behaviour of other pest species is unknown and was beyond the scope of this study. However the results confirm that all of the species sighted are capable of locating and willing to enter a fence breach. In the absence of further knowledge on invasion behaviour for the mammalian pest species seen at Maungatautari, it seems reasonable to suggest that for all pests (with the possible exception of individual male ship rats), the worst case invasion risk scenario should be assumed: that is, when pest mammals find and enter a breach, they will stay within the reserve.

IMPLICATIONS OF RE-INVASION

Rodents

Mice were the species most likely to enter a breach when seen in the summer, and though seen less in the winter, were still very likely to enter. The mouse diet is highly flexible, and includes small invertebrates (particularly Lepidopteran larvae and adult Coleopterans) and plant material (mostly seeds, including rimu (*Dacrydium cupressinum*)) (Beveridge 1964; Ruscoe & Murphy 2005). A single pregnant female mouse is capable of re-colonising the reserve. The direct effects of an individual mouse or a small number of mice may not in themselves be cause for great concern in a protected reserve; the greatest threat posed by mice (and also rats) lies in their ability to rapidly increase in population size. Non-commensal mice do not normally breed in winter, except in mast-seeding years in beech forests (Ruscoe et al. 2003). In the presence of a potentially vast food supply and no predators, winter breeding may be possible at Maungatautari and could result in a significant mouse population increase. If uncontrolled, this may in turn affect the composition of plant communities within the reserve, by preferential seed predation (e.g. of rimu seed), and/or the composition of the invertebrate community, where large litter-dwelling species are particularly vulnerable (Ruscoe & Murphy 2005). It is unknown what the true population potential for mice is at Maungatautari in the absence of any other mammaliam species, but mice are known to reach plague proportions rapidly when environmental conditions allow it (Boonstra & Redhead 1994; Choquenot & Ruscoe 2000). In a plague situation, ecological damage could happen on a massive scale at Maungatautari. Ultimately, a large population of mice could also potentially sustain any invading predators, such as stoats (King 2002) and cats (Fitzgerald & Karl 1979).

Ship rats are likely to offer a similar or even greater threat of invasion than mice, because of their high activity within the fence hood. It is possible that a breach may be entered by a single rat only; however, as with mice, a single pregnant female is sufficient to re-colonise the reserve. It is possible that multiple rats may enter (e.g. if they were nesting in a tree that fell over the fence from the *outside* of the reserve, or if they were moving within the fence hood). Multiple individuals would be capable of establishing a population at a much faster rate than an individual; particularly if both genders were represented in the group. The ship rat diet is omnivorous, and they are known to be significant predators of vegetation, invertebrates and birds (Innes & Barker 1999). Rat densities are known to fluctuate according to food supply (Daniel 1978), and an invading rat population is likely to increase rapidly depending on season. In the event of re-colonisation, many indigenous bird populations are likely to suffer greatly; the effects of ship rat predation on species such as kokako (*Callaeas cinerea wilsoni*) and native pigeon (*Hemiphaga novaeseelandiae*) are well documented (Innes et al. 1994; Innes et al. 1999; Innes et al. 2004). Again, a rat population could also provide a staple food source for stoats, ferrets and cats.

In the event of fence damage that may have allowed pest invasion, the standard MEIT response within the reserve is to deploy a 50 metre by 50 metre network of tracking tunnels containing ink-cards, peanut butter, rabbit meat and Pestoff® 20R brodifacoum pellets to a radius of 200m from the point of breach (Speedy & de Monchy 2008). The ink cards are checked daily for three days, then every three days for the next 10 days (P. de Monchy pers. comm.). Using this system, mice and ship rats have been detected within the reserve after 3 serious breach events (2 tree falls and one flood scouring event), although it is impossible to guarantee whether the detected individuals were survivors or invaders. Low numbers of invading rats are difficult to detect using ink-cards and subsequently kill using toxic baits, because of abundant alternative foods in a no-pest environment, and the rats' atypical behaviour (Thorsen et al. 2000; Russell et al. 2005; Speedy et al. 2007). This difficulty may increase as ecological recovery of the mountain progresses, and food resources within the reserve become more prolific and are more favourable as food sources than any available poison baiting technology.

Hedgehogs and Possums

The effects of invading hedgehogs and possums are also undesirable. Insectivorous hedgehogs consume mostly invertebrates, but also lizards, frogs and the eggs of ground-nesting birds (Jones & Sanders 2005). Hedgehog populations do not increase as rapidly as those of rodents, although once again, conditions inside the reserve are likely to be optimal for hedgehog reproduction, depending on the time of year. Similarly, possums are known to prey on bird eggs and chicks (Brown et al. 1993; Brown et al. 1998), compete for food resources with species such as kokako (Leathwick et al. 1983), and significantly affect vegetation through browsing (Cunningham 1979). When colonising new areas, possum populations tend to increase slowly but steadily, reach a peak, and then rapidly decline to stable levels (Pekelharing & Reynolds 1983). However, because of their slow rate of population increase (by comparison to rodents), possum incursion probably poses a less urgent threat to the reserve.

In the event of a breach, both hedgehogs and possums may be attracted to the peanut butter attractant deployed inside the standard tracking tunnels. Possums are probably more difficult to detect as their size usually excludes them from the tunnels, and again, both species are likely to become more difficult to detect as ecological recovery progresses, and food supplies increase. Possums are capable of climbing to the top of the fence and exiting exclosures and have been observed to do so at Maungatautari (T. Day unpubl. data); whether invading possums would emulate Speedy et al's (2007) ship rats in doing this routinely is unknown. As hedgehogs cannot readily climb to the top of fences (T. Day unpubl. data), they are unlikely to exit once fence integrity has been restored.

Lagomorphs

Lagomorphs are less likely to cause serious ecological problems if they re-invade. Both rabbits and hares occupy open country; rabbits in particular prefer grazed grassland, and densities are low in wet areas (Gibb et al. 1978; Norbury & Flux 2005; Norbury & Reddiex 2005). Rabbits feed largely on grasses, as do hares, which may also eat shrubs and tussocks in the winter (Norbury & Flux 2005;

Norbury & Reddiex 2005). What little suitable habitat exists within the reserve is limited to the very edge, directly inside the fence.

Monitoring for lagomorph presence is not specifically carried out at Maungatautari, although where sighted, MEIT makes use of Pindone, a first-generation anticoagulant poison, and shooting. A well-established rabbit population could potentially support invading predators, and although their eradication is not a high priority in relation to other species (e.g. mice), removal is still recommended.

Predators

The re-invasion of cats is a more serious prospect. Where rodents and rabbits are common, they form the staple diet of cats, with birds being only a small proportion of their diet (Gillies & Fitzgerald 2005). However, on New Zealand's offshore islands, cats have clearly been responsible for, or at least accelerated, the local extinction of many indigenous bird species (e.g. saddleback, *Philesturnus carunculatus*; Cook's petrel, *Pterodroma cookii*; yellow-crowned kakariki, *Cyanoramphus auriceps*; and New Zealand snipe, *Coenocorypha aucklandica* (Fitzgerald & Veitch 1985; Imber et al. 1987; Veitch 2001)). Cats have also been significant predators of kakapo (Karl & Best 1982), bats (both long-tailed, *Chalinolobus tuberculatus* and Lesser short-tailed, *Mystacina tuberculata*) (Daniel & Williams 1984) and lizards, particularly skinks (Gillies & Fitzgerald 2005). Cats are also capable of kiwi predation (Gillies et al. 2003). Once any of these highly vulnerable indigenous species have been re-introduced to Maungatautari, a cat incursion could have serious implications. Even if the impact of predation by an invading cat did not have a population-level effect, predation of even a single reintroduced individual of an iconic species (e.g. takahe, kakapo or kiwi) could be devastating.

A single pregnant female cat is capable of founding a population within the reserve. Whether an invading cat would remain once inside the reserve is debatable. The proximity to a known landscape and the presence of staple prey species immediately outside the fence would suggest they might quickly export themselves; cats are physically capable of exiting out of fences such as the Xcluder™ fence at Maungatautari at will (T. Day pers. comm.). On the other hand, an avian paradise within the reserve, including (eventually) large numbers of big, flightless birds such as kiwi and kakapo, may encourage them to stay (at least in the short term). If a pregnant female (or one with young kittens, as was seen patrolling the fence in the summer study) entered the reserve, behaviour may be different again to that of a solitary male. In the immediate aftermath of a breach event, the placing of rabbit meat in tracking tunnels is likely to result in cat detection, but cat removal may be difficult and time-consuming. The longer a cat remains within the reserve, the greater the potential for ecological damage.

Similarly, mustelids greatly threaten indigenous fauna, although again, lagomorphs and rodents are their staple food species. Both ferrets and stoats are major predators of ground-dwelling species such as kiwi (*Apteryx* spp.) (McLennan et al. 1996; King & Murphy 2005). Stoats, being excellent climbers, have also contributed to the extinction of some species (e.g. South Island kokako, *Callaeas c. cinerea*, and South Island saddleback, *Philesturnus c. carunculatus*), and to the decline of others (e.g. kakapo; takahe, *Poryphyrio mantelli hochstetteri*; and kaka, *Nestor meridionalis*) (King & Murphy 2005). In the context of a fenced reserve that will contain populations of endangered species such as kakapo, the feeding behaviour of stoats is a cause for concern. Where the opportunity arises, stoats are known to kill as many prey as possible, and cache the surplus (Oksanen et al. 1985), although this behaviour is likely to be stimulated only where prey is congregated, e.g. at a nest full of chicks. Whether a stoat would remain inside the reserve after invading is again unknown, but potentially, a single female is sufficient to re-colonise Maungatautari: modelling suggests that left unchecked, the resulting population may number 50 individuals within 3 ½ years, and after 4 ½ years, 100 individuals (Choquenot et al. 2001). Young females are mated before leaving the natal den, and females are almost always carrying either blastocysts or embryos, depending on season (King & Murphy 2005). Individual stoats, particularly pregnant females, are notoriously difficult to detect and catch, and learn to be extremely wary of traps and tracking tunnels (King & Moody 1982; Crouchley 1984). The use of rabbit meat and fenn traps post-breach may result in detection and destruction of an invading stoat; but if an invader is not immediately detected, the ecological results could be catastrophic, and removal of the stoat may be extremely difficult. Although mustelids are far less abundant than other species at the fenceline, they have the potential to cause major ecological damage within the reserve in a short space of time, and must be prevented from entering if at all possible.

RECOMMENDATIONS

Breach Response

This study has confirmed that a) pest mammals are very common directly outside the fence; b) multiple pest mammals are almost certain to encounter a fence breach within 24 hours; c) when pests encounter a breach, they are very likely to show interest and enter; d) the greatest threats of re-invasion come nocturnally, from rodents, and in the summer; and e) after a breach happens, there is *always a risk* of pest exploitation, and that risk is *always increasing* with every minute that response is delayed.

Despite the apparent risks, the practical experiences of the MEIT show that pest invasion can be managed effectively when rapid response is employed, following standard operating procedures suggested in the MEIT Breach Response Plan (Speedy & de Monchy 2008). At least 12 significant risk events (1 x vehicle gate open, 1 x water gate jammed open, 10 x tree falls) were recorded over the initial three year period from establishment of the 47km of Xcluder^{TM} fence. (T. Day unpublished data, P. de Monchy pers. comm.). These risk events resulted in three recorded invasions: two events each resulting in a rat detection; one event resulting in a mouse detection. The detected invaders were removed in all three cases (as evidenced by animal capture and subsequent cessation of animal tracking). On all three occasions where invasion resulted, there was a significant time delay (between 6 and 24 hours) between the fence compromise and staff being able to repair the breach. In contrast, rapid response to the other nine breaches resulted in no detected animal invasions (Day & MacGibbon 2007). This knowledge has resulted in the MEIT currently attempting to physically respond to any alarm notifications of breaches within 90 minutes (P. de Monchy pers. comm.)

The establishment of a pest control ‘buffer zone’ around the fenceline has been suggested to reduce pest numbers in the vicinity of the fence, and thus reduce the risk of pests encountering a fence breach. The costs involved in setting up and maintaining such a regime would be high. Many hours of labour would be needed to carry out the programme, and MEIT presence on adjoining landowners’ properties would significantly increase (Speedy 2008). The effectiveness of such a programme in terms of reducing the risk of breach discovery by pests is debatable; indeed, the programme may even have the effect of *increasing* the risk, through the inevitable influx of naïve migrating mammals into the buffer zone, constantly testing the fence as a barrier to movement. A buffer zone cannot guarantee the removal of every pest, and therefore cannot remove the risk, the need for immediate breach response, and the need for effective monitoring following a breach (Speedy 2008). In addition, a buffer programme that relies on the continued use of toxins and traps (tools that would normally be used to manage a pest invasion inside the fence) may significantly reduce the efficacy of those tools due to animal habituation, behaviour or physiological resistance or learned avoidance (Speedy 2008; T. Day pers. comm.).

For these reasons, it is vital that the Trust:

1) continues to use a remote monitoring system that can alert project managers to real-time compromises in fence integrity;
2) continues to physically inspect the integrity of the fence on an ongoing basis to ensure breaches that cannot be detected remotely are found in as shorter timeframe as possible;
3) continues to physically respond to notifications of fence breach as quickly as possible, especially during the hours of darkness;
4) continues to repair fence integrity breaches as soon as practically possible and (because invasion risk is NEVER zero) always implements an invader detection and control regime after a fence breach;
5) acknowledges that a significant delay in response is almost certain to result in multiple pest mammals re-entering the reserve.

Future Research

There is room for a great deal of research on mammalian pests in relation to their behaviour around the pest-proof fence at Maungatautari. I concur with the recommendations of Speedy (2008), and strongly urge that research be continued into the following questions, in order of priority:

1. How do mammals behave once they have re-invaded the reserve? Particular focus should be on the invasion behaviour of ship rats and mustelids (especially stoats); these pose the most significant threats to the reserve. The current study has further confirmed that pest mammals (of many species) will at some point enter the reserve, and knowledge of resulting behaviour is vital. The 'invader' study described by Speedy et al. (2007) should be expanded to all pest species, and many scenarios could be investigated, e.g. multiple individuals, one gender only, both genders, dispersing juveniles, pregnant females etc. Difficulties may arise in ensuring the integrity of the reserve, but the knowledge gained would be immensely valuable for managers, and could allow more efficient and accurate breach response procedures to be developed.

2. What is the behaviour of pest mammals at 'real' fence breaches? Do they enter, or does (e.g.) a large fallen tree deter them? In this study, it is likely that the presence of a cage deterred (or attracted) individuals of some species, e.g. possums and cats; however they commonly showed interest. The behaviour of all species should be investigated at breaches such as large tree-falls, which are physically quite different from those simulated in this study. This question is more difficult and more expensive to answer, and a purpose-built exclosure might be required. Difficulties include the need to duplicate a real event: a captive animal's motivation to *escape* an *en*closure would probably be quite different to that of a non-captive animal that merely had an option to *enter* an *ex*closure.

Less vital research could be carried out to answer the following questions:

3. How far do ship rats range within the fence hood, and will this behaviour channel them directly to a fence breach?

4. How do pest mammals use the fenceline? In particular, do individual cats and mustelids ‘patrol’ the roadway, or are visits intermittent? Is there significantly more mustelid activity directly beyond the road edge?

5. Are cats at the fenceline feral, or domestic? Many farmhouses lie within 1 km of the fence. This may have implications if the MEIT were to implement a ‘buffer’ pest control zone around the fenceline.

SUMMARY

The vision of the Maungatautari Ecological Island Trust is “To remove forever, introduced pests and predators from Maungatautari, and restore to the forest a healthy diversity of indigenous plants and animals not seen in our lifetime” (McQueen 2004). The Trust’s vision depends entirely on maintaining the integrity of the Maungatautari pest-proof fence. This study has confirmed that mammalian pests are consistently present directly outside the Maungatautari pest-proof fence. Fence breaches are highly likely to be encountered by pests within 24 hours, and when encountered, are highly likely to be exploited. Rodents are most likely to enter a fence breach in either summer or winter, but all other species (hedgehogs, possums, rabbits, hares, cats, ferrets and stoats) have been seen to show interest or enter simulated breaches also. While an immediate response appears to be effective for minimising pest invasion risk in practice, a delayed breach response is very likely to result in increasing numbers of pests encountering and entering the breach.

I recommend that the Maungatautari Ecological Island Trust continue to respond to a fence breach as quickly as possible. I strongly suggest that further research should be undertaken on the behaviour of individual pest mammal invaders (particularly ship rats and mustelids) within the reserve, and of all species at actual breach events, particularly at tree-falls. This information is vital to the continuing improvement of breach response procedures, and to the long-term viability of Maungatautari Ecological Island.

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