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Long-term automated monitoring of the distribution of small carnivores

C. M. King[A,B,D], *R. M. McDonald*[A], *R. D. Martin*[A,C], *G. W. Tempero*[A,B] *and S. J. Holmes*[A]

[A]HortResearch, Private Bag 3123, Hamilton, New Zealand.
[B]Department of Biological Sciences, University of Waikato, Private Bag 3105, Hamilton, New Zealand.
[C]Present address: Department of Conservation, Tongariro Taupo Conservancy, Private Bag, Turangi, New Zealand.
[D]Corresponding author. Email: cmking@waikato.ac.nz

Abstract. A new automated monitoring device for small carnivores, the Scentinel®, is a 'smart' tracking tunnel. It records time, date, weight and a digital photograph of every animal visiting it, and stores the data to be downloaded on command. This paper describes a field trial aiming, first, to verify the Scentinel's species identifications against those given by footprint tracking papers, and then to compare the efficacy of routine monitoring with the Scentinel against standard tunnel tracking methods. In February–April 2005 we identified to species 98% of 1559 visiting animals, mainly hedgehogs (*Erinaceus europaeus*), ferrets (*Mustela furo*), cats (*Felis catus*) and rats (*Rattus rattus* and *R. norvegicus*) in 1718 Scentinel-nights. In May–June 2005 we set up three monitoring lines 1 km apart, each with 10 tracking tunnels and two Scentinels. We recorded 656 visits by ship rats (*Rattus rattus*), 88% of them on only one of the three lines, in 198 Scentinel-nights (over 5 weeks). The 30 footprint tracking tunnels set intermittently (360 trap-nights) recorded high (70–100%) tracking rates on all lines. The presence of a stoat (*Mustela erminea*) was detected by both methods, but earlier by Scentinels than by tracking tunnels. These results confirm that it is possible to use automated devices to record detailed monitoring data on small carnivores in remote areas over long periods, unaffected by interference or bait loss from common non-target species.

Introduction

Small mammals (<2 kg) are too inconspicuous and secretive in their habits to observe directly. They are sparse and mobile in both space and time, so standard live-trapping techniques requiring daily visits can be carried out only intermittently (Flowerdew *et al*. 2004). Neophobia, trap avoidance and resistance to recapture (or trap addiction) are common distortions of the normal behaviour of animals in a population exposed to baited traps (Hammond and Anthony 2006). Monitoring efficiency is often compromised if common non-target species block traps or remove bait intended for less common target species.

Other conventional methods of monitoring small mammals using pitfalls or by radio-tracking are also labour-intensive, so can be operated only for short periods at a time (Fitzgerald and Karl 1979; Innes *et al*. 1995; Alterio and Moller 1997). Therefore, few field methods suitable for small mammals meet all the criteria for a desirable index of abundance (practical, sensitive, precise, robust, multispecies-capable and location-specific) listed by Engeman (2005).

Various methods of distinguishing footprints have been developed, reviewed for stoats (*Mustela erminea*) by Jones *et al*. (2004), but these are too labour-intensive to be applied continuously over an extended period. The recent development of hair tubes is encouraging, because they can sample animals for individual or species identification without restraining them, but the identification of hairs and/or of DNA sequences in hair follicles requires skilled staff and specialised equipment, and sampling is best limited to a single animal per tunnel, each sample collected manually (Horton *et al*. 2005). Existing camera traps are expensive and demanding to operate over long (>1 month) periods, and few of them are suitable for small target species (Claridge *et al*. 2004; Silver *et al*. 2004). Hence, high labour and equipment costs make continuous long-term surveys of small mammals impractical, but surveys covering shorter periods represent an undefined sample of the real distribution, numbers and activities of the species observed.

All of these problems are especially acute for species that are both small and rare, especially if they are also active, intelligent, wide-ranging predators with flexible hunting behaviour and unstable populations (Alterio *et al*. 1999). All small carnivores, such as the Holarctic mustelids and the Australian dasyurids, fit this description. Yet extensive and/or long-term monitoring of small carnivores is often urgently needed, both for keeping track of the distribution and numbers of native species, and for locating, guiding and auditing control operations against alien species.

Virtually the only feasible method of long-term monitoring applicable to mustelids at the landscape scale is the use of kill-trap records collected from regular culling operations in national parks or game estates, suitably corrected for trapping effort (King 1983; McDonald and Harris 1999). This method can be very informative when well controlled and applied con-

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sistently over many years (Tapper 1999), and also produces information from carcasses not available from live animals (such as details of reproductive condition and age); however, like all removal sampling systems, it reduces natural longevity in the target population (King *et al*. 1996). Monitoring of protected native small carnivores, such as all Australian marsupials and some European mustelids, can often be done only by indirect means such as collecting roadkills (Sleeman 1988), by live trapping, or by indexing (Engeman 2005).

Monitoring of intelligent and wary carnivores presents special problems. For example, monitoring data on most carnivores are often hard to interpret without simultaneous data on their prey, but few truly multispecies techniques are available. Carnivores often demonstrate great behavioural flexibilty, and an ability to learn from individual experience combined with suspicion of unfamiliar baits and devices placed in familiar places. Some individuals known to be present will not enter a trap or tunnel at all during a short period of observation (King and McMillan 1982; Dilks and Lawrence 2000); breeding females are especially wary, and can avoid traps placed right outside their den (Murphy and Dowding 1995).

Effective monitoring of elusive small carnivores also depends on a high visitation rate by the target species. Scent lures, preferably based on natural secretions from the anal glands of the target species, are traditionally considered important. They can improve visitation rates by stoats (Clapperton *et al*. 1999) and ferrets (Spurr *et al*. 2004), but supplies of natural anal gland material are limited.

We describe here a potential new tool for monitoring of multiple species over large areas. The Scentinel® is an automated monitoring device using a 'smart' bait dispenser and a scent lure, designed to operate for long periods unattended (Technology Transfer Ltd, Wellington, New Zealand: www.scentinel.co.nz). This paper describes one of a series of a field trials designed to test the use of Scentinel technology for large-scale, labour-efficient surveys of small mammal species.

Our overall objectives were (1) to conduct a proof-of-concept test of the technical performance and reliability of the Scentinel in detecting the presence or absence of small mammals in field conditions; and (2) to make a preliminary comparison of the ability of the Scentinel to detect the local distribution of rodents and mustelids in forest, compared with standard tracking tunnels.

Methods

Construction of the Scentinel

The Scentinel comprises a set of modular parts including: (1) a simple tunnel, (2) a metal weighbridge in the tunnel floor, (3) two aerosol cans containing fresh, soft semiliquid bait, (4) a small digital camera, and (5) an electronics package controlling both the camera and the bait-delivery mechanism (Fig. 1). The size and configuration of the Scentinel's component parts (e.g. the diameter of the tunnel entrance and positions of the bait cans), and the programming of its electronics, can be varied to suit the aims of the survey and the target species.

The weighing system is programmed to ignore non-target animals under a specified trigger weight, in order to prevent false alerts caused by wind, rain or debris. Once triggered, the Scentinel responds differently to species of different weight, and then automatically resets itself. This flexibility is possible because the weighbridge can be programmed to respond in different ways to a series of user-defined threshold weights, typically (1) *alert* (the minimum needed to trigger any response), (2) *record only* (a series of weight measurements taken, with or without a photograph), and (3) *bait delivery*.

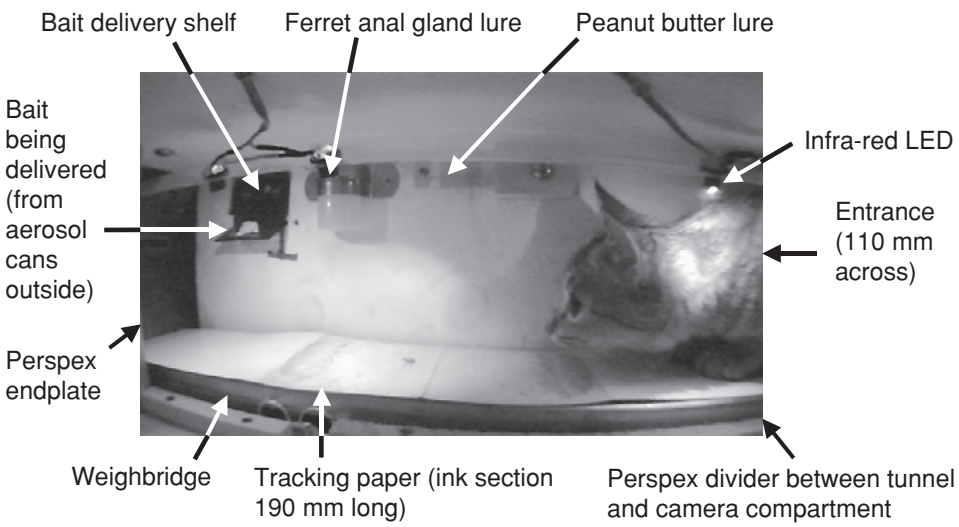

Fig. 1. The camera's eye view of the interior of the Scentinel® tunnel, showing the relationships between the working parts. In this prototype (Mk 5) the camera was in a separate side compartment, and the electronics package plus two aerosol cans holding bait were on the roof. The first aerosol can delivered 'taster' or lure bait, accessible outside. Some also dribbled inside, through a slot in the endplate at left. If an animal exceeding 400 g in weight entered the tunnel, through the hole at right, it was detected by the weighbridge in the floor. Then the second can delivered bait onto the shelf at left, which could be seen by the camera under IR flash illumination as a white mark against the black background.

The bait is held in two sealed, sterilised aerosol cans, and can stay in fresh condition for years (R. McDonald, unpublished data). It can be based on any smooth, semiliquid material attractive to the target animals. The egg-based mixture used in our trials (see below) so far has been attractive to most species.

One bait can, controlled by a timer, dribbles a 'taster' lure, a small sample (typically 1 g) of fresh bait, down the outside of the tunnel, renewed daily. Some of this lure runs through a slot in the tunnel wall into a tray inside, where a visiting animal can see and smell it, but cannot reach it except by entering the tunnel. The scent of the taster lure is attractive in itself, and also encourages visitors to recognise the bait delivered by Scentinels as potential food, and to try it before deciding whether to venture inside. Bait from the other can, which may be different in quantity, formulation or additives, is delivered only to animals of a specified size, standing on the weighbridge inside the tunnel.

The camera has a fish-eye lens with a broad view of the weighbridge, and the 170° distortion of the images can be simply corrected using standard image-editing software, if required. As soon as any weight exceeding the trigger threshold touches the end of the weighbridge, the camera takes a series of infrared-illuminated pictures in quick succession (e.g. after 2, 8, 15 s), which will usually show an animal in the tunnel. After a suitable interval, e.g. 20–60 min, a fourth picture records whether the bait has been eaten, and the Scentinel resets itself ready for the next event. The number and timing of all these events are programmable. The delayed reset discourages individual animals from taking multiple doses of the internal bait. This effect can also be minimised by programming the Scentinel to be active only at appropriate intervals, from days to months apart.

Proof of concept and reliability of species identification

For the first stage of the trial, we worked on farmland near Waotu, in the central North Island of New Zealand (38°09′S, 175°41′E). Almost all the land is privately owned, improved pasture grazed by beef and dairy cattle and some sheep, with scattered patches of remnant native forest. In early February 2005 we marked out a grid of 24 squares of 100 ha each, in a block measuring 3 km by 8 km (authors' unpublished data). The western boundary of the block was defined by Lake Arapuni, part of the Waikato River; the southern and eastern boundaries bordered a large plantation forest (*Pinus radiata*). Between 11 and 13 February we set out one Scentinel within each block, placing them in patches of cover likely to be favoured by ferrets. Considerable local variation in topography and access meant that the 24 sites averaged 1.19 km apart (range 0.72–1.64 km). All the Scentinels operated continuously and were visited once a week, until they were withdrawn on 29 April 2005.

At this stage of the trial, the dimensions of the tunnel were 600 mm long, 110 mm wide and 175 mm high; the trigger threshold was set at 50 g and the bait threshold at 400 g. Both bait cans contained the same bait, a creamy mixture of egg and flax-seed oil. The outside can delivered one bait every 24 h, and the inside can delivered bait when triggered, with a reset delay of 20 min. To maximise the number of opportunities to test the Scentinel's reaction to different-sized animals, we added both anal gland lures (following Spurr *et al*. 2004) and peanut butter, the standard lure for rodents (Fig. 1). The use of multiple lures and attractive, non-toxic baits permitted repeat visits by the same few individuals, but increased the sample size for our test of the Scentinel's reliability (the number of cycles of triggering and resetting of the mechanism).

All visitors weighing <50 g were ignored; visitors of 50–400 g weight were photographed but not offered bait; visitors of >400 g weight were photographed and offered bait. Events recorded by the Scentinel's own internal data-logger and camera were tabulated for each Scentinel site and each species detected and downloaded at each weekly visit. The photographs were cross-checked against footprint tracking papers ('Black Trakka', Connovation Ltd, Auckland, NZ) in the tunnels, to confirm identifications and to detect any camera malfunctions.

Performance comparisons

For the second stage of the trial (21 May to 23 June 2005), we moved to Te Umukaraka Bush, a large patch of cutover native broadleaved/conifer forest near Limestone Downs (37°28′S, 174°46′E) on the west coast of the North Island. The forest is diverse and relatively intact, dominated by regenerating rimu (*Dacrydium cupressinum*), kahikatea (*Podocarpus dacrydioides*) and kowhai (*Sophora* spp.), with stands of secondary kauri (*Agathis australis*) and northern rata (*Metrosideros robusta*), mostly with an excellent broadleaved understorey. Tree ferns (*Dicksonia* sp. and *Cyathea* sp.), pukatea (*Laurelia novae-zelandiae*) and kahikatea occupy the wetland gullies. The vegetation cover is classified as secondary forest (70%), primary forest (10%), scrub (15%) and wetland (5%) (Leathwick *et al*. 1995).

We compared the performance of the Scentinel as a device for monitoring rodents and mustelids against a standard protocol using footprint tracking tunnels (King and Edgar 1977). The protocol was developed by the New Zealand Department of Conservation (DOC) (C. Gillies and D. Williams, unpublished) and is widely used by field staff carrying out pest surveys on conservation land in New Zealand.

For rodents, the DOC standard protocol specifies that lines of 10 tunnels be placed at 50-m intervals, each line at least 200 m from the next, and baited with peanut butter. For stoats, lines of five tunnels at 100-m intervals are baited with a cube of meat, using every second tunnel on those rodent lines that are at least 1 km apart. These spacings are based on the typical average home-range size of these animals (King 2005), and assumes that they will not travel further than these distances during a short monitoring session.

The protocol assumes that each line will be independent of the next, but not that the tunnels within each line will be independent of each other (Brown and Miller 1998). In fact, stoats can travel further than 1 km in a day (Purdey *et al*. 2004), but the protocol aims for a compromise between the ideal and the practical arrangement of tunnels, especially in areas accessible only on foot. Tunnels must be set out at least three weeks in advance of the trial or baiting program to allow resident animals to become familiar with them.

We set three lines of 10 tracking tunnels at 50-m intervals spaced 1 km apart, so that we could comply with the DOC protocol for stoats as well as for rats. The three tunnel lines were oriented north to south, and positioned on the landscape to sample habitats representative of the whole site. In practice,

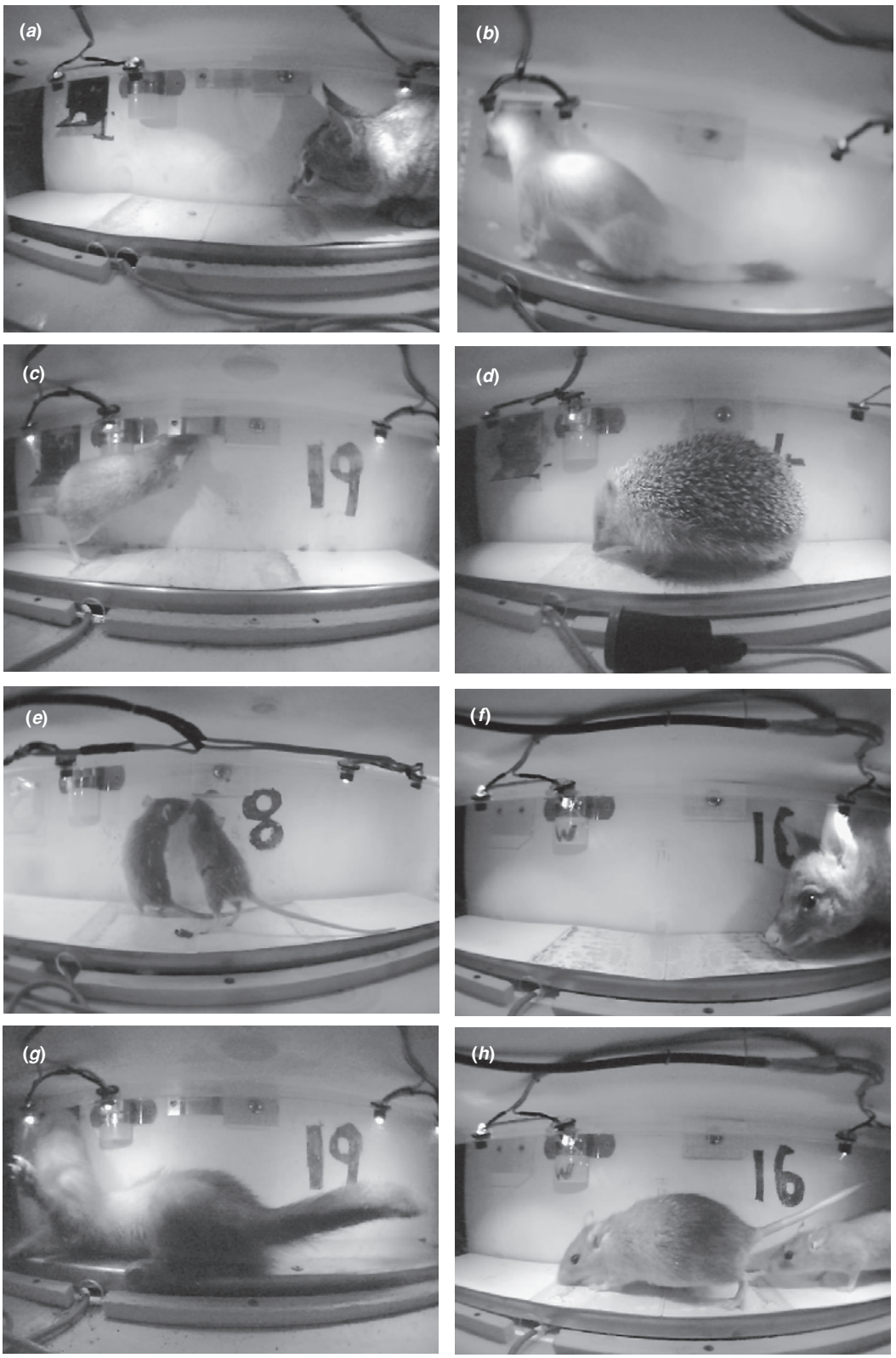

Fig. 2. Digital images of animals captured by the Scentinels, all taken in total darkness by infrared flash photography. (*a*) Cat unable to reach bait (white streak); (*b*) stoat eating bait; (*c*) ship rat, apparently trying to avoid the tracking ink; (*d*) hedgehog; (*e*) two feral house mice; (*f*) brush-tailed possum unable to enter tunnel; (*g*) ferret searching for more bait; (*h*) two ship rats.

DOC would not recommend so small an operation, because three lines are too few to obtain meaningful information about the animals (C. Gillies, pers. comm.). This trial, however, was designed to make a comparison between the two forms of technology, and it met the requirements of the protocol in all respects other than the number of lines laid out.

We ran three tracking sessions, each session comprising three days of effort spread over five working days (26–30 May, 9–13 June, and 16–20 June 2005). For the first day of each session, the tunnels were set to sample rats; for the second to fifth days, they were rearranged to sample mustelids.

On the first day, the tunnels were loaded with ink pads (diluted food colouring) and tracking paper (brown kraft grade), and baited with peanut butter smeared just inside both ends of every tunnel (50 m apart). On the second day, the tracking papers were recovered, any remaining peanut butter removed, and then every second tunnel (100 m apart) was reloaded with fresh tracking paper and ink, and baited in the centre with a small cube of rabbit meat. On the fifth day, all tracking papers were recovered, taken back to the laboratory and read by comparing the tracks with the standard identification guide (Ratz 1997). If only a single animal visited any one of the 10 stations in a line on the first night, the score for that species on that line was 10%; if it or any other animal of the same species visited two tunnels, 20%, and so on. When only every second tunnel was set for stoats (total five tunnels over three nights), the scores were 20%, 40% and so on.

We placed a Scentinel at Positions 3 and 8 of the 10 possible positions on each of the three tracking tunnel lines, and 50 m off to one side or the other (determined by coin toss). The Scentinels sampled fewer locations (6 compared with 30) but were set all the time, so they were able to record visitations during the days that the tracking tunnels were not set. The Scentinel sites were labelled 1/3, 1/8; 2/3, 2/8; 3/3 and 3/8.

To ensure that the tracking tunnels and Scentinels were equally attractive to rodents, we retained the peanut butter lures inside the Scentinel tunnels, but to avoid deterring stoats, we omitted the ferret anal gland lure (Fig. 1). To check that the Scentinel's facility for reprogramming of the weight thresholds was reliable, and because we expected the most frequent visitors in forest to be rats, we changed the bait threshold to 80 g during this stage of the trial. The Scentinels therefore offered the egg-based bait on demand to visitors of >80 g at any time for the whole five weeks.

The stored data did not have to be downloaded until the end of the trial, so the minimum number of field visits required was only two. Nevertheless, we visited them once a week in order to track their performance closely, and to ensure that the data from the two trials would be comparable. The first stage of the trial had shown that the cameras were reliable, so we did not set tracking papers inside the Scentinel tunnels (Fig. 2*b*).

Results

Reliability of species identifications

The 24 Scentinels set on farmland over the period 11 February to 29 April 2005 recorded a total of 1559 visitors in 1718 trap-nights. From the combination of image and weight data we identified 98% of them to species, including 198 visits by ferrets, 871 by hedgehogs, 283 by rats, 98 by cats, 40 by possums, three by rabbits and 38 by unknown animals. In addition, 300 false events were recorded, mostly owing to minor mechanical faults (corrected progressively as we refined the tunnel architecture) or occasional interference by cattle or possums.

The species identifications made by the cameras were confirmed by the tracking papers. The footprint papers taken alone identified slightly fewer (86%) visitors, in part because they were not changed daily and the prints became confused after a week. However, they did detect 28 visits by mice. Because the alert threshold was set at 50 g, the cameras were expected to ignore mice, and they usually did, but on one occasion, two mice jumping at the peanut butter lure together were heavy enough to trigger a photograph (Fig. 2).

The Scentinel's photographs showed some unexpected behaviours by visiting animals, some of which suggest interesting hypotheses for future testing. For example, some rats appeared to be trying to avoid stepping on the ink pads while reaching for the peanut butter, and some visited the tunnels in groups (Fig. 2).

Performance comparisons

The six Scentinels set in forest between 21 May and 23 June 2005 were activated 797 times, in a total of 198 trap-nights. Four of them performed without error throughout. Two Scentinel tunnels were disturbed by large animals (possums or pigs), causing multiple false events (Table 1). Most of these (~80% of 107) accumulated in short sequences that did not significantly affect the routine collection of data, and could have been pre-

Table 1. Visitation data from six Scentinels, set in pairs 250 m apart, one pair to each of three tunnel lines 1 km apart

Cells show counts of animal visits. Most of the 'faults' were caused on two occasions when a large animal knocked the tunnel over (see text)

	Line 1		Line 2		Line 3		Total
Scentinel number	1/3	1/8	2/3	2/8	3/3	3/8	
Rat visits	303	274	22	2	3	52	656
Possum visits	0	10	1	2	0	2	15
Stoat visits	6	1	0	2	0	0	9
Mouse visits	0	0	0	0	0	0	0
Unknown	1	0	5	0	2	1	9
Faults	0	28	0	79	0	0	107
Trap-nights	34	34	33	33	30	34	198

vented by pegging the tunnels down. The Scentinels continued to operate in all weathers.

All but 9 of 690 visitors (99%) in forest were identified to species. Most (82%) visits were by rats (331 per 100 trap-nights, $n = 656$), plus 15 by possums (*Trichosurus vulpecula*) (7.7 per 100 trap-nights) and nine by stoats (4.5 per 100 trap-nights). Possums were too large to enter the tunnel, but often stepped on the end of the weighbridge and pushed their head inside. No mice visited in groups large enough to trip the camera.

Distribution of common species

The 30 tracking tunnels (three lines of 10) detected rats and mice on all three lines during all three sessions (Table 2). There was no clear difference in tracking rates between the lines across the five weeks. Rain spoiled the first session that started on 26 May (Table 2), but the following two sessions beginning on 9 and 16 June, respectively, were conducted in mainly fine weather. Scores on most tracking tunnel lines were high – often 6 or 7 out of 10, and on three occasions, 10 out of 10.

The six Scentinels gave a quite different impression of the distribution of rats in the forest. Of the 656 rat visits recorded by Scentinels, 88% were on Line 1 (Table 1). The Scentinels on other two lines were visited by rats only occasionally.

Detection of rare species

On 31 May, a stoat was recorded by one of the Scentinels on Line 1, during a period of wet weather when no tracking tunnels were set. Between June 12 and 22, six stoat visits were recorded by the second Scentinel on Line 1, and on June 19 another two visits were recorded by a third Scentinel, 1.08 km away on Line 2. The pronounced sexual dimorphism in stoats makes it very likely that the first visit was by a female (weighing 147 g), and all the other visits were by one or more males (the 8 median weights ranged from 298 to 350 g).

The tracking tunnels did not record a stoat until 16 June, when one of the 10 tunnels on Line 2, baited with peanut butter, was marked by a stoat. During the following three days when half the tunnels were rebaited with meat, all five tunnels on Line 1 were marked by a stoat (Table 2).

The tracking tunnels sampled three lines 1 km apart (using a total of 30 non-independent sites) intermittently for a few days each, while the Scentinels sampled the same three lines (using a total of six non-independent sites) continuously over 34 days. In accordance with DOC's current advice (C. Gillies, pers. comm.), we should discard the first week's data from the tracking tunnels. The number of recording opportunities available was therefore slightly less for tracking tunnels (2×30 tunnel-nights for rats and 2×45 tunnel-nights for stoats, total 150) than for Scentinels (198 tunnel-nights), at a greater cost in human effort (three weeks of three days in the field, compared with five weeks of one day). The tunnels sampled a wider area, but they did not detect the presence of stoats until after 105 intermittent tunnel-nights at 30 sites; a Scentinel did so on 31 May, after 60 continuous tunnel-nights at six sites.

Discussion

Monitoring abundance

In homogenous habitats, a short-term correlation between tracking rate and absolute density of rats has been confirmed both by Brown *et al*. (1996) and by Blackwell *et al*. (2002). Variations in

Table 2. Tracking tunnel data from Te Umukaraka Bush, Limestone Downs

The cells show the number of tunnels on each of the three lines that were marked by the given species, and the mean ± s.e. For rats, 10 tunnels were baited with peanut butter bait for one night; for stoats, 5 tunnels were baited with rabbit meat for three nights, on the dates shown. The DOC protocol requirement that the tunnels should be set in fine weather was met only during the second and third sessions

	Part A: Tracking tunnels baited with peanut butter ($n = 10$)					Part B: Tracking tunnels baited with meat ($n = 5$)				
	Line 1	Line 2	Line 3	Mean	s.e.	Line 1	Line 2	Line 3	Mean	s.e.
Session 1[A]										
% Rats	20	0	20	13.3	6.7	60	80	60	66.7	6.7
% Possums	0	0	0	0	0	0	0	0	0	0
% Stoats	0	0	0	0	0	0	0	0	0	0
% Mice	20	10	20	16.7	3.3	40	80	80	66.7	13.3
% Unknowns	0	0	0	0	0	0	0	0	0	0
Session 2[B]										
% Rats	70	70	70	70	0	60	100	80	80	11.5
% Possums	0	0	0	0	0	0	0	0	0	0
% Stoats	0	0	0	0	0	0	0	0	0	0
% Mice	60	70	90	73.3	8.8	40	80	100	73.3	17.6
% Unknowns	0	0	0	0	0	0	0	0	0	0
Session 3[C]										
% Rats	30	70	40	46.7	12.02	80	100	40	73.3	17.6
% Possums	0	0	10	3.3	3.33	0	0	0	0	0
% Stoats	0	10	0	3.3	3.33	100	0	0	33.3	33.33
% Mice	10	20	60	30	15.28	80	80	80	80	0
% Unknowns	0	0	0	0	0	0	0	0	0	0

[A]Session 1: Part A, 26–27 May 2005; Part B, 27–30 May 2005.
[B]Session 2: Part A, 9–10 June 2005; Part B, 10–13 June 2005.
[C]Session 3: Part A, 16–17 June 2005; Part B, 17–20 June 2005.

rat density documented by tracking tunnels are also broadly confirmable by measured conservation outcomes. For example, after a control operation against rats, wherever the residual tracking rate has fallen below a certain level (usually <5%), a clear benefit to the resident birds can confidently be expected (Innes *et al*. 1999).

Indices of abundance derived from tracking data of any sort can be confounded by the failure to distinguish repeated counts of a few individuals from the same number of visits by different individuals. The DOC protocol minimises this error by calculating tracking indices over a short period (one night per quarter for rats, three nights pooled per quarter for stoats). The problem is that wide-ranging small carnivores may visit any given locality only intermittently, because they do not occupy all parts of their large home ranges all the time. Hence, short periods of monitoring can miss many resident animals that do not happen to find, or choose to enter, a tunnel within the time allowed. Permanently sited Scentinels can be programmed to operate on any set schedule that best balances the incompatible requirements of a survey designed both to maximise the chances of detecting animals that are present, and to minimise error in counting them.

The DOC protocol assumes that stoat prints found in tunnels set 1 km apart were made by different animals. In this study, both tracking tunnels and Scentinels detected stoats on two lines 1 km apart, and the Scentinels' photographs and date/time/weight data suggested that there were indeed at least two stoats present, a male and a female.

Since the eight visits by a male stoat were recorded by Scentinels on two lines 1 km apart, the same logic would conclude that there were two males present. In this case, however, the photographs and weight records relating to all eight visits were very similar, so they could have all been made by the same animal. A previous trial in beech forest also documented marked stoats moving between two or three Scentinel sites set 1 km apart (Purdey *et al*. 2004).

Monitoring species distributions

From Table 2 and years of previous experience (Innes *et al*. 1995; Innes *et al*. 2001) it would be reasonable to assume that rats are uniformly distributed throughout most stands of mixed North Island forest. We therefore expected that all six Scentinels we set would be visited by rats at roughly the same rate. All the Scentinels were set out at the same time, so all resident rats had the same opportunity to find the baits. Instead, 88% of all rat visits were recorded on only one of the three lines (Table 1). The visits were probably not all by a small number of individuals, since the distribution of bodyweights recorded at the heavily used sites (authors' unpublished data) was close to a normal curve spanning the expected weight range of the species (King 2005). These observations suggest that the distribution of local populations of rats in the study area was patchy rather than uniform. This possibility raises questions about sampling design for predator monitoring that should be tested further.

Seven of the nine stoat visits detected by Scentinels were recorded on Line 1, the same line where Scentinels most often recorded visits by rats (Table 1). In a previous trial, Purdey *et al*. (2004) noticed that the Scentinel sites in beech forest most often visited by stoats were the same ones where mice were also recorded. These coincidences raise two intriguing testable hypotheses concerning whether the activities and distributions of stoats and rodents in apparently homogenous forest could be correlated at such a fine local level. (1) Extensive arrays of Scentinels set to record visits by both mustelids and rodents could cast new light on the microdistribution of small predators and their prey. (2) Where rats can be individually marked in ways detectable by Scentinels, competing explanations, such as local differences in the extent of learned repeat-visit behaviour of resident rats, could be eliminated. The most recent (Mk 6) version incorporates an optional automated PIT tag reader, confirmed as reliable in field trials in 2006 (C. M. King, R. M. McDonald, I. Malthus, N. Gillingham, S. Holmes, R. D. Martin, M. Stirnemann and T. Connolly, unpublished data).

The cost of routine monitoring: Scentinels versus tracking tunnels

The ability to detect the presence of rare animals regardless of how many common animals dominate the records could be especially important in biodiversity surveys. For example, remote monitoring in the Southern Ark Project area of Victoria in Australia could help to document the expected recovery of small threatened marsupials after intensive fox control (Murray *et al*. 2005). In parts of New Zealand, stoats must be held to low densities in kiwi sanctuaries (Basse *et al*. 1999), so monitoring is important to detect the few that survive trapping, or recolonise cleared areas. The massive costs of using tracking tunnels for this purpose were illustrated by a simple deterministic model (Choquenot *et al*. 2001). It predicts that ~350 tracking tunnels would be needed to give managers a 75% chance of spotting a single stoat arriving in an area of 10 000 ha, the minimum area needed to support a kiwi population viable over the long term (Basse and McLennan 2003).

The major cost of running a regular monitoring operation is in labour, not materials. To explore the difference it could make if this cost could be minimised, we made a hypothetical calculation based on real experience and 2005 prices (R. McDonald and R. Martin, unpublished). The retail price of commercial Scentinels is unknown at present, and also depends on the user's requirements, but a reasonable projection illustrates the dominant influence of labour over capital costs. It assumes (1) that two Scentinels are as effective in surveying the small mammals of a given area of forest as is a line of 10 tracking tunnels, and (2) that one Scentinel with camera might cost ~15 times as much as one tunnel, but needs visiting only once per survey instead of three times.

The minimum capital outlay for setting up a standard quarterly survey with 10 lines of 10 tracking tunnels is about $2500 (100 tunnels at $25 each, including materials and labour for assembly). The same operation using 10 pairs of Scentinels would cost roughly four times more to set up. However, if the labour rate (including overheads) is $65 h^{-1}, and each day's field work incurs the cost of two vehicles and a standard range of charges, consumables, depreciation etc, then a series of tracking tunnel surveys that requires 36 staff-days a year (three staff for three days each, four times a year) would cost about $25 000 $year^{-1}$ in labour. With 20 Scentinels (two per line, 10 lines), each programmed to operate only one week a quarter (or,

for more frequent surveys at no more cost, one week a month), the same survey could be run with 12 staff-days (three staff for one day each, four times a year). Under these assumptions, Scentinels could provide more detailed data for less than half the annual cost.

Conclusions

The results of our study confirm that Scentinel technology is capable of reliable performance in field conditions. During the proof-of-concept stage of the trial, visitation rates were high, and identification rates adequate. The cameras effectively documented the presence and behaviour of individual mustelids and rodents inside the Scentinel tunnels.

The comparison between tracking tunnels (cheap to make, labour-intensive to use) and Scentinels (dearer to make but cheap to use) for routine monitoring, illustrates a useful contrast for managers: tracking tunnels can sample many sites over a short period, whereas Scentinels can sample fewer sites over a long period and report more detailed data (including earlier detection of mustelids). In places where labour costs can be reduced by use of volunteers, tracking tunnels might still be favoured for routine monitoring. By contrast, in places where high annual labour costs are inescapable, and early detection of invaders is critical, the Scentinel's continual scrutiny might be the deciding factor. The potential implications of these contrasts for surveying small and elusive mammals, either protected native species or damaging invaders, will depend on the mobility of the target species, the extent of potential confusion with non-target species, and on whether qualitative or quantitative data are needed.

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