Spatial distribution of the rodent population at Boundary Stream Mainland Island and determination of the efficacy of different baits used for rodent control

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Poison operations are a widely used technique for rodent control in the indigenous forests of New Zealand. This study examined the bait-take and rat monitoring data obtained for continuous poison operations at Boundary Stream Mainland Island (BSMI), Hawke's Bay, between 1996 and 2007.

Since the beginning of the Mainland Island project at BSMI in 1996, 800 ha of indigenous forest have been treated with an 'Integrated Pest Management' approach, in which rodents (primarily ship rats) have been targeted by consecutive ground poison operations. The aim of the intensive pest control was to allow the ecosystem to recover and provide a safe environment for threatened native bird species to recover or be re-introduced. Another important aim of this pest control is to provide experience and expert knowledge in management techniques especially applicable to the protection of indigenous habitat on the New Zealand mainland.

This research study had two main aims: to identify spatial patterns of the rodent population at BSMI and to determine the efficacy of the different rodenticides applied for their control.

The distribution of the rodent population was investigated by spatial analysis of bait-take across the reserve and through time. Visualisation of high and low bait-take areas revealed that there was a noticeable reinvasion from adjacent unmanaged native forests, but not markedly from exotic forest or pasture. Reinvasion from small and isolated adjacent forests ceased to be noticeable consistently after approximately four years of the poison operation,

while a large scenic native reserve, as well as a narrow part of the treatment area surrounded by many native bush patches, were continuously affected by reinvasion through the entire project time. Bait-take was visibly higher after the bait had either been removed, or left in the field unserviced, over winter. No consistent areas of no bait-take were identified. Further statistical analysis of bait-take data revealed that bait-take was higher in bait stations within 150 m of the treatment edge than interior bait stations. Bait-take in broadleaf/tawa/podocarp forest was significantly higher than in kamahi/kanuka/rewarewa, beech and cloud-cap forest.

The second aim of the study was to determine the efficacy of the various bait types with different active ingredients used during the operation. Rat monitoring data, namely rat tracking indices (RTI) obtained from tracking tunnels, were statistically modelled using Generalised Linear Models. Diphacinone cereal pellets (Pestoff® 50D, 0.05g/kg diphacinone) obtained the lowest RTI, followed by pindone cereal pellets (Pindone Pellets®, 0.5g/kg pindone), brodifacoum cereal pellets (Pestoff® 20p and Talon®, 0.02 g/kg brodifacoum), coumatetralyl paste (Racumin®, 0.375 g/kg) and diphacinone bait blocks (Ditrac®, 0.05 g/kg). Cereal pellet baits worked better than any other bait type used at this location.

Season had no statistically significant effect on either RTI or bait-take estimates.

The overall goal of the poison operation to decrease rat numbers, and to maintain low levels, has been met. However, the results of this study suggest that baiting needs to be done continuously and over the entire treatment area. Edge bait stations – particularly next to adjacent native forests – should be prioritised to target reinvading rodents. Poisons presented in cereal pellet baits should be preferred to other bait types. Both pindone and brodifacoum showed very good results, as well as diphacinone in cereal pellet baits.

Keywords: Rodents, ship rats, *Rattus rattus*, mainland island, native forest, conservation, pest control, ground control, bait stations, bait efficacy, brodifacoum, pindone, diphacinone, coumatetralyl, warfarin, cholecalciferol, 1080

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Abbreviations

a.s.l.	above sea level
au	autumn (March-May)
BSMI	Boundary Stream Mainland Island
DOC	Department of Conservation
LSD	Fisher's Least Significant Differences
RTI	Rat tracking index
SE	Standard error
SED	Standard error of the differences
SEM	Standard error of the means
sp	spring (September-November)
su	summer (December-February)
wi	winter (June-August)

Chapter 1: Introduction

1.1 Rodents in New Zealand

1.1.1 Background

The arrival of humans in New Zealand has led to tremendous impacts on natural habitats. Where forest cover once predominated the landscape, it was eventually diminished to the less reachable or unprofitable areas. The majority of lowland forests were converted to farmland and settlements (King, 1984, 2005) and the remaining forests were modified by logging activities. Both the reduction in forest cover and the modification of the remains started during pre-European times, but were carried out at much faster pace after the arrival of Europeans.

Human arrival was accompanied by the introduction of terrestrial mammals, which in pre-human times had been absent from New Zealand apart from some bat species. Many of the arriving mammals were purposefully released while others arrived by accident (King, 2005). The combination of vast reduction in forest cover, the browsing of game animals and the invasion of predators resulted in habitat loss and destruction to the extent of decline and loss of many native – often endemic – plant and animal species (King, 2005; Saunders and Norton, 2001).

Predatory mammals such as possums (*Trichosurus vulpecula*), mustelids (Mustelidae) and rodents (Murinae) and have had a particularly dramatic impact on forest species, having been made responsible for the dramatic decline of bird populations, in a number of cases to extinction (Duncan & Blackburn 2004; King 2005; Tennyson & Martinson 2006).

1.1.2 History of colonisation

The first rodent species to arrive in New Zealand was the kiore (*Rattus exulans*), which came for certain with the early Maori settlements about 900 years ago, and may have arrived beforehand with Polynesian explorers (Holdaway, 1996). Three further rodent species arrived on European ships in the late 18th and early 19th centuries: ship rat (*R. rattus*), Norway rat (*R. norvegicus*) and house mouse (*Mus musculus*) (King, 2005).

House mice probably first arrived in the North Island in the 1820s, with a delay of about 30 years to the South Island. They arrived on ships, and were then transported inland in supply stores for farms and settlements. By the beginning of the 20th century they had spread across the whole country and remain abundant in most natural habitats today (Ruscoe and Murphy, 2005).

Kiore were once widespread and very damaging in the whole country, but are now reduced to small numbers restricted to few areas in the southern South Island and on some offshore islands. Similarly, the Norway rat – the first of the European rat species to arrive – first spread across the country in a short period of time, presumably playing a part in the isolation of the formerly established kiore, but is now also reduced to remnants (King, 2005).

The most common rat species in New Zealand today is the ship rat, which did not spread until the late 19th century and seemingly displaced both kiore and Norway rat in most natural habitats on the New Zealand mainland (Innes, 2005). Reasons for this development – which is quite contrary to the natural history of rodents in many other parts of the world – are still unknown (King, 2005; Lund, 1994). Ship rats are now present throughout North, South and Stewart Islands, almost wherever suitable habitat is available (Innes, 2005). In natural habitats, such as native forests, they often highly outnumber Norway rats (Innes, 2005), which is also considered to be the case in the study site of this research (DOC, 1998).

1.1.3 Impact on the environment

To put a stop to the decline of threatened bird species and to generally allow the forest ecosystems to recover, much effort is put into the control of many introduced species in New Zealand. In this context the control of rodents is indispensable, since they occur almost everywhere in the country, often at high densities, and feed on almost anything they come across, thus putting remaining native bird species at risk. Additional native species of conservation value that rodents are presumed to impact are lizards and invertebrates, and although not yet proven, they may also have an impact on the seedbank and subsequent forest regeneration (Innes, 2005).

1.2 Rodent management in New Zealand

1.2.1 Background

The protection as well as control of wildlife in New Zealand is regulated by the 'Wildlife Act 1953'. Among other things, the Act regulates the protection status of species and the consequences which the protection status entails for the species. Many introduced species are listed as 'unprotected wildlife' under Schedule 5 of the act. If listed there, a species can be controlled by private land owners as well as central and regional government agencies if deemed necessary (Innes and Barker, 1999).

All rodent species are currently listed as unprotected wildlife under Schedule 5 of the Wildlife Act. Since rats in particular have proven to be a threat to the native bird fauna, there are many

rat control operations for conservation purposes in place, not only on public conservation, but also on private land.

1.2.2 Rodent control

The most commonly used rodent control technique in developed western countries is the application of toxic bait (Buckle, 1994). In New Zealand, poison operations against rodents are also very common, although kill-trapping is also used.

On offshore islands, the goal of rodent control programmes tends to be the eradication of the species. To date, this has been accomplished on a number of New Zealand offshore islands, with the size of islands with successful eradication programmes ever increasing (King, 2005). Rat-free islands have proven to be important sanctuaries for threatened species, with successful translocations of species on the brink of extinction on the mainland, followed by consistent population growth in absence of predators (King, 2005). The eradication of house mice has also been attempted more recently and thus far has only been successful on a small number of offshore islands (Ruscoe and Murphy, 2005).

Despite the surrounding water as a natural barrier, offshore islands are at constant risk of reinvasion (Russell et al., 2008). Lacking this natural barrier, mainland habitats can be reinvaded by individuals of an unwanted species at any time. Since the eradication of rodents from the New Zealand mainland is not realistic with currently available methods, rodent control has to be an ongoing process (King, 2005).

On the New Zealand mainland, the preservation of the remaining biodiversity in natural habitat fragments is equally dependent on adequate predator control as on offshore islands (King, 2005; Saunders and Norton, 2001). Several small areas have been fully fenced off by the installation of predator-proof fences, thus creating a similar situation to offshore islands within the mainland. Without this means of preventing reinvasion, continuous control – whether this may be ongoing or regularly repeated – is the only option to achieve and maintain low pest numbers (Gillies, 2001; Saunders and Norton, 2001).

The control of rats on the New Zealand mainland has had crucial impacts on the recovery of threatened species such as the North Island kokako (*Callaeas cinerea wilsoni*; Basse et al., 2003; Innes et al., 1999; Sinclair et al., 2006). Mouse control on the mainland, however, has rarely been effective (Ruscoe and Murphy, 2005) and mouse populations recover quickly (Miller and Miller, 1995). Little is known about the impact of mice on forest ecosystems on the New Zealand mainland, but their role in sustaining fellow predator species has been apparent in many areas with intensive predator control: as rat numbers decrease, mice

numbers rise, which is probably due to decrease in both predation and food competition (Innes et al., 1995; Miller and Miller, 1995; Ruscoe and Murphy, 2005). Then again as mice numbers rise, food availability for rats increases as well. This has been found expressed in increased rat numbers after mouse population eruptions during beech mast years, which in turn impacted stoats, who commonly prey on rats (Dilks et al., 2003; King, 2005). This highlights the complicated relationship between prey and predators and the need to take these relationships into account when designing predator management strategies.

1.2.3 Rodent monitoring

To establish the need of a rodent control operation in a particular area, it is necessary to first estimate the rodent density in that area. After identification of the need for, and the establishment of, a control programme, it is equally important to monitor the rodent densities to be able to evaluate the efficacy of the operation (Brown et al., 1996). A rodent control programme therefore should be preceded and accompanied by an appropriate and consistent monitoring programme to ensure that the action taken has the desired and anticipated effect.

Two commonly used rodent monitoring techniques in New Zealand are kill-trapping and tracking tunnels (Blackwell et al., 2002; Brown et al., 1996). Kill-trapping operations are usually based on snap traps or other trap types placed in a grid or in lines. The trapping index is calculated as the number of captures per 100 trap nights. Sprung traps are incorporated in the trapping index (Blackwell et al., 2002). Footprint tracking, in contrast, is a 'non-destructive' monitoring technique. Rather than catching the whole animal, it is only their footprints that are monitored. Footprints are collect using tracking tunnels that are put in grids or lines. Tracking indices are calculated as the percentage of tunnels tracked by the same species (Blackwell et al., 2002; Brown et al., 1996; Gillies and Williams, 2002, unpublished).

Both techniques are usually used to estimate relative densities rather than absolute densities. It is assumed that both trapping and tracking indices directly correlate to absolute densities, so that regularly collected indices reveal population trends (Brown et al., 1996).

The accuracy and precision of such indices for density measurement is debatable (Blackwell et al., 2002). Blackwell et al. (2002), for example, suggest that tracking tunnels can only be compared if placed in the same vegetation type and that tunnels need to be run in corresponding vegetation types in both the treatment and non-treatment sites during the same nights. Tracking indices should ideally also be correlated with a second density measure to increase the confidence for observations of population trends over time. Furthermore, the spacing of tracking tunnels should carefully reflect the underlying behaviour of the species to minimise the chance that one individual uses two neighbouring tunnels on the same night. For

rodent tracking, Blackwell et al. (2002) suggest a spacing of 100 m, while DOC tracking tunnel protocol requires a spacing of 50 m (Gillies and Williams, 2002, unpublished).

1.3 'Mainland Islands'

To develop and trial efficient and practical control techniques specific for the New Zealand mainland, the Department of Conservation (DOC) established six 'mainland islands' in 1995 and 1996. Unlike real islands, these mainland islands are all situated on the New Zealand mainland, without any physical barrier to the surrounding land which are generally not managed for conservation purposes. The 'island' situation is simply created by intensive pest management regimes aiming to maintain low pest densities to allow ecosystem restoration (Saunders and Norton, 2001).

The six mainland islands differ not only in size, vegetation types, pest species composition, and/or objectives in site-specific species recovery; they also differ significantly in broader parameters such as previous habitat modifications and the intensity of previous and ongoing human activity in the surrounding area. Each mainland island was deliberately set up to address specific questions relating to the particular ecosystem as well as the kind of environment it is situated in. The variety of mainland islands ensured that a range of management strategies could be applied and tested, which are relevant for management decisions elsewhere in New Zealand.

To ensure applicability of the activities at mainland islands in a broader context of conservation on the New Zealand mainland, eight management principles were formulated by DOC. These management principles for mainland island projects can be grouped into learning, biodiversity and community outcomes. Learning includes rigorous trials and experiments accompanied by intensive monitoring and evaluation, with the information made accessible to the public (DOC, 2008). Biodiversity is aimed at through intensive management, which allows ecosystem restoration and recovery, but essentially is ranked behind the learning outcomes. Community involvement is encouraged and in many cases essential to achieve the level of management needed (DOC, 2008).

1.4 Ecology of ship rats (*Rattus rattus*) in New Zealand

Of the three rat species present in the New Zealand mainland, ship rats are by far the most common. Their presence is therefore of most concern in rodent control New Zealand natural habitat.

1.4.1 Distribution & Habitat

Wild ship rats are common throughout New Zealand. Apart from their occurrence around human settlements, they also occupy many natural habitat types (Innes, 2005). In native forests, for example, they tend to be most abundant in podocarp-broadleaved forests, while they are typically scarce in pure beech (*Nothofagus*) forest, with beech mast years as an exception (Clout, 1980; Innes, 2005). With increasing maturity and diversity of a forest habitat, rat numbers increase. King et al. (1996) found this also to be true in exotic forest: In a young pine (*Pinus radiata*) plantation ship rats were practically absent altogether, while in an older plantation they did occur, although at comparatively low numbers. In native forest they were abundant throughout, but were most frequently caught on warmer and steeper sites, indicating that site preferences also exist within habitat types.

1.4.2 Habitat use

Ship rats are well adapted to a forest environment. As agile climbers they can use all layers of the forest from the ground to the canopy. Nest and den sites for daytime use of the nocturnal animals are always found in trees or shrubs (Dowding and Murphy, 1994; Hooker and Innes, 1995), while food is available on the forest floor as well as in the trees. Besides for occasional foraging, ship rats also use the forest floor for travelling between trees. The ratio of time spent in trees or on the forest floor, however, differs between studies: Nine radio-tracked rats in a native forest in the central North Island, for example, were located at least 2 m above ground 74 % of the time, which includes 18 % at least 8 m above the ground (Hooker and Innes, 1995). A similar radio-tracking study in a kauri (*Agathis australis*) forest in Northland, however, showed noticeably different results: the 11 radio-collared rats were located on the ground 90% of the time (Dowding and Murphy, 1994). These differing results may reflect the location of seasonal food availability at the time. The physical structure of the forests in the two different study sites may also be responsible for differing habitat use, the density of the sub-canopy layer being relatively open in the kauri-dominated forest (Dowding and Murphy, 1994).

1.4.3 Home Range

As opposed to commensal ship rat populations, wild ship rats in New Zealand forests do not form close-knit colonies, but are rather evenly dispersed throughout suitable habitat (Hooker and Innes, 1995; Innes, 2005). Individual rats form home ranges which are – in the North Island – approximately circular to slightly oblong (Daniel, 1972; Dowding and Murphy, 1994; Hooker and Innes, 1995) and are roughly traversed every night (Innes and Skipworth, 1983).

Ship rat home ranges in New Zealand forests vary in size and exclusiveness between sexes and seasons. To determine their size, a number of radio-tracking studies have been conducted (Dowding and Murphy, 1994; Hooker and Innes, 1995; Innes and Skipworth, 1983; Pryde et al., 2005). Ship rats in a North Island kauri forest, for example, displayed home ranges with a mean length of 175 m, averaging 0.79 ha ± 0.07 (n = 11) without significant differences between sexes. Ranges overlapped between rats of the same as well as opposite sex (Dowding and Murphy, 1994). The tracking in this study was mostly done outside the breeding season, which may account for noticeable differences to findings in other studies. Hooker & Innes (1995), for instance, who tracked nine rats during the breeding season, found the home ranges of females with a mean length of just over 100 m (0.5 ha ± 0.07, n = 4) to be considerably smaller than that of male rats in the same area (1.52 ha ± 0.28, n = 5). Furthermore, the female ranges appeared to be discrete, as opposed to the male ranges, which overlapped with several females as well as other males. Dowding & Murphy (1994) conclude that while ship rats regardless of their sex appear to have similar-sized home ranges in winter, male rats enlarge their ranges during the breeding season – presumably to improve breeding success – whereas females become more territorial.

1.4.4 Diet

Ship rats are omnivorous generalists, feeding on both plant and animal food year round (Innes, 2005). They eat seeds, fruits, nuts, leaves, as well as arthropods, lizards, small mammals, eggs and chicks, or small adult birds (Innes, 2005). Even other trap-killed rats are readily used as a food source. In New Zealand, their food includes many species of conservation value, including many endemic species, of which some – such as the endangered North Island kokako – are threatened by serious decline on the New Zealand mainland (Innes and Flux, 1999).

New food sources, or even familiar food items placed in new objects, are regarded with a strong avoidance known as ‘neophobia’ (Innes, 2005). After an initial avoidance of unfamiliar food, small quantities may then be sampled. Unless ill effects are experienced, they may return several hours later and then accept the novel food as a food source (MacNicoll, 2007). If illness occurs, however, the rats will avoid the novel food. The scepticism of new foods also includes the avoidance of newly-installed bait stations, which can take anything between a few days to several weeks to fully overcome (Clapperton, 2006).

How much food ship rats actually consume in the wild is not known. Wild-caught ship rats in captivity ate an average of 16 g worth of pellets per day (Clapperton, 2006). With an average body weight of 143 g (mean of male and female ship rats in 5 studies conducted in the North

Island, as cited in Innes, 2005), this amount equals about 10-12 % of their body weight. This is only an indication of their daily food intake, because their normal meals are more varied; individual meals tend to consist of a selection of food items rather than from one single kind of food (Clark, 1982). If these food items are found in the open, they prefer to carry small pieces to a sheltered place, rather than immediately starting to eat (Innes, 2005).

Induced by seasonal food availability, their diet is dominated by different foods through the year. In native forests of the North Island, plant food dominate in autumn and winter while animal food dominate in spring and summer (Daniel 1973; Innes 1979, 2005). The plant food consists largely of seeds, nuts and fruits, whichever is most available and ripe at the time. The most common animal food is arthropods, with tree weta (Orthoptera) highly dominating (Best, 1969; Daniel, 1973; Innes, 1979).

Although native birds are commonly regarded at risk with the presence of rats in New Zealand native forests, they are not, in fact, a major food source. In various studies, feathers and eggshells constituted only a small proportion of stomach contents for a few individuals, and whether these bird signs derived from nest predation or scavenging of already failed nest can not usually be determined (Best, 1969; Daniel, 1973; Innes, 1979). The reason why ship rats nonetheless remain one of the most frequent causes of nest predation in New Zealand forests is due to their sheer abundance and ubiquity. Together with their ability and habit to climb high up in the trees, some rats will always come across a nest sooner or later (Innes, 2005). What makes bird populations particularly vulnerable is that most nest predation induced by rats seem to happen between September and December, which coincides with the breeding season of native birds (Innes, 1979).

1.4.5 Breeding

In laboratory studies, ship rats reach sexual maturity at the age of 2-4 months (Daniel, 1972; Innes, 2001). Whether this age can be applied to wild rats is unknown, but field trials in New Zealand indicate that female rats born early in the breeding season can deliver their first litter within the same season. If born late, they appear not to reach maturity until the beginning of the following season (Innes et al., 2001; Miller and Miller, 1995).

The breeding season of wild ship rats in New Zealand starts in September and runs through to April. The highest reproduction activity occurs in summer and autumn (Innes et al., 2001; Miller and Miller, 1995), when the young from earlier in the season join the breeding cycle.

A typical litter size as indicated by numbers of embryos found in kill trapped rats is around 5-6, with a wide range of 3-9 found in different studies. Wild ship rats in New Zealand seldom

grow older than one year, thus normally producing up to three litters during their lifetime, thus potentially delivering nearly 20 offspring (Daniel, 1972; Innes et al., 2001).

The early life stages of wild ship rats are largely unknown. Juvenile rats, and hence family behaviour, are rarely observed in the wild. They are also seldom caught in traps, although – considering that lighter-weight mice are commonly found dead in rat or mustelid traps – their body weight should be enough to set off traps at an early age (Hooker and Innes, 1995). The rare field observations are consistent with laboratory studies in suggesting that the raising of the young is solely the responsibility of the female (Hooker and Innes, 1995). Captive rats have been found to wean their young at the age of 21-28 days (Cowan, 1981, as cited in Hooker and Innes, 1995) and to abandon them completely shortly afterwards (Ewer, 1971, as cited in Hooker and Innes, 1995).

1.4.6 Implications for rat control techniques

Control techniques generally targeting ship rats in New Zealand forests are typically carried out on or near the forest floor. This is reasonable even for the largely arboreal ship rats, since they regularly use the forest floor for travelling and foraging. If bait stations are used for poison applications, the home range size also needs to be considered to determine feasible grid spacing (Pryde et al., 2005). Hooker & Innes (1995) suggest that in North Island forests a bait station grid size of 100 x 100 m spacing would expose most rats to poison within their home range, and all rats would be exposed at a 50 m grid spacing.

The neophobic response to new food sources can cause problems in poisoning operations, when rats take too long to accept provided toxic bait to show the desired effect on monitoring numbers. Given that at BSMI bait stations were placed in a permanent grid with the bait remaining for at least a month before changeover – each bait being used for at least three months in short trials or in combination with non-toxic prefeed in case of acute-acting bait being applied for a shorter period of time – any neophobic response of the rats is not expected to show in the data.

Abandoned territories are taken over by invaders from adjoining ranges within days (Innes, 2005; Innes and Skipworth, 1983), implying sustained rodent control is necessary. In regard to a possible behavioural change after poison intake, Hooker & Innes (1995) found no significant change of home range and activity of radio-collared rats before and after ingestion of a lethal dose of bait containing brodifacoum.

1.5 Rodenticides

1.5.1 Background

Rodenticides are lethal chemical agents used for the control or eradication of rodents. For a rodenticide to be useful, it needs to meet a number of requirements. These requirements can be grouped into four main characteristics: *efficacy*, *safety*, *residues* and *humaneness*.

Efficacy

Obviously, the main requirement of a rodenticide is that it is toxic to rodents. A widely used measurement of toxicity is LD_{50}, which is the amount of the active ingredient that if consumed per individual will kill 50 % of a test population (Buckle, 1994).

Toxicity alone, however, does not yet necessarily make a good rodenticide. The efficacy of a rodenticide incorporates a number of aspects, which (Buckle, 1994) identifies as follows:

Firstly, a poison needs to be palatable to the target species. A potent rodenticide that the rodents do not like eating will not be helpful in a rodent control operation.

Secondly, a poison should be able to target as many target species (e.g. rats, mice) simultaneously as possible to ensure economic as well as practical feasibility. Similar to being effective against many species, it should be equally effective against all individuals within the same species, regardless of sex and age. Applied to New Zealand, this means that the poison should be effective against all rodent species alike, but should ideally exclude any other non-target species being affected through primary or secondary poisoning.

Finally, one important factor influencing the efficacy of a rodenticide is the speed of action. Although a poison that leads to death within a short period of time should be very effective, this efficacy can easily be mitigated if a high number of rodents ingest sublethal doses before experiencing ill effects. Connecting symptoms of illness with ingestion of the bait can result in ‘bait shyness’, which may make the same bait and poison ineffective for future operations in this area. To meet rodents’ particular feeding habits, the time between ingestion and onset of symptoms should be long enough to blur the association with the food source, thus not discouraging from using it again until a lethal dose is ingested.

Safety

Not only the toxicity itself is relevant to safety of a poison operation. What also needs to be considered is secondary or tertiary poisoning of target or non-target species, safety issues regarding humans, livestock and pets, as well as persistence in the environment (Alterio, 2000; Eason and Wickstrom, 2001). These safety issues will be explained as follows.

Secondary or tertiary poisoning is the consumption of poison not by feeding directly on toxic bait, but indirectly by preying on or scavenging poisoned animals and thus ingesting residues of the poison in the tissues of the scavenged animal. The longer these residues persist in the tissues of an animal, the higher is the risk of secondary poisoning. One way of keeping non-target species safe is to use poison that is highly specific to rodents. Since the life processes of rodents are very similar to other mammalian vertebrates, specificity to them has proven virtually impossible. At best, some important non-target species may be excluded (Buckle, 1994), which is attempted by containing bait inside bait stations.

Similar to safety requirements regarding non-target species, health and safety issues of humans and domestic animals are important matters (Buckle, 1994). The importance of this is of course increased in relation with commensal rat populations, but also in remote forest settings in New Zealand there is often livestock present in adjoining areas, and humans are involved in the application process.

Apart from health issues to animals and humans, the environment should not be affected negatively through the poison application. Both the contamination of soils, waterways or plant tissues, as well as the accumulation of poison in animals through the food chain are undesirable and should be avoided (Buckle, 1994).

Finally, the poison should lead to a humane death, regardless of whether target or non-target species are affected. Similarly, sublethal doses should not result in lasting damage to the health of any animal (Buckle, 1994).

Rodenticides are usually classed into two groups: acute or fast-acting poisons and chronic or slow-acting poisons. Both will be characterised in the following.

1.5.2 Acute-acting poisons

Acute-acting poisons cause death within a few hours of ingestion of a single lethal dose (MacNicoll, 2007). Numbers of pest animals can potentially be reduced quickly. The disadvantage is that the consumption of a sublethal dose, resulting in serious illness, can cause the development of conditioned taste aversion (CTA) – or bait shyness – which prevents rats from using this food source again. This not only leads to reduced success for the initial poison operation, but it also renders this particular bait unfit for use in the same area for a certain time period. Only a short time of application is therefore practical, preceded by application of non-toxic prefeed to overcome any initial neophobic response to new food items. Acute-acting poisons commonly applied in rodent control in New Zealand are sodium monofluoroacetate (compound-1080 or 1080) and cholecalciferol (Eason and Wickstrom, 2001).

Sodium monofluoroacetate (1080)

1080 is an organic compound found in a number of plants around the world. Once ingested, a possum dies within six to 18 hours (Eason and Wickstrom, 2001). In New Zealand, the principal target species are possums and rabbits (Eason and Wickstrom, 2001), but it is also commonly used for rat control (Alterio, 2000); for possum control it is the most widely used poison (Eason and Wickstrom, 2001) and it can reduce possum numbers rapidly over a large area when applied in an aerial drop.

1080 is available in both carrots and cereal bait for aerial applications, and as cereal bait, paste and gel for use in bait stations. Cinnamon is often used to mask the taste of 1080, which may also deter some birds (Eason and Wickstrom, 2001).

Cholecalciferol

Compared to cyanide and 1080, cholecalciferol (Vitamin D_3) is slower in mode of action, and is therefore often referred to as a subacute poison. Due to the lack of an exact definition, it can also be found as classed as a chronic poison (Buckle, 1994; MacNicoll, 2007).

A further difference to 1080 and cyanide is that in New Zealand it is registered for both possum and rat control (Eason and Wickstrom, 2001). Although it takes longer for poisoning symptoms to occur than the previously mentioned fast-acting poison, it is still short enough for rats to be able to detect early symptoms and develop bait shyness. Accordingly, non-toxic prefeed is still necessary (MacNicoll, 2007).

Cats and dogs are relatively less sensitive to cholecalciferol than the actual target species, which by no means makes it safe for pets, although is has been classified as such in the past (Eason and Wickstrom, 2001).

Cholecalciferol was first registered in NZ in 1995 in a cereal bait (8 g/kg cholecalciferol) for possums. In 1999 Feracol® paste was first introduced with a toxic load of 8 g/kg cholecalciferol for possums, followed in 2000 by a rodent paste bait with a strength of 0.8 g/kg (Eason and Wickstrom, 2001).

1.5.3 Chronic poisons / Anticoagulants

Slow-acting or chronic poisons used in New Zealand all belong to the group of so-called ‘anticoagulants’. Anticoagulants act by inhibiting the vitamin K cycle and thus preventing the synthesis of blood-clotting proteins (Buckle, 1994; MacNicoll, 2007). These proteins degrade over 48-72 hours after ingestion of the poison, gradually decreasing blood-clotting to the point of where multiple fatal haemorrhages occur some four to five days later (Fisher and Broome, 2006; MacNicoll, 2007). Long-term health damage to either sublethally exposed rodents or humans is generally not associated with anticoagulants (Buckle, 1994).

It was the disadvantages of the acute poisons that regularly led to bait shyness in rat populations that made anticoagulants so successful as rodenticides (Buckle, 1994). A delay of onset of poisoning symptoms of four to 10 days prevents rodents from associating the symptoms with the food source that caused them, which discourages the development of bait shyness and therefore allows application of the same poison for extended periods of time (Buckle, 1994). Today, anticoagulants are the most widely used agents for small mammal control worldwide (Eason et al., 2002).

In regards to health and safety for humans and non-target species, vitamin K_1 does provide an antidote in cases of accidental poisoning. The delayed mode of action also allows sufficient time to administer the antidote (Buckle, 1994; MacNicoll, 2007).

There are two groups of anticoagulants: the early poisons that were developed and made available commercially between 1950 and 1970 are generally referred to as 'first-generation' anticoagulants, the newer poisons and more potent are referred to as 'second-generation' anticoagulants (Buckle, 1994).

First-generation anticoagulants are characterised by relatively low potency, which is indicated by the requirement for animals to ingest the poison repeatedly over several days to cause death (Buckle 1994; Fisher & Broome 2006; MacNicoll 2007). The acute LD_{50}, which is the amount of a single lethal dose, is typically higher than the chronic LD_{50}, which is the lethal dose ingested daily over several consecutive days (Table 1.1). Continuous access to the first-generation bait over a prolonged period of time is therefore beneficial. The major concern about first-generation compounds, however, is that many rodent populations of ship rats, Norway rats and house mice have been discovered to have developed physiological resistance against those compounds in many countries around the world (MacNicoll, 2007). In New Zealand, resistance has not yet been identified.

Table 1.1: Anticoagulant products used at Boundary Stream Mainland Island with the acute oral LD_{50} for brodifacoum (2nd generation) and chronic oral LD_{50} for the 1st generation compounds. All values for Norway rats except acute LD_{50} brodifacoum: ship rats and chronic LD_{50} for warfarin and pindone: rat species not specified.

Active ingredient	Acute LD_{50} (mg/kg)	Chronic LD_{50} (mg/kg)	Source
Brodifacoum	0.69	n/a	(Buckle, 1994; Dubock and Kaukeinen, 1978)
Warfarin	15	1 x 5 days	*(Buckle, 1994); **(Eason et al., 2002)
Diphacinone	7	0.35 x 5 days	(Fisher and Broome, 2006)
Pindone	88	5 x 5 days	*(Eason and Wickstrom, 2001); **(Eason et al., 2002) ***
Coumatetralyl	16.6	0.3 x 5 days	(Buckle, 1994)

* acute; ** chronic; *** chronic LD_{67} for pindone

Second-generation anticoagulants are more potent than first-generations ones and were specifically developed to overcome the resistance to first-generation compounds (MacNicoll, 2007). The ingestion of one lethal dose, possibly obtained in a single feed, is sufficient to cause death several days later (Eason et al., 2002; MacNicoll, 2007). Their major drawback, however, is their considerably increased persistence in the environment, which has been reported as at least six months for brodifacoum in possum liver (Eason et al., 2002). Brodifacoum, which is a second-generation anticoagulant, has a half-life of 113.5 days, whereas warfarin (first-generation) has a half-life of 26.2 days, and diphacinone and pindone (both first-generation) three and two days respectively (Eason et al., 2006). Accordingly, the relative safety of providing bait in bait stations excluding non-target species is virtually negated by the high risk of secondary poisoning through predation on sublethally contaminated or the scavenging of killed animals (Eason et al., 2006).

A number of anticoagulants are currently registered for use in rodent control operations in New Zealand. Some of the more commonly used ones are characterised in the following section.

Brodifacoum

Brodifacoum is a second-generation anticoagulant and is regarded as the most potent of that group (Buckle, 1994). It is likely for rats to eat a lethal dose as part of their normal food intake within a single day (Buckle, 1994; Eason et al., 2002). The LD_{50} of brodifacoum for warfarin-susceptible ship rats is 0.65 mg/kg for females and 0.73 mg/kg for males (Dubock and Kaukeinen, 1978).

As mentioned before, brodifacoum is highly persistent in the environment. Especially in the liver of sub-lethally exposed animals it will remain for about six months and can thus contribute to secondary and tertiary poisoning through predation for a long time. Apart from other introduced mammals, the contamination of which is of less concern, many native birds have been found contaminated, including endangered ones (Eason et al., 2002). Of direct concern for human consumption is the fact that brodifacoum residues have been found in game animals, especially feral pigs (*Sus scrofa*), which connect the poison application to the human food chain (Eason et al., 1999; Eason et al., 2002).

Coumatetralyl

Coumatetralyl is a first-generation anticoagulant from the hydroxycoumarin group. It was developed in the 1950s by Bayer AG in response to the increasing resistance in rodent populations against warfarin (DOC, 2006, unpublished). Its acute LD_{50} is 16.6 mg/kg for Norway rats (Buckle, 1994), but as with all first-generation compounds it has an increased potency if taken continuously over several days: then the chronic LD_{50} decreases to 0.3 mg/kg

a day for five consecutive days (Buckle, 1994; Eason et al., 2002). A rat ingesting a lethal dose of 0.375 g/kg baits will die within approximately eight days after poisoning from multiple haemorrhages throughout the body. During the last two or three of which the animal stops ingesting any food (DOC, 2006, unpublished).

Little is known on safety for non-target species. Toxicity to invertebrates and birds seems to be relatively low and no fatal exposure of native animals has been reported so far. Toxicity to mammals is highly variable, and pigs have been found fatally poisoned in New Zealand and overseas (DOC, 2006, unpublished). Reports on how long residues remain in inner organs after sublethal exposure to coumatetralyl vary between half-lives of 55 and 70 days (DOC, 2006, unpublished). Toxicity in secondary poisoning is not well known, but in a research project where dead poisoned rats were fed to 10 ferrets (*Mustela furo*) and 10 weka (*Gallirallus australis*), two of the ferrets died, but no weka displayed any ill effects, suggesting a relatively low risk of secondary poisoning for scavenging birds and mammals (O'Connor et al., 2003).

Diphacinone

Diphacinone is a first-generation anticoagulant from the indane-diones group. Acute LD_{50} values vary but tend to be reported as below 7.0 mg/kg for Norway rats but has also been reported with as much as 43.3 g/kg. Chronic LD_{50} is 0.35 mg/kg daily for five consecutive days (Fisher and Broome, 2006). Against house mice, however, diphacinone is characterised with low potency: the acute LD_{50} is between 141-340 mg/kg (Buckle, 1994). Rats take five to eight days to die and stop feeding one or two days before death. Diphacinone is most effective, if the rodent populations are exposed to the poison for at least 10 days without running out of bait (Fisher and Broome, 2006). Poison residues and persistence in intestine tissues as well as secondary poisoning is not well reported, and there is no information specific to New Zealand. Resorting to overseas studies, birds and invertebrates seem to be relatively resistant, while feral pigs and cats and dogs will probably be killed by continuous exposure to bait or poisoned rat carcasses (Fisher and Broome, 2006).

Diphacinone has been applied in several locations in New Zealand and has been found successful in suppressing rat numbers to low levels. Best results seem to occur where possum numbers are low or efficient possum control measures supplementary to the rodent control are in place (Gillies et al., 2006).

Pindone

Pindone also belongs to the indane-dione class and is one of the oldest first-generation anticoagulants. It was first introduced as an insecticide before it became known to be effective against rodents as well (Buckle, 1994; Eason and Wickstrom, 2001). Its chronic LD_{67} for rats

is 5.0 mg/kg daily over five consecutive days (Eason et al., 2002). Pindone is less persistent in animals than diphacinone (Eason and Wickstrom, 2001).

In New Zealand, pindone has been proven highly effective in rabbit control, but less in possum control (Eason and Wickstrom, 2001) and it has only recently been registered for use against rodents.

Warfarin

Warfarin is a Hydroxycoumarin and was the first of the anticoagulants widely used as a rodenticide (Buckle, 1994). Many Norway rat and house mouse populations in Europe and North America – and to a lesser degree ship rat populations – have developed resistance against warfarin, which has reduced the worldwide popularity of the compound since the early years. The acute LD_{50} for Norway rats is between 10-20 mg/kg (Buckle, 1994) or 1.0 mg/kg daily for five consecutive days (Eason et al., 2002). House mice have shown a high degree of tolerance to warfarin, which is suspected to also be the case for ship rats (Buckle, 1994).

Table 1.2: Anticoagulant products used at Boundary Stream Mainland Island, and their toxic concentration. The lethal dose is a calculation of the respective LD_{50} as listed in Table 1.1, the toxic concentration of the product and the average weight of a ship rat (143 g). Values for toxic loads are sourced from Annual Reports, Pestlink Reports, and trial reports (published and unpublished) of Boundary Stream Mainland Island. All values for Norway rats except acute LD_{50} brodifacoum: ship rats and chronic LD_{50} for warfarin and pindone: rat species not specified.

Active ingredient	Trade name	Toxic concentration (g/kg)	Acute lethal dose (g)	Chronic lethal dose (g)
Brodifacoum	Pestoff®/Talon®	0.02	4.934	n/a
Warfarin	Wanganui No. 7	0.5	4.290	0.286
Diphacinone	Pestoff® 50D	0.05	20.020	1.001
Pindone	Pindone Pellets®	0.5	25.168	1.430
Diphacinone	Ditrac®	0.05	20.020	1.001
Coumatetralyl	Racumin®	0.375	6.330	0.114

1.5.4 Implications for rat control

Wild ship rats in captivity have been found to eat 14-18 g worth of pellets a night (Clapperton, 2006). If a rat consumed only half of this amount in toxic bait would be sufficient to ingest a lethal dose of anticoagulants, less for second-generation components.

1.6 Aims & objectives

In theory, the more that is known about the spatial patterns of a specific rodent population, the more efficiently it can be targeted in a pest control programme. This research therefore looked at the spatial distribution of the bait-take at BSMI and aimed to identify spatial patterns for the rodent population by answering the following research questions:

1. Were there any spatial patterns in the bait-take distribution and/or were they influenced by season?
2. Was the bait-take distribution influenced by habitat features such as vegetation, elevation and streams, or by infrastructure such as roads or walking tracks?
3. Was any edge effect displayed by the bait-take distribution and can reinvasion routes be detected?

The second objective of this research project was to determine the relative efficacy of the different bait types and active ingredients used at BSMI. This is to help with future management decisions as to which bait types and poisons to be repeatedly used.

Chapter 2: Methods

2.1 Study site

One of the six mainland islands that were established by DOC in the 1990s is Boundary Stream Mainland Island (BSMI) in Hawke's Bay. It was established in 1996 to investigate management options for forest remnants amidst farmland, which around BSMI is mainly pasture used for grazing cattle and sheep (Figure 2.1).

BSMI is situated on the Maungaharuru Ranges approximately 70 km northwest of Napier. It contains Boundary Stream Scenic Reserve – in this work often referred to as the 'main reserve' or 'main part of the reserve' – and Section 4, which is a smaller area to the west of Boundary Stream Scenic Reserve, separated from such by a gravel road and some pasture land. Together they cover an area of 800 ha. Apart from pasture, some unmanaged native and exotic forest are also adjacent to BSMI.

Since the establishment of BSMI, DOC has been undertaking 'Integrated Pest Management' to allow the ecosystem to recover and provide a safe environment for the re-introduction of formerly present endemic birds (DOC, 1998). To date, North Island robin (*Petroica australis longipes*), North Island brown kiwi (*Apteryx australis mantelli*) and North Island kokako (*Callaeas cinerea wilsoni*) have been successfully re-introduced since pest management commenced (DOC, 2006).

The integrated pest management in place at BSMI comprises a suite of control programmes targeting multiple mammalian pest species. Among the target species are ungulates, namely red deer (*Cervus elaphus scoticus*), feral pigs (*Sus scrofa*) and goats (*Capra hircus*), and small predators, namely possums (*Trichosurus vulpecula*), feral cats (*Felis catus*), mustelids (Mustelidae) and rodents (Saunders and Norton, 2001).

Rodent control at BSMI is based on a poison operation. After an initial aerial drop of 1080 (sodium monofluoroacetate), various anticoagulants and 'acute-acting' poisons have been applied to an evenly distributed grid of permanent bait stations (DOC, 1998). The efficacy of the poisoning operation has been monitored using tracking tunnels.

Two comparison sites (Thomas Bush, 87 ha, and Cashes Bush, 187 ha, see Figure 2.1) are associated with BSMI, with identical monitoring but no pest control. It is considered that the monitoring in the comparison sites reflects the abundance of pest species that could be expected at BSMI in the absence of pest control. The comparison sites therefore provide reference values for estimating the outcome of any particular treatment within BSMI (DOC, 1998).

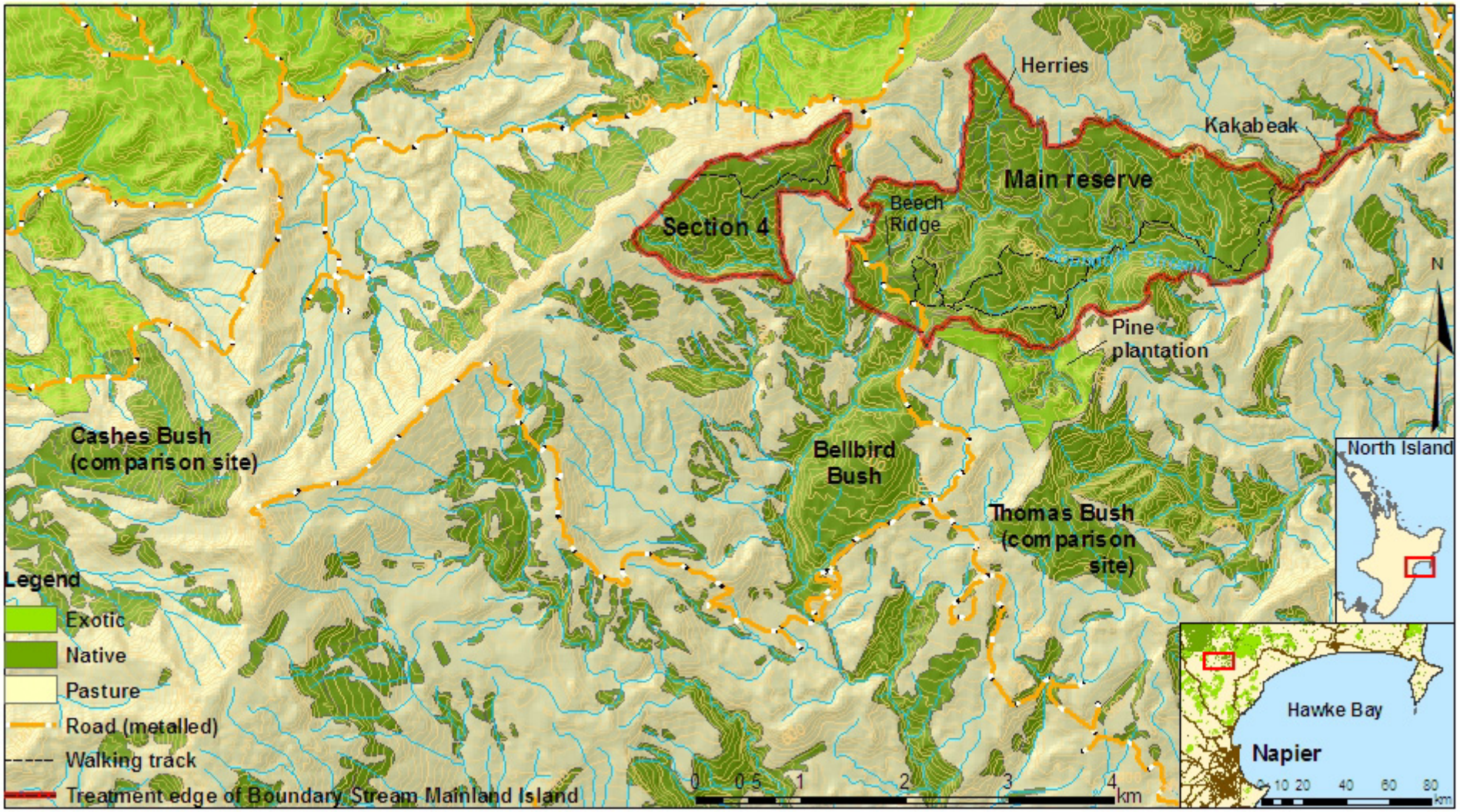

Figure 2.1: Location of Boundary Stream Mainland Island and associated comparison sites, Hawke's Bay, New Zealand.

2.1.1 Topography

BSMI covers an altitudinal range from 300 m to 1000 m above sea level (a.s.l.). Numerous streams and waterfalls have formed a complex topography of bluffs in the limestone rocks. The boundaries of BSMI roughly coincide with the ridgelines surrounding the valley system dominated by Boundary Stream. This stream traverses the centre of the main part of the reserve in an eastward direction and has given the name to the surrounding scenic reserve and the mainland island.

In concurrence with the eastward flow direction of Boundary Stream, the whole valley system in the main part of the reserve is orientated in an east-west direction. The right bank of the river is therefore predominantly north facing and, as such, tends to receive more sunshine making this area drier than the left bank of the river.

A long and narrow stretch of forest in the eastern end of the reserve is referred to as the 'Kakabeak block' and differs strongly from the rest of the reserve. Topographically it is dominated by two large cliff faces, one along the southern edge of Boundary Stream and the other one parallel to it along the southern reserve boundary. The north-facing aspect of the cliffs and the comparatively low altitude create a climate warmer and dryer than the rest of BSMI. The long narrow shape of the section results in presumably high levels of influence from the surrounding farmland. The western end of the Kakabeak block is dominated by Shine Falls, which is the highest waterfall in Hawke's Bay. The relatively easy access from the car park at the eastern tip of Kakabeak makes this a popular destination for visitors, attracting high visitor numbers using the walkway in this section.

2.1.2 Vegetation

BSMI comprises at least 12 distinct vegetation types and supports at least 220 species of indigenous plant species, several of them classified as 'threatened' (DOC, 1998; Walls, 1995). For practical reasons, which are explained on page 34, these 12 vegetation types were combined into four broader groups of vegetation: cloud-cap forest, broadleaved forest with tawa and podocarp, beech, and kamahi/kanuka/ rewarewa
(Figure 2.2).

The cloud-cap forest is found at high altitude just below the ridgeline of the Maungaharuru Ranges. Some small patches of red beech (*Nothofagus fusca*) are also found within this area. The boundary between the cloud-cap forest and broadleaved dominated forest closely follows the contour line at 860 m a.s.l. (Walls, 1995).

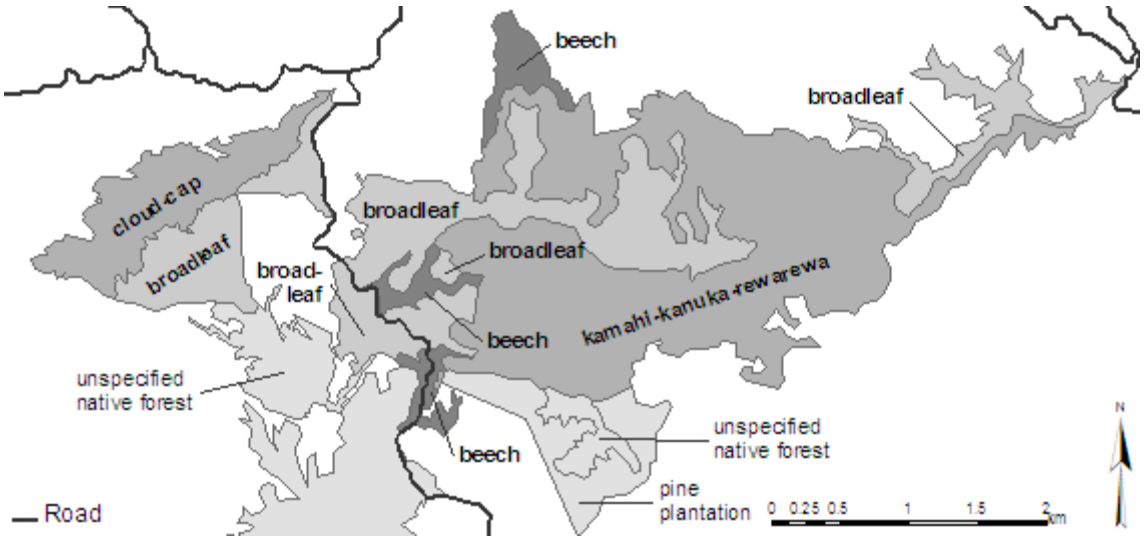

Figure 2.2: Vegetation at BSMI.

Broadleaved forest is found in the wetter areas of the reserve, which are, on the one hand, found at higher altitude and, on the other hand, in the lower parts of the valleys. A high-altitude version of broadleaved forest, with red beech and podocarps (Podocarpus), is found in Section 4, below the cloud-cap forest. Separated by deforested land and now used as farmland, broadleaved forest continues in the western part of the main reserve in a mid-altitude variety with beeches and big podocarps. Along the Boundary Stream valley, which runs eastward through the centre of the reserve, it merges into a broadleaved forest dominated by tall tawa (*Beilschmiedia tawa*) and big podocarps. Some of the stream valleys discharging into Boundary Stream from the north are covered in similar tall gully forest of tawa and other broadleaved trees. Some more broadleaved forest can be found on the left bank of Boundary Stream in the Kakabeak block. This narrow broadleaf area is characterised as low-altitude broadleaved forest with big podocarps and is discrete from the continuous area of broadleaf dominated land as described before (Walls, 1995). All these broadleaf dominated areas were combined to the vegetation class ‘broadleaf/tawa/podocarp’ or just ‘broadleaf”.

Areas of beech forest are found adjoining the broadleaved forest in the main reserve. In the western end of the main reserve, for example, is an area of mixed red beech-black beech (*Nothofagus solandri var. solandri*) forest. Being found on some ridges above about 750 m altitude, this area is known as ‘Beech Ridge’. Red beech forest is also found on the northern tip of an area above 700 m that stretches into the adjoining farmland known as ‘Herries’. Finally, red and black beech is found directly south of the reserve and stretches into BSMI where the road enters from the south (Walls, 1995).

The rest of the reserve is covered in kamahi (*Weinmannia racemosa*), kanuka (*Kunzea ericoides*) and rewarewa (*Knightia excelsa*), with one of the species alternating in dominance (Walls, 1995). The distribution of this vegetation type can be summarised by drier ridges, hill sides and terraces (Gundry, 2001), which is expressed in the fact that the north-facing and drier right bank of Boundary Stream is largely dominated by kamahi/kanuka/rewarewa.

2.1.3 Rodent management

2.1.3.1 Background

Of the four rodent species present in New Zealand, ship rats, Norway rats and house mice occur at BSMI, but ship rats and house mice are by far the most common (DOC, 1998). Although Norway rats are occasionally caught in stoat traps, this species occurs at negligible numbers, which is consistent with their country-wide rat distribution (King, 2005).

House mice are abundant at BSMI and have remained so throughout the rodent control programme. In fact, with the relative absence of predators they occur at higher densities than they usually do in comparable habitats, including the comparison sites of BSMI. Due to their small body size and considerably smaller amount of food intake per day compared to that of rats, however, only a small proportion of the overall bait-take is considered to be accounted for by mice.

For the purpose of this work, it was assumed that first and foremost it is the ship rat population that was firstly responsible for the bait-take as well as notably impacted by the poisoning operation.

2.1.3.2 Rodent control

Rodent control at BSMI was based on toxic baiting, applied in permanently installed and regularly serviced bait stations. Philproof® bait stations were nailed on trees about 20-25 cm above the ground to prevent ground-nesting birds and other non-target species from being exposed to the poison. Bait spillage, however, was regularly reported and exposed a wide range of non-target species to the poison, an issue that is unlikely to be permanently resolved.

Bait station setup 1

In 1996, 558 bait stations were permanently installed within BSMI. Of these bait stations, 229 were placed on the perimeter of the reserve at a 100 m spacing. Some 21 of these 'perimeter bait stations' were placed along the road which cuts through the main reserve and runs along the boundary of Section 4. The remaining 329 'interior bait stations' were placed at a grid of 150 x 150 m spacing across the reserve (Figure 2.3). These numbers include a total of 132 bait

stations that were situated in Section 4, 63 of which were in the interior and 69 on road and perimeter.

Rodent control in the Kakabeak block commenced in winter 1997, when 29 bait stations were installed. Due to its irregular shape, and being dominated by large cliff faces, the bait station setup in this area follows access practicality rather than a grid shape. Half of the bait stations follow the walking track and the other half is placed along the northern boundary between forest edge and farmland.

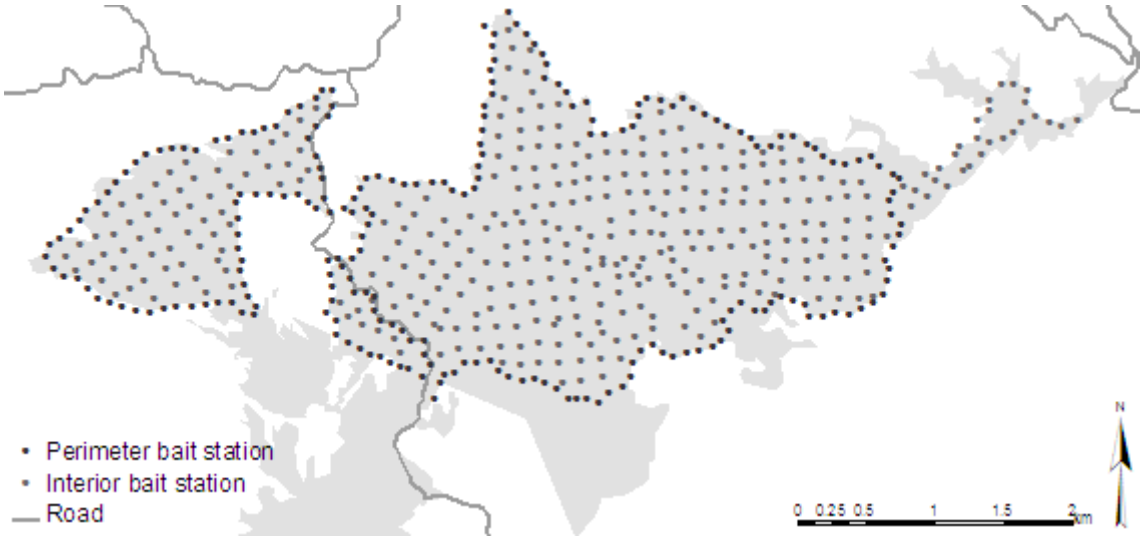

Figure 2.3: Bait station setup until 2006. The Kakabeak bait stations were added in 1997 and were treated the same way as interior bait stations.

Bait station setup 2

During winter 2006, the grid size of the interior bait station was decreased to 150 x 75 m. In the process, 281 bait stations were added in between already existing bait stations in the main reserve and 69 in Section 4 (Figure 2.4). BSMI now comprised 679 interior bait stations. The setup of the perimeter bait stations remained largely the same. The only alteration here was that the Kakabeak block received seven extra bait stations to comply with the 100 m spacing of perimeter bait stations and since then has been treated as a perimeter bait station line.

Figure 2.4: Bait station setup from 2006 onwards. Kakabeak bait stations were treated the same way as perimeter bait stations.

On two occasions the poison was not, or not entirely, applied in bait stations. Firstly, prior to commencement of the bait station based rodent control, an aerial drop of 1080 was carried out in 1996. Secondly, during the coumatetralyl regime in 2006, for a period of 6 months extra coumatetralyl baits packed in re-sealable plastic bags were nailed on trees in addition to the baiting in the bait stations. Two plastic bags were placed between bait stations, reducing the bait station grid to 150 x 50 m. High take of the bait from the plastic bags and particular animal signs in close proximity suggested that it was not only rodents, but often feral pigs and other non-target species that also consumed those baits.

2.1.3.3 Rodenticides and their recording

Ten different commercial products of toxic bait with seven different active ingredients were used at BSMI between 1996 and 2007. Each product came in different bait sizes and varied in quantity of bait put into bait stations at the time. The bait-take was recorded at each bait station servicing and followed different classifications. Both the history of bait usage and the recording methods – largely in chronological order – are described in the following section. If, at the fillers' discretion, finer estimations of bait-take were recorded, then these finer estimates were used in the analysis.

Sodium monofluoroacetate (1080)

Aerial-sown 1080 was applied in late May 1996 prior to commencing the ground poison operation. As opposed to the following poison applications, this initial aerial operation covered both treatment area (BSMI), the non-treatment comparison sites as well as public conservation land within a 5 km radius (DOC, 1998). Due to equipment failure, in Cashes

Bush – one of the two comparison sites – the bait was hand-sown three weeks after the aerial drop and subsequently bait-take was not recorded.

In 2005, 1080 was applied in a ground operation. The amount of 250 g of cereal 1080 was applied in bait stations for a two week period, after 10 days of 250 g of non-toxic cereal prefeed (DOC, 2006). The bait-take was recorded in steps of 10 % for both.

Brodifacoum

Brodifacoum was used in cereal pellets with a toxic load of 0.02 g/kg (Pestoff® 20p manufactured by Animal Control Products Ltd., and Talon®) for the first five years of the mainland island project (DOC, 2003). No other second-generation anticoagulant has been used at BSMI since, and DOC policy now strongly favours the less persistent first-generation anticoagulants for sustained use on the New Zealand mainland.

After the initial 1080 drop, 500 g of bait was applied on a monthly basis. In November 1997, this was reduced to 250 g on a two-monthly cycle. In both cases, bait-take was assessed by measuring the portion of remaining bait in a calibrated container (DOC, 2000) and was recorded in steps of 10 %. Remaining bait in good condition was left in the station and topped up with fresh bait.

Warfarin

Warfarin was trialled only in Section 4 for a period of three months in winter 1999 (DOC, 1999, unpublished). In May 1999, 500 g of non-toxic prefeed (Wanganui No. 7 cereal pollard, unflavoured; manufactured by Animal Control Products Ltd.), was put in for one month, and once during this time checked and refilled. In June the prefeed was replaced with 500 g of toxic warfarin bait with a toxic load of 0.5 g/kg. It was checked and refilled once before being removed in August 1999.

At time of each bait check and change-over, the bait-take in steps of 10 % was recorded and stations refilled with prefeed or bait respectively (DOC, 2000).

Cholecalciferol

Cholecalciferol was applied twice over the years. In 2000, Feracol® paste with a toxic load of 1 g/kg cholecalciferol manufactured by Feral Control Products was trialled to investigate alternatives to the brodifacoum regime at the time. In May, all bait stations were filled with 100 g of cholecalciferol paste (Feracol®). In July the stations were checked and refilled. In August all cholecalciferol was replaced with brodifacoum (DOC, 2000, unpublished). At each bait check, the percentage of bait-take was recorded in three classes: 100, 50 or 0 %. In August, when the Feracol® was replaced with brodifacoum, the bait-take was recorded in

steps of 10 %. Non-toxic prefeed, as commonly used for acute poisons such as cholecalciferol, was not used.

In 2007, Feracol® with 8 g/kg cholecalciferol (manufactured by Connovation Ltd.) was applied in a pulsed application only on the perimeter bait stations in 2007. After four weeks of non-toxic prefeed, toxic bait was applied for four weeks before it was replaced with coumatetralyl. This pulsed regime replaced the previous application of Feratox® in preventing possum reinvasion (see below).

Cyanide

Cyanide was used to prevent reinvasion of possums into the reserve. Feratox® capsules (now manufactured by Connovation Ltd.) were placed in peanut butter paste and put in small re-sealable plastic bags, which were attached to the bait stations. First trialled in Section 4 coinciding with the cholecalciferol trial in 2000, it was then applied continuously in all perimeter bait stations between 2001 and 2007. At times it was applied to some interior bait stations with continuously high bait-take.

Although the cyanide was solely targeting possums, peanut butter is a better lure for rodents. This eventually led to discontinuity of the application of Feratox®, since with extremely low possum densities in the area around BSMI, a lot of bait interference was contributed to rats (Thomas et al., 2003).

For the purpose of this work, Feratox® is regarded as irrelevant for the rodent control operation.

Pindone

Pindone Pellets® (cereal pellet bait manufactured by Pest Management Services Ltd.) with a toxic load of 0.5 g/kg was used between 2000 and 2005 (DOC, 2006). During this time its application was discontinued for a period of six months for an experimental trial of diphacinone in 2003/2004.

Every six to eight weeks, the bait-take was checked and refilled to 250 g per bait station or replaced as needed. Bait-take was recorded in steps of 10 %.

At the time, pindone was actually not registered for rodent control in New Zealand.

Diphacinone

Between December 2003 and June 2004, diphacinone (0.05 g/kg in Pestoff® 50D cereal pellet baits, manufactured by Animal Control Products Ltd.) was trialled in all bait stations as part of a National Science and Research trial (DOC, 2005; Gillies et al., 2006). Bait-take was recorded in steps of 10 %. Like pindone, bait stations were checked, refilled, and if necessary

degraded bait was replaced, on a two-monthly cycle. In June 2004, diphacinone was once again replaced with pindone.

Due to the previous good results with diphacinone during this trial, the pindone was then replaced with Ditrac® in March 2005 (0.05 g/kg diphacinone in block baits, manufactured by Bell Laboratories Inc.). Nine blocks of Ditrac®, which added up to about 250 g, were strung on a wire and attached to each bait station. Each wire was replaced with a new one with nine fresh blocks if, at the time of bait station servicing, equal or less than four baits appeared to be in good condition. If at least five blocks were in good condition, the wire was left in the bait station for another month. Due to the cost of Ditrac® blocks, bait was recycled unless they were mouldy. On bait checks, the number of remaining bait blocks was recorded. In a Microsoft Excel© spreadsheet, the number of remaining bait blocks were subtracted from the remaining bait of the previous month. Due to all bait blocks being equally available for consumption, the recording of remaining bait blocks proved difficult. Partially eaten bait blocks were interpreted differently by different fillers as in respect to the estimation of the number of remaining bait blocks. The following example was frequently found on the recording sheets: during one bait check the filler recorded seven or eight remaining bait blocks and left them in the field. The following bait check, the same bait station was recorded with nine remaining bait blocks. As this resulted in a negative bait-take, the bait-take was manually changed to zero.

The use of Ditrac® was discontinued for a period of a month in June/July 2005 for the duration of the previously mentioned 1080 application, and was resumed afterwards.

Coumatetralyl

Coumatetralyl was used at BSMI in Racumin® paste with the standard toxic load of 0.375 g/kg (manufactured by Bayer AG; DOC, n.d., unpublished) between 2006 and 2008. Racumin® paste was packed in individual packets of 100 g each.

Between February and May 2006, three paste packets of Racumin® were applied in bait stations as well as in each of the additionally installed re-sealable plastic bags that were nailed to trees or fence posts between bait stations (see section 2.1.3.2). Due to the size of the bait blocks, the field recording was measured in broad categories of zero bait-take, 1-100 g left (up to one paste block), 101-200 g left (up to two paste blocks) or 201-300 g left (up to three paste blocks).

In May 2006, the amount of bait was reduced to two paste packets. The field recording was amended accordingly to zero bait-take, 1-100 g or 101-200 g. In August 2006, the additional

re-sealable plastic bags were removed, but successively additional bait stations were installed and filled with 200 g of bait.

In this work, the bait-take of coumatetralyl was converted to the midpoint of each category. The bait-take of the re-sealable bags was not included in the analysis since the exact location of those bags is not known.

2.1.3.4 Rodent monitoring

To ensure the effectiveness of the poisoning operation, population trends were closely monitored at all times. To do this, tracking tunnels were run concurrently with the rodent control operation. These tunnels were generally placed in lines of 10-25 tunnels with 50-75 m spacing and were monitored on a regular basis at least four times per year, covering every season. Additional runs were undertaken if needed, such as before and after specific bait trials, or before and during bird species re-introductions or translocations. For example, during the diphacinone trial in 2004, rodents were monitored twice during autumn and the following winter. In 2006/07, the tunnels were monitored more often than usual to check whether tracking indices complied with the requirements for a proposed transfer of North Island kokako, which requires rat tracking indices (RTI) < 5 % (K. Nakagawa, biodiversity ranger at BSMI, pers. comm., 2008).

The setup of the tracking tunnel lines was reviewed and changed several times as follows:

Tracking tunnel setup 1

In April 1996, four permanent lines of 25 tunnels at 50 m spacings were set out in the Treatment Site, and two in each of the non-treatment sites (Figure 2.5, lines marked with '1'). All lines were established in relation to major vegetation types, namely kamahi, kanuka, tawa-podocarp and beech, which – apart from the separation of kamahi and kanuka – matches the vegetation classes used in this work. The lines were randomly placed within large contiguous areas of each forest type (DOC, 1998). Due to the small size of the two non-treatment sites, some lines were not randomly placed, but were situated adjacent to existing tracks. Philproof® tracking tunnels were used, being a 75 cm long x 8 cm wide base, with circular entrance holes with a diameter of 6 cm on either end of the tunnel (DOC, 1998). There was no line in Section 4, and none in the lower eastern part of the reserve.

Tracking tunnel setup 2

In September 1997, a specific tracking tunnel trial was established to assess the following concerns: The existing 150 x 150 m spacing of bait stations was suspected to be too large for the poison to be available to the entire rodent population. Furthermore none of the original lines had been placed in the upper or lower parts of the reserve, therefore may not have

adequately sampled the entire treatment site. For the trial, two tracking tunnel lines with 25 tunnels each were established in relation to existing bait station lines in the upper (Section 4) and lower (Wallow/Cecilies) parts of the reserve. Of these 100 new tracking tunnels, 32 tracking tunnels were placed next to bait stations, 36 tunnels 75 m (halfway between two bait stations) and 32 tunnels 105 m away from bait stations (midpoint between four bait stations) (Figure 2.5, lines marked with '2'). These lines were run and baited in the same way and on the same days as the existing tracking tunnels (DOC, 2000). After the end of the trial, these additional tracking tunnels continued to be used for rodent monitoring.

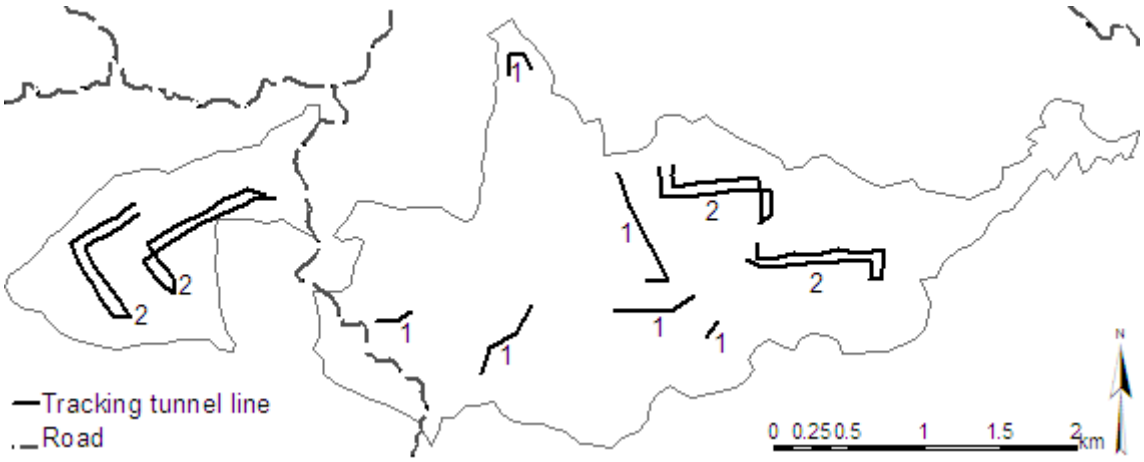

Figure 2.5: Tracking tunnel setup 1 and 2. Lines marked with '1' are the original lines. Lines marked with '2' were added in 1997. Data sources: (1) map in the BSMI project report of 1998-2000 (DOC, 2000); (2) tracking tunnel line descriptions compiled and used by DOC staff at the time. These descriptions included information on the location at or between bait stations.

Tracking tunnel setup 3

In November 2001, the rodent monitoring was converted to another existing tracking tunnel setup that previously had been used for mustelid monitoring in November 2001 (DOC, 2002). Instead of few long lines, these original mustelid lines were shorter, covered more area (Figure 2.6), and improved the efficiency of the small mammal monitoring. Each tracking tunnel line consisted of 10 Corflute® tunnels with 50 m spacing. Line directions ran from random start points. Eight lines were located in BSMI and six lines in the comparison sites. In BSMI, the lines were placed evenly in the major vegetation types in relation to their proportional area: one line was placed in beech, one in high altitude forest (Section 4), two in kamahi/kanuka/rewarewa, and one in tawa/podocarp/broadleaf. Three additional lines ran along the edge of the reserve. Non-treatment lines were established using a similar process (DOC, 2000, 2002).

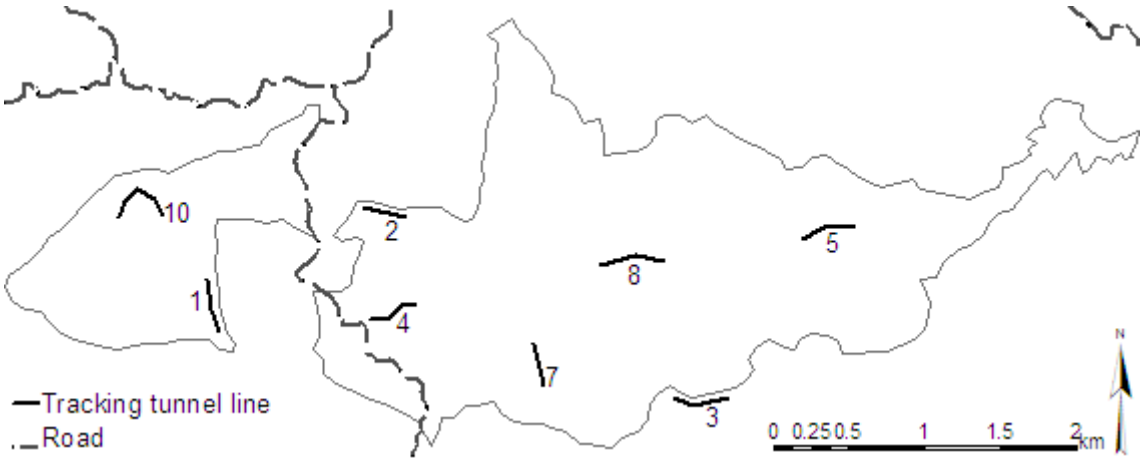

Figure 2.6: Tracking tunnel setup 3. All lines had been previously used for mustelid monitoring. Labels refer to the original numbering. Lines 1-3 were placed on the treatment edge, line 4 in beech, line 5 and 7 in kamahi/kanuka/rewarewa, line 8 in broadleaf/tawa/podocarp and line 10 in high altitude forest. Line 6 and 9 had been removed prior to shifting the rodent monitoring to these lines. Data source: map in the BSMI project report of 1998-2000 (DOC, 2000).

Tracking tunnel setup 4

Due to some concern regarding the lack of true randomness of tracking tunnel setup 3, these lines were then replaced by 12 new random lines in 2006 (Figure 2.7). The bait station spacing was also reconsidered at this time (DOC, n.d., unpublished).

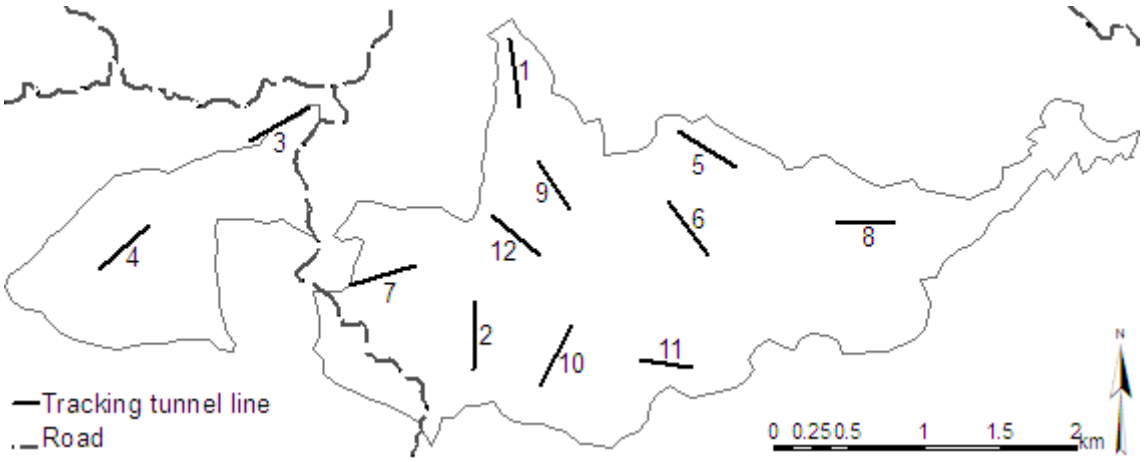

Figure 2.7: Tracking tunnel setup 4. Data source: Locations of beginning and endpoints of each line were collected using GPS handheld units. The points were then connected by a straight line in ArcGIS™.

Tracking tunnels in comparison sites

The tracking tunnel lines that were installed in the non-treatment comparison sites were monitored at the same time as in the treatment site. The tracking tunnel setup in the non-treatment sites was only changed once: in 2001 the originally four lines of 25 tracking tunnels were each replaced by six lines of 10 tracking tunnels each (equivalent to change from tracking tunnel setup 2 to 3).

2.2 Field data

All field data was obtained from the regular field work conducted at BSMI and includes the entire bait station servicing records as well as the rodent monitoring data from the start of the project in 1996 until the end of spring 2007, covering all four seasons of 11 years. All data collection was carried out by five permanent staff members continuously employed by DOC, as well as varying numbers of temporary contractors and volunteers.

2.2.1 Bait stations

2.2.1.1 Data collection

Every four to twelve weeks all bait stations were checked, the bait-take recorded and, if necessary, refilled with fresh bait, the amount and type of which was documented as well. The field recordings were mostly based on visual estimation and categorised with an accuracy varying between the different bait types. Observations of bait degradation, signs of animal activity and other indicative information were also noted (DOC, 1998).

2.2.1.2 Data transformation

The entire data set was transformed into a Microsoft Excel© 2003 data set containing the following information for each bait station at each servicing:

1. Date of servicing;
2. Active ingredient and trade name of bait used for refill;
3. Active ingredient and trade name of bait used at previous servicing;
4. Amount of bait remaining and refilled; and
5. Bait-take estimated in % and grams.

The specification of bait used and the amount of bait refilled derive directly from the field recording sheets. Depending on the recording technique used at the time, either the amount of bait remaining or the bait-take in % is also taken directly from the recording sheets. The remaining bait values were calculated in the Microsoft Excel© spreadsheet as follows:

1. Bait-take: If bait-take was recorded in %, the value was converted into bait-take in g and vice versa.
2. Bait remaining: Subtraction of bait-take in g from the amount originally put in.

Every bait-take-entry was assigned to a season according to when the data was collected. Bait station servicing between September and November were assigned to spring, December to February to summer, March to May to autumn and June to August to winter.

Bait station servicing was done separately for perimeter and interior bait stations, but within those two groups they were done collectively. Weather and staff permitting, it usually took between one and three weeks to complete the servicing of either the interior or the perimeter bait stations, the latter usually being completed more quickly. If the bait station servicing for either the interior or the perimeter bait stations was started in one season and finished in another, the entire bait station servicing was assigned to the season in which it was begun. Only if no more than one or two bait station lines were done in the previous season, was the whole bait station run assigned to the following season.

2.2.2 Tracking tunnels

2.2.2.1 Data collection

To monitor the relative rodent densities and their fluctuations over time, 'rodent tracking indices' were collected regularly at BSMI throughout the rodent control operation. After one night in the field, the tracking tunnel papers were collected and individually analysed by identifying the footprints left behind by animals that had passed through during the night. Since footprints of mice and rats are distinctly different, this method allows distinguishing between the two, although a distinction between the two different rat species is not possible.

The percentage of tunnels tracked by each species was then calculated. Tracking tunnels where the papers were not found in place at time of pick up, which hedgehogs were suspected to have been squeezing through the tunnel and pulling the papers out in the process, were removed from the sample (DOC, 1998). The resulting percentage is referred to as the tracking index for each species and are used to evaluate the efficacy of rodent control programmes (Brown et al., 1996). In this work, only rat tracking indices (RTI) were analysed.

2.2.2.2 Data transformation

The factors possibly influencing the RTI were the tracking tunnel setup, the poisons used at BSMI, the number of bait stations installed at BSMI, seasons during which the RTI were collected, as well as weather patterns during the time when the tracking tunnels were deployed in the field. These factors were incorporated into a Microsoft Excel© 2003 spreadsheet with the following information:

1. Season in which tracking tunnels were monitored;
2. RTI for each season in BSMI (average if more than one RTI was collected in one season);
3. RTI for each season in the non-treatment comparison sites (average if more than one RTI was collected in one season);

4. Number of RTI used to calculate the average (if more than one RTI was collected during same season);
5. Number of tracking tunnels used for the calculation of the RTI (if information available, excluding interfered tracking tunnels that were removed from the sample);
6. Weather condition during tracking tunnel run (rain or no rain);
7. Tracking tunnel setup (previously mentioned tracking tunnel setup 1-4);
8. Number of bait stations installed at BSMI; and the
9. Active ingredient and bait type.

If more than one poison was used during a season, the bait that was applied during the majority of the season was incorporated into the spreadsheet. This required that those poisons that were restricted to certain areas do not appear in the analysis. This includes the bait trials in Section 4 (warfarin in winter 1999 and cholecalciferol in winter 2000) and the pulsed poison applications (1080 in 2005 and cholecalciferol on the perimeter in 2007).

For the time period between summer 1998/99 and winter 2001, only the RTI and the corresponding bait information are available. Weather information and the number of tracking tunnels used for the calculation of the RTI are not available for this time period.

2.3 Analysis of bait-take

The spatial distribution of the rat population at BSMI is based on the amount of bait taken from the bait stations as recorded every time the bait stations were checked and refilled. The spatial analysis of the bait-take was done using ArcGIS™ version 9.2. Further statistical analysis was done using Genstat version 11 (see chapter 2.3.3 for further details).

Habitat factors possibly affecting rodent distribution include topography, vegetation type, proximity to streams, roads, walking tracks or the edge of the treatment area. Topography is associated with gradients in temperature and humidity, whereas vegetation, often coherent with topography, is associated with habitat preferences and food abundance. Edge effects may also influence the rodent population by identifying reinvasion, while streams within the reserve provide water and potential migration routes. Roads and walking tracks may also be possible reinvasion and migration routes. In regards to possible source populations for reinvading rats, the adjoining landscape and their vegetation types were also taken into account.

2.3.1 Spatial data

All habitat factors derived from the following sources and were added as layers to ArcGIS™:

2.3.1.1 Bait station locations

The location of the bait stations were obtained by DOC staff and volunteers using various Garmin GPS handsets prior to the beginning of this research. The accuracy of the locations varied due to the forest canopy, but an effort has been made to stay within ± 10 m accuracy whenever possible, at times with the help of makeshift aerials. Three bait station locations were not determined with GPS but were added in ArcGIS™ (pe111, pe209, fal74). Their locations were estimated in relation to the forest edge or distance to neighbouring bait stations with known location.

2.3.1.2 Vegetation

The vegetation layer was based on a vegetation survey map of BSMI produced prior to the beginning of the mainland island project. In the hand-drawn map, Walls (1995) identified 12 distinct vegetations types in and around what was to become BSMI. This map was scanned, georeferenced and digitised in ArcGIS™.

Due to the difficulty of transferring a hand-drawn map accurately into digitised form, the original 12 vegetation types were combined to four broader vegetation classes (Figure 2.2):

1. Beech;
2. Broadleaf/tawa/podocarp;
3. Cloud-cap-forest or high-altitude forest; and
4. Kamahi/kanuka/rewarewa.

2.3.1.3 Treatment area

The treatment area of BSMI was confined by the bait station coverage. All perimeter bait stations, including the Kakabeak bait stations, were connected by a straight line, marking the effective treatment edge.

2.3.1.4 Further map features

1. The forest edge was digitised from aerial photos retrieved from MapToasterTopo© map revision 4.0.
2. The locations of streams were digitised from the Topographic Map 260-V19 Te Haroto (1:50000) (LINZ, 2000).
3. The location of the walking tracks inside BSMI was based on GPS data collected by DOC staff and volunteers.
4. Topography was based on the North Island Digital Elevation Model (DEM) with a cell grid size of 25 x 25 m. It was clipped to an appropriate size relevant to BSMI ("BSMI-DEM").

2.3.2 Spatial analysis

2.3.2.1 Inverse Distance Weighted interpolation

To turn bait-take data into spatial data, the average bait-take for each bait station during specified time periods was calculated for each bait station in Microsoft Excel©. The time periods varied with each research question and ranged from individual seasons to the bait-take during the same season over a number of years. These mean values were then joined to a shapefile containing the point locations of the bait stations in ArcGIS™. Bait stations without any bait-take values for the corresponding time period were removed from the shapefile.

Each point layer was then interpolated to the whole area of BSMI using 'Inverse Distance Weighted interpolation'. Inverse Distance Weighting is a local interpolation method that uses the known values of data points in a specified neighbourhood to predict the values for all unmeasured locations in between (Burrough and McDonnell, 1998). The value of any point between measured sample points is assumed to be a distance-weighted average of the known data values in the specified neighbourhood. The closest neighbours are given the greatest weight, whereas the influence of further away data points rapidly decreases (Mitchell, 2005). In an automated cross-validation, each measured point is removed and compared to the predicted value. The power value in the interpolation process that minimises the root-mean-square of the cross-validation is the 'optimised power value'. This determines the decrease of the weight of a data point with increasing distance (Johnston et al., 2001). The result is a continuous grid layer that visualises effectively how values are distributed across the whole area.

For the interpolation of the bait-take data, the inverse distance weighted interpolation method in the Geostatistical Analyst within ArcGIS™ was used. The number of neighbours included in the interpolation process was set to 12[1], with a minimum of 10. Then optimised power value was calculated and applied for the interpolation as provided by the Geostatistical Analyst. For the seasons after the increase of bait stations from 587 to 944 in 2006, the number of bait stations included in the interpolation process was adapted to the number of bait stations serviced during the corresponding time period.

If single missing values in perimeter bait stations resulted in incomplete coverage of the reserve area, the extent of the interpolated layer was manually changed to the same extent of

[1] This mostly included the immediate neighbours at a high weight and the bait stations immediately surrounding those at a lower weight. This takes into account that one rat with a home range of maximum 175 m length (Dowding & Murphy 1994) would feed only from the immediately surrounding bait stations, but no more. Therefore only the closest bait stations were likely to be closely related to each other, while the influence rapidly decreased beyond.

the BSMI-DEM. Only when the Kakabeak block was not serviced an entire season, or before installation of bait stations in this area, the area appears blank in the maps.

The default output is a filled contour grid layer, which was then manually classified as described in the following section.

2.3.2.2 Bait-take classification

In order to be able to display and visually compare bait-take of different poisons, bait types, amounts of bait put out and differing recording methods, a classification that fitted all poisons as best as possible was necessary. The bait-take in grams was chosen, because the analysis included grouping of bait-take by season across many years and various amounts of poison put out. The following classification was applied in all spatial analyses:

1. 0 g (unused bait station);
2. 1-10 g;
3. >10-50 g;
4. >50-150 g; and
5. >150 g.

Bait-take class 2, of no more than 10 g bait-take, would be enough to kill a rat if consumed by one single rat in one single feed (in particular second-generation anticoagulants) and in multiple feeds over five consecutive days (first-generation anticoagulants; Buckle, 1994). Assuming, however, that bait stations are usually within reach of more than one rat – and likewise assuming that all rats use a bait station equally – then 10 g is not likely to have been sufficient bait-take to kill a single rat. Bait-take classes 1-2 therefore are not considered to having impacted the local rat population.

Bait-take of 10-50 g (bait-take class 3), however, is highly likely to have killed at least one rat. Because anticoagulants allow a rat to keep eating bait after the ingestion of a lethal dose, however, it is possible that only one rat could have eaten most of it, thus only killing one single rat. With offspring over two per rat per year, the kill of one rat is not a decimation of the rat population.

All following bait-take class breaks is at multiples of 50 g. The highest bait-take class is bait-take over 150 g and includes 100 % bait-take, which means that more bait may have been consumed if more had been available.

2.3.3 Statistical analysis

2.3.3.1 Effect of vegetation

To determine whether the vegetation type around bait stations had an effect on bait-take, each bait station was allocated to the corresponding vegetation class 1-4 (see chapter 2.1.2). This was done in ArcGIS™ by going through the following process:

1. Each vegetation class 1-4 was selected and exported into a separate shapefile.
2. All bait stations which were located within this particular vegetation class were selected using the 'Select by location' function.
3. Using the field calculator, the vegetation class name was then added to the attribute table of the bait station shapefile (perimeter bait stations that were right on the forest edge or just outside the forest were manually assigned to the corresponding vegetation class inside the treatment area).

To attach the vegetation information to the bait-take dataset, the attribute table of the bait station shapefile was opened in Microsoft Excel© and attached using the VLOOKUP function.

2.3.3.2 Edge effects

Any possible edge effects were decided to be most likely shown within 150 m from the treatment edge. This includes not only the perimeter bait stations, but also a number of interior bait stations.

The bait stations located within a 150 m buffer from the treatment edge were selected with the 'Select by location' feature in ArcGIS™ and identified as such in the attribute table of the bait station shapefile. The attribute table was then opened in Microsoft Excel© and the appropriate information attached to the bait station dataset using the VLOOKUP function.

2.3.3.3 Analysis

To determine whether vegetation or edge effects had an effect on bait-take, both variables were incorporated into a Generalised Linear Mixed Model with a normal error distribution using Genstat version 11. This analysis was run on the percentage bait-take for each individual bait station over the entire research period between 1996 and 2007. The reason for choosing the bait-take in percent for this analysis is because these values followed a normal distribution. Random terms in the model were the year, season and the individual bait station serviced during those seasons. The fixed terms in the model were the active ingredient, stations in the 150 m buffer from the treatment edge, vegetation class and the season in which the bait-take was recorded.

Significance of each factor was determined by Wald tests, with each factor individually dropped from the full model to assess significance (Fahrmeir and Tutz, 2001). To allow pairwise comparisons, the maximum standard error of differences was multiplied by 1.96 to approximate a Least Significant Differences (LSD) with $\alpha = 5$ %. If the difference between two factor comparison values exceeded the LSD, these two categories were considered to be significantly different.

2.4 Analysis of rat tracking indices

Rat tracking indices (RTI), as calculated from the tracking tunnel data, were analysed to determine the efficacy of the rat control programme at BSMI. RTI estimates and associated factors were analysed in Genstat version 11 using a Generalised Linear Model with a normal error distribution. For this analysis, the mean RTI was calculated for each season. This was done because monitoring was not conducted at set dates, however, there was always at least one monitor conducted each season. To best fit the model to the data, the data was log-transformed. The associated factors were:

1. Number of bait stations installed at BSMI at the time (bait station setup 1-2);
2. Season;
3. Weather (rain or no rain); and the
4. Bait treatment (poison and bait type).

The mean RTI were then weighted by the number of tracking tunnels that were used for calculating the RTI to allow for changes in the tracking tunnel setup 1-4. The significance of each factor was determined by Wald tests, with each factor individually dropped from the full model to assess significance. To allow pairwise comparison between categories within each factor, Fishers Protected LSD with $\alpha = 5$ % were calculated. If the difference between two log-transformed values exceeded the LSD, these two categories were considered to be significantly different.

For visualisation in graphs, the actual mean values were used. Standard errors were also added to account for the variation.

To validate the findings, the same analysis as above was repeated on the RTI estimates in the comparison sites. The RTI were also weighted by the number of tracking tunnels used for calculation of the RTI, but did not need to be log-transformed. Of the above factors, only season and weather were applicable since no treatment was done in the comparison sites. However, the effect of the change in the tracking tunnel setup 1-2 in the non-treatment sites was included as a factor for this analysis.

Chapter 3: Results

3.1 Bait-take over time

The research period of this work started in winter 1996 and continued to spring 2007, which included 46 individual seasons. Perimeter bait stations were filled, checked and refilled 119 times, while interior bait station lines were serviced 90 times.

Altogether, 53,164 servicings of individual bait stations were recorded. This included 1,011 entries with no bait-take records because of first fills of new bait stations or refills after previous bait removal. These entries were removed from the sample before any spatial or statistical analyses.

Of the remaining 52,153 bait check entries, 717 were 'missing values'. Missing values came about when, for example, field recording sheets disappeared before data entry, when bait stations were failed to be recorded in the recording sheets, when started bait station lines were not completed or when individual bait stations were not found in the field. Missing values were disregarded in statistical and spatial analyses.

Figure 3.1 shows how both the overall bait-take across the entire reserve as well as the average bait-take per bait station developed through the 46 seasons of the research period.

Each changeover to a new bait product applied in the entire reserve was accompanied by a peak in the same or the following season in either overall and/or mean bait-take. Bait-take in both categories was highest in spring 1996 when all bait stations were checked and refilled for the first time. Both bait-take categories were again high following the bait-removal from the entire reserve and the warfarin trial in Section 4 in winter 1999. After 1999, the mean bait-take per bait station fluctuated roughly between 50 and just over 1000 g, while the overall bait-take rarely exceeded 150 kg per season. Both bait-take categories were lowest around the first introduction of pindone in autumn and summer 2003/04 and just before the diphacinone trial in 2004.

Mostly, peaks and low points in both datasets corresponded. At only few occasions they did not. In winter 1999, for example, the overall bait-take was very low while the mean bait-take was extremely high. The low overall bait-take was due to the bait removal from the entire reserve in the previous season. The extremely high mean bait-take in this winter only refers to the bait stations in Section 4, where warfarin was trialled. Overall and mean bait-take also digressed from the mostly corresponding peaks and lows during coumatetralyl application with beginning of the installation of extra bait stations in winter 2006. While the mean bait-

take stayed at a consistent level, the overall bait first dropped in winter, then rose steadily to a peak in autumn 2007 and then dropped just as steadily until the end of the research period.

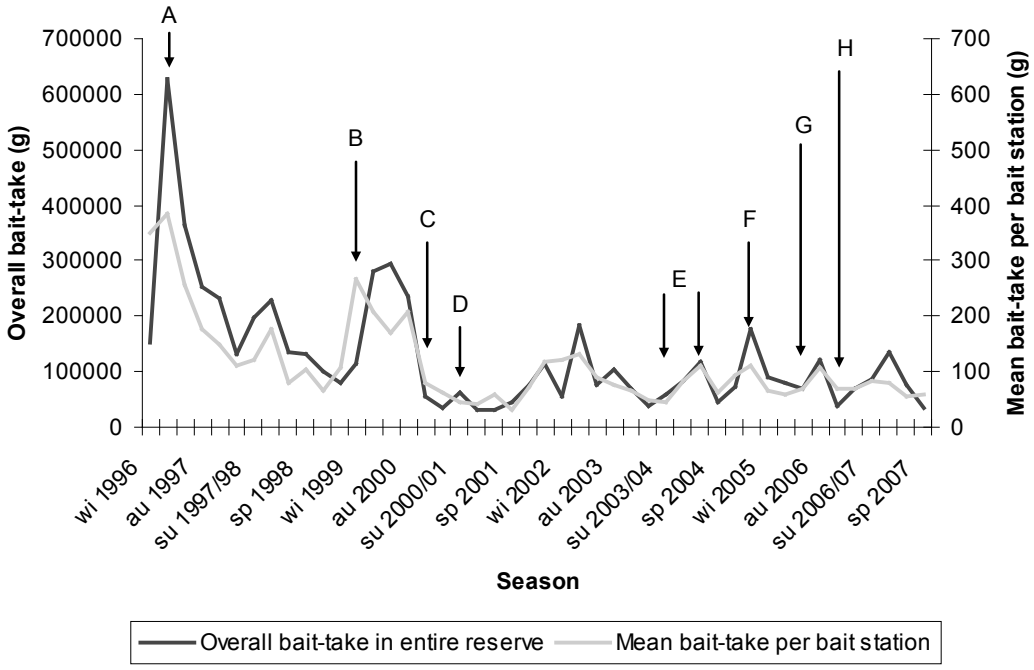

Figure 3.1: Development of the bait-take through the whole research period and important events. The bait-take is plotted by overall take across the entire reserve and the mean take per bait station. (A) First season with all bait stations filled and checked; (B) bait removal over the winter period in 1999 and warfarin trial in Section 4; (C) cholecalciferol trial in Section 4; (D) changeover to pindone; (E) beginning and end of diphacinone trial in entire reserve; (F) changeover to diphacinone; (G) changeover to coumatetralyl with extra bait in plastic bags in between bait stations; (H) successive installation of 357 extra bait stations.

3.2 Bait-take and rat tracking index

The average bait-take per bait station was nearly 400 g at the beginning of the project and then dropped quickly (Figure 3.2). Between 1997 and 2003 it fluctuated mainly between 50 and 150 g, between 2003 and 2007 between 50 and 100 g. A peak was recorded in 1999 and 2000 after the bait removal during winter 1999. The mean bait-take was always well below the amount of bait that was put out into each bait station. Generally, when bait amounts were reduced, this was done as a reaction to bait-take levels that suggested that less bait would suffice in making bait available until the next bait station servicing in most bait stations.

RTI were at 15 % prior to the initial 1080 aerial drop and reached undetectable rates at the end of 1996. For most of the period between 1996 and 2007 the RTI remained below the target level of 5 %. Only two peaks were recorded: prior to the bait removal in winter 1999 the RTI was monitored at nearly 15 %, whereas afterwards they were between five and 10 % until three seasons later when rats were at undetectable levels. In the more recent years between

late 2005 and 2007, RTI were again found above the 5 % target with the newly installed, 'randomly-placed' tracking tunnels tracking 15 % in summer 2005/06 and in summer 2006/07 at 8 %.

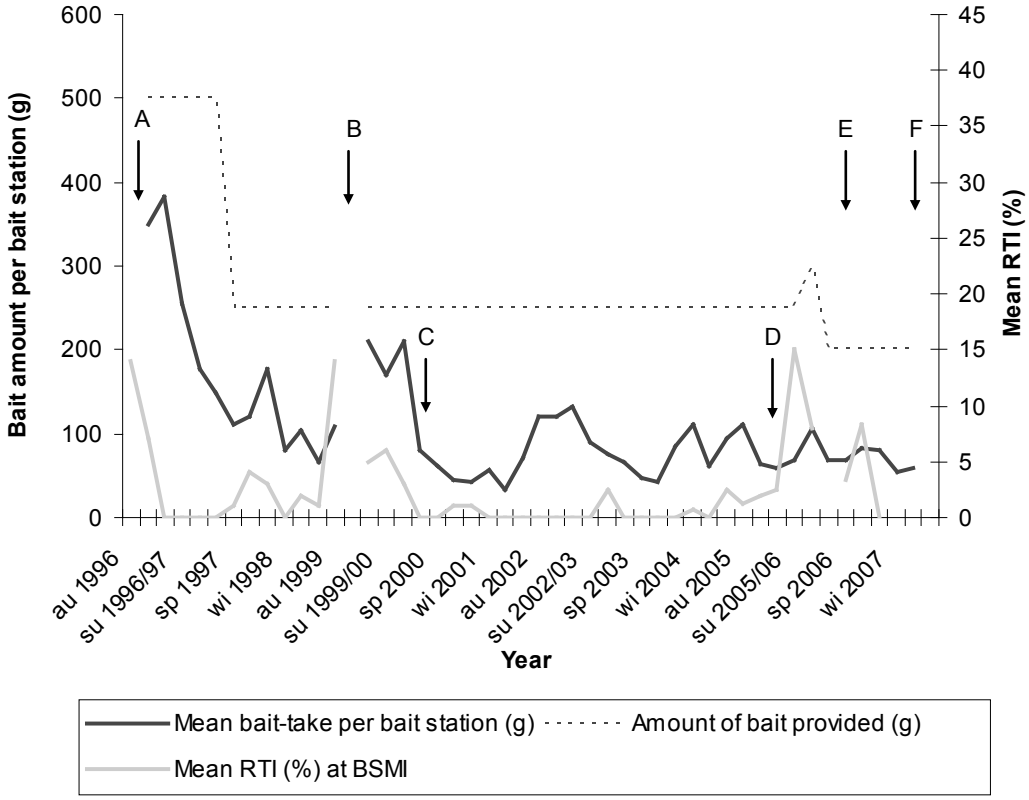

Figure 3.2: Amount of bait put into each bait station, mean bait-take per bait station and RTI (%) (mean if tracking tunnels were monitored more than once in the same season) over the research period. (A) Initial 1080 aerial drop; (B) bait removal over the winter period in 1999 (Warfarin trial in Section 4 not presented on this graph); (C) cholecalciferol trial in Section 4 during winter 2000 (included); (D) 1080 application in bait station for 2 week period in winter 2005; (E) and (F) no monitoring done in winters 2006 and 2007.

3.3 Spatial analysis of bait-take

3.3.1 General observations

Three areas with comparatively high bait-take are the Kakabeak block, Section 4, as well as the western end of the main reserve. Of the three areas, Kakabeak displayed the most consistent repetition through the seasons and years. The majority of the reserve, however, did not display any particular spatial pattern. Bait-take decreased as distance from the treatment edge increased; however, there was neither a linear relationship between bait-take and distance from the edge, nor was the same tendency observable all the time. No area could be identified, that received consistently no or little bait-take. The bait-take as recorded after the

installation of extra interior bait stations in 2006 tended to be less mosaic, but more uniform, with one or two bait-take classes dominating in large areas.

3.3.2 By season

Highest bait-take occurred in Kakabeak, Section 4 and along virtually the entire southern treatment edge (Figure 3.3a). All bait-take areas of at least 150 g per season were directly adjacent to, or in close proximity of, the treatment edge and adjacent unmanaged forests.

After the installation of extra interior bait stations in 2006, Kakabeak, Section 4 and the southern treatment edge also appear with higher bait-take than the majority of the reserve, although at a lower level (Figure 3.3b). Few and only small areas of bait-take over 150 g occurred, none at all in autumn and winter. The high bait-take levels adjacent to unmanaged forests along the south-eastern edge were not as clear as previous to 2006. Bait-take distribution was generally more uniform than in the first 10 years of the project.

3.3.3 By year

In bait-take displayed by year (spring through to winter), Kakabeak, Section 4 and the western end of the main reserve received highest bait-take (Figure 3.4). The high bait-take areas along the south-eastern edge were recorded only from 1996/97-1999/2000. From 2000/01, only the western end of the southern edge continued to show higher bait-take levels, although not consistently every year.

1996/97, 1999/00 and to a lesser degree 2002/2003 were characterised by visibly higher bait-take throughout or in parts of the reserve. In 2006/07, the bait-take was uniformly distributed, with the bait-take category of an average of 50-100 g per year dominating. 2006/07 was also the only year without any 150 g bait-take area.

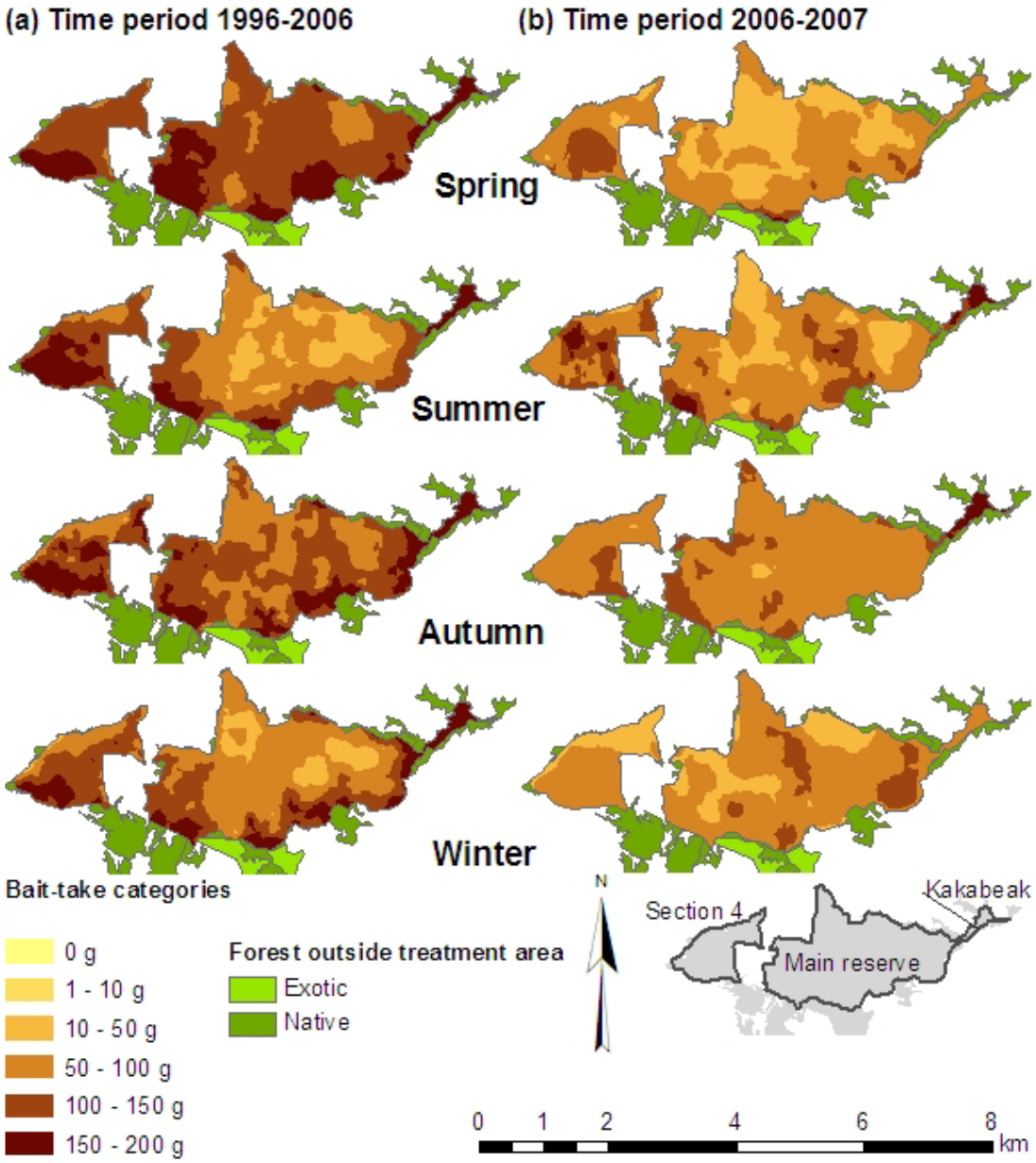

Figure 3.3: Mean bait-take by season interpolated across the entire treatment area (a) before and (b) after the installation of 357 extra interior bait stations in 2006. The change in bait station setup coincided with changeover to a different bait and a comparatively coarse recording method, which made separation of the two time periods necessary. Interpolation method: Inverse Distance Weighting. See Appendix 4, Table A.1 for statistics.

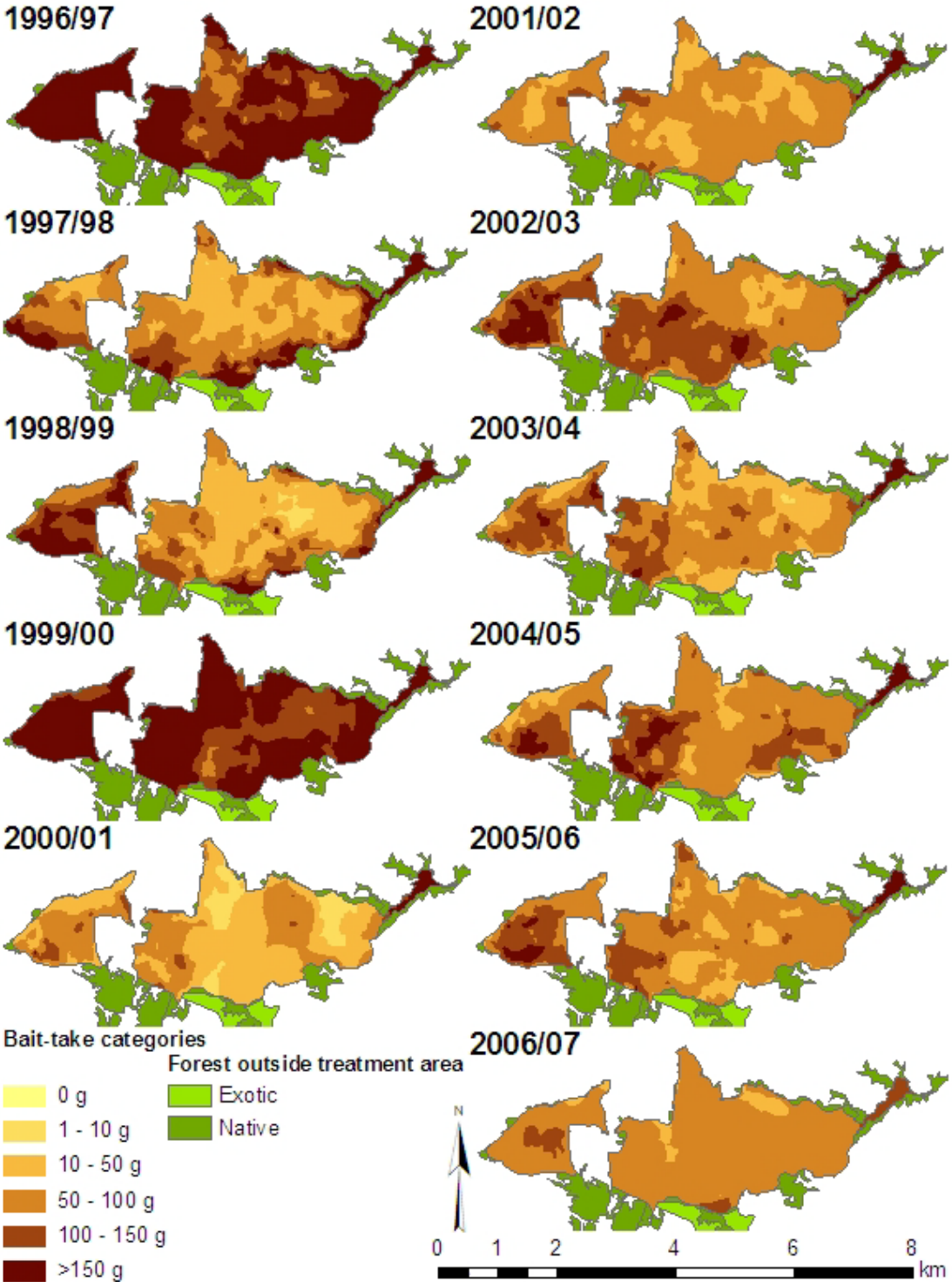

Figure 3.4: Mean bait-take by year (spring-winter) interpolated across the entire treatment area. Interpolation method: Inverse Distance Weighting. See Appendix 4, Table A.2 for statistics.

3.3.4 By bait

During brodifacoum application, highest bait-take was observed virtually along all edges and bait-take decreased towards the interior (Figure 3.5a). These strong edge effects were not repeated in the following bait applications (Figure 3.5b-e). Only the western end of the main reserve, parts of Section 4 and Kakabeak continued to receive relatively high bait-take. During both diphacinone applications, patches of elevated bait-take were also found in the interior of the main reserve. Low bait-take of less than 10 g per application period occurred only in small patches during application of diphacinone cereal pellets and was restricted to the northern half of the main part of the reserve (Figure 3.5c). Pindone (Figure 3.5b) and coumatetralyl (Figure 3.5e) were characterised by a stronger uniformity in bait-take class distribution than the other application periods.

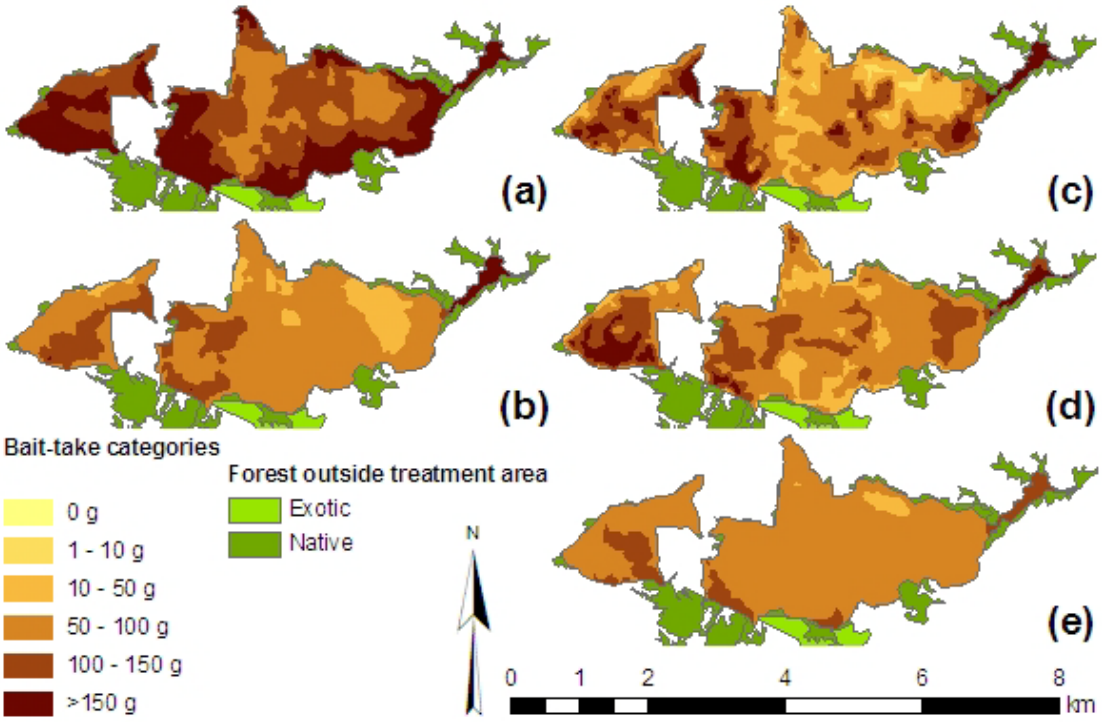

Figure 3.5: Mean bait-take by poison interpolated across the entire treatment area. (a) Brodifacoum, 1996-2000; (b) pindone, 2000-2005 except during (c) diphacinone cereal pellets, December 2003-June 2004; (d) diphacinone blocks, 2005-2006; and (e) coumatetralyl, 2006 onwards. Interpolation method: Inverse Distance Weighting. See Appendix 4, Table A.3 for statistics.

3.3.5 Individual seasons

Bait-take distribution revealed a very high variability when plotted against individual seasons (Figure 3.6, Appendices 1-3). Bait-take classes formed a patchy mosaic that was not repeated in other seasons. Comparison of all spring seasons through the project period, however, reveal that apart from spring 1996 – which was the first season of area-wide baiting – spring 1999 and spring 2002 also appeared to be higher throughout the reserve than all other spring

seasons (Figure 3.6). Edge effects were strong in spring seasons of 1997, 1998, 2001 and 2006. In spring seasons 2003-2005, highest bait-take was concentrated more in the interior.

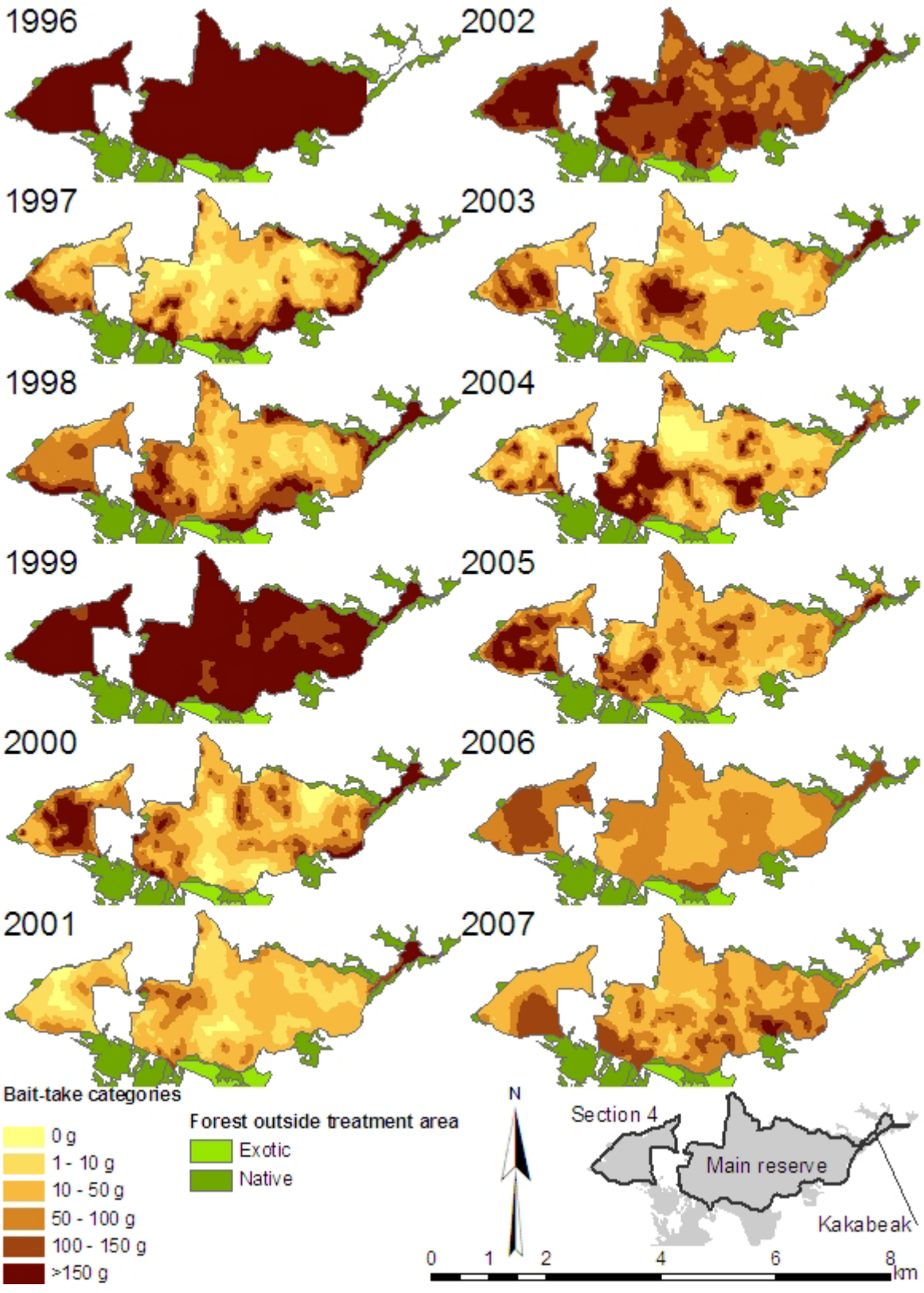

Figure 3.6: Mean bait-take during each spring season interpolated across the entire treatment area. Interpolation method: Inverse Distance Weighting. See Appendix 4, Table A.4 for statistics.

3.4 Statistical analysis of bait-take

The active ingredient (no particular bait formulation; $F_{9,3680}$=97.68; P<0.001), the location within 150 m from the treatment edge ($F_{1,27362}$=390.66; P<0.001) and the vegetation type ($F_{3,23215}$=117.40; P<0.001) all had a significant effect on the bait-take at BSMI. Seasons did not have a significant effect ($F_{3,31}$=1.08; P=0.372).

The significant factors will be further described as follows.

3.4.1.1 Active ingredient

The highest mean percentage of bait-take was recorded for warfarin (84.71 %) and 1080 prefeed (82.19 %). Both were significantly higher than all other compounds (Figure 3.7). Warfarin prefeed was also high (64.47 %) and significantly higher than the remaining compounds. All other anticoagulants (brodifacoum=39.93 %, diphacinone=39.04 %, pindone=32.60 %, coumatetralyl=30.63 %) as well as 1080 (35.72 %) were all in a range between 30 and 40 % and not significantly different from each other. The lowest bait-take was recorded for the non-toxic (25.39 %) and toxic (11.36 %) cholecalciferol. The bait-take of cholecalciferol – together with 1080 among the acute-acting poisons – was significantly lower than all other toxic and non-toxic compounds
(Figure 3.7).

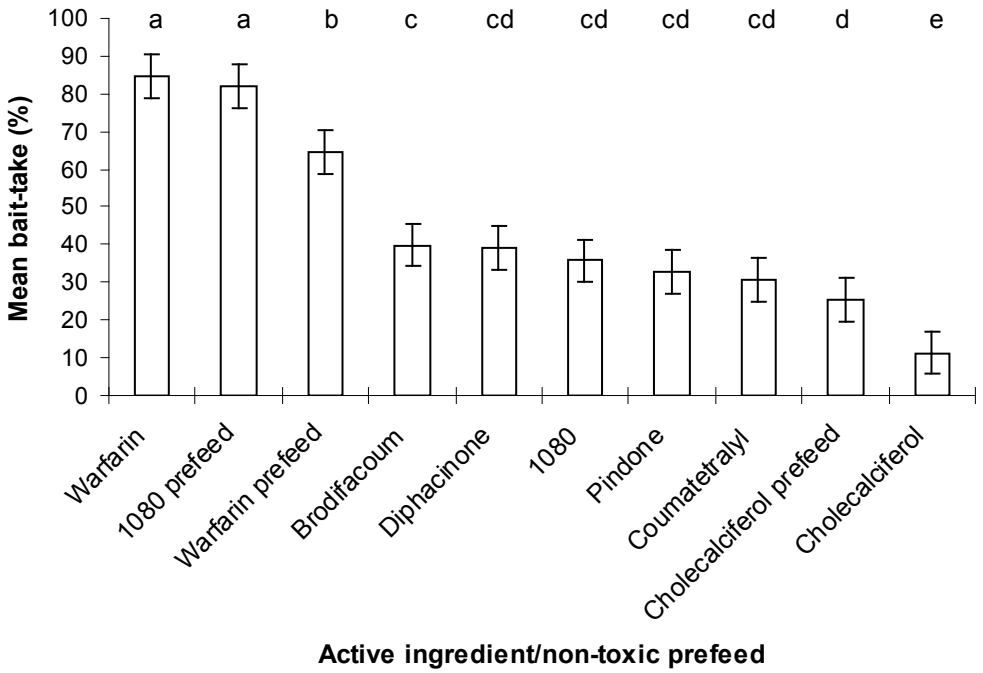

Figure 3.7: Mean bait-take (%) per active ingredient (± SED). All prefeed products are non-toxic and were applied prior to application of the toxic equivalent. Letters above the bars indicate statistical difference at α=5 % LSD.

3.4.1.2 150 m edge buffer

The mean percentage of bait-take was significantly higher within 150 m from the treatment edge (48.57 %) than in the remaining interior of BSMI (40.64 %) throughout the research period (Figure 3.8).

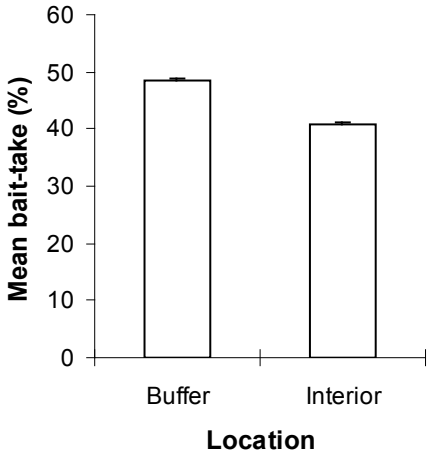

Figure 3.8: Mean bait-take (%) within 150 m from the treatment edge and in the remaining interior of BSMI (± SED).

3.4.1.3 Vegetation

The mean percentage of bait-take was highest in broadleaf/tawa/podocarp (50.29 %) and significantly higher than in the remaining vegetation classes. Kamahi/kanuka/rewarewa (43.27 %), cloud-cap forest (43.03 %) and beech (41.83 %) were not significantly different from each other (Figure 3.9).

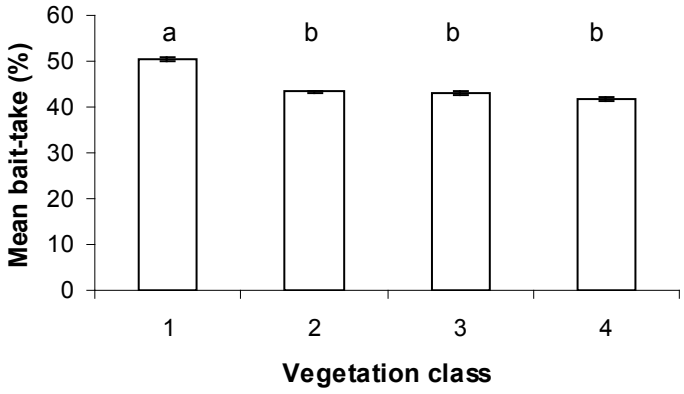

Figure 3.9: Mean bait-take (%) with respect to the vegetation class (± SED). (1) Broadleaf/tawa/podocarp; (2) kamahi/kanuka/rewarewa; (3) cloud-cap forest; and (4) beech. Letters above the bars indicate statistical difference at α=5 % LSD.

3.4.1.4 Season

Seasons did not have a significant effect on the mean percentage of bait-take. However, the bait-take was highest in autumn (50.99 %) and lowest in winter (40.40 %) (Figure 3.10).

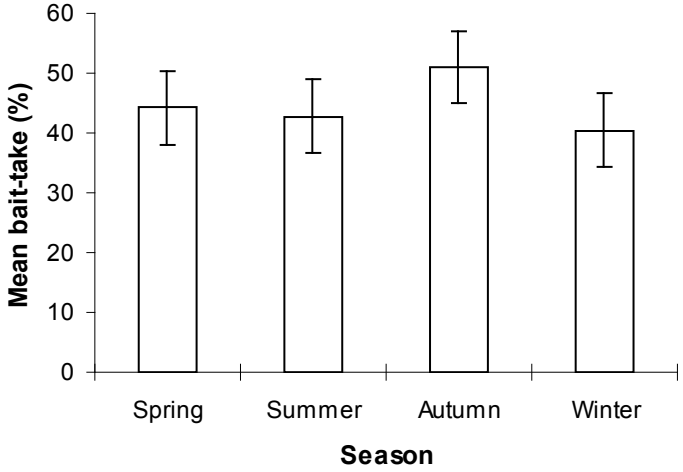

Figure 3.10: Mean bait-take (%) with respect to season (± SED).

3.5 Statistical analysis of tracking tunnel data

The rat tracking indices in the treatment area were generally much lower than in the comparison sites (Figure 3.11).

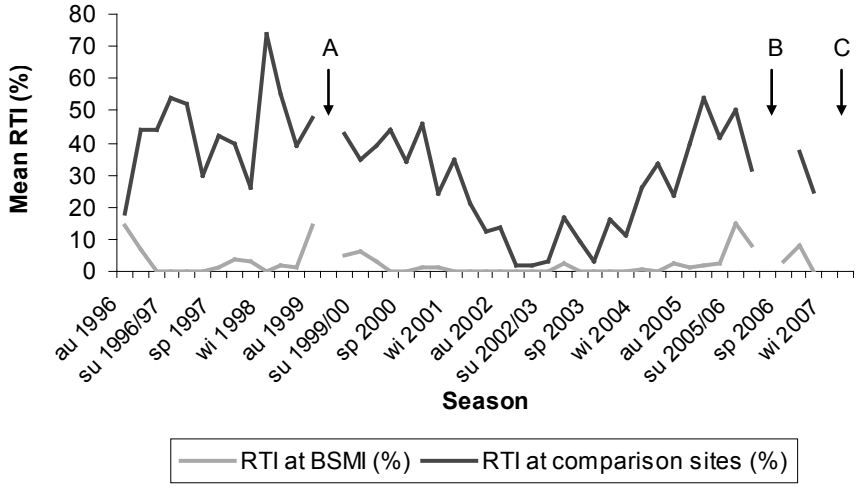

Figure 3.11: Mean RTI (%) at BSMI and the comparison sites between 1996 and 2007.

Within BSMI, only the bait treatment ($F_{4,27}$=6.13; P=0.003) had a significant effect on the rat tracking indices. Increasing the number of bait stations at BSMI did not have a significant

effect ($F_{2,27}$=1.38; P=0.278). Neither did the effect of weather ($F_{1,27}$=0.51; P=0.487) or season ($F_{3,27}$=2.73; P=0.076), although the latter was relatively close to being statistically significant.

In the comparison sites, weather ($F_{1,26}$=1.32; P=0.268) and season ($F_{3,26}$=0.40; P=0.753) did not have an effect either. The change in the tracking tunnel setup in 2001, however, did have a significant effect ($F_{1,26}$=5.20; P=0.038).

The significant and nearly significant factors will be further described as follows.

3.5.1.1 Treatment

The rat tracking indices were lowest during application of diphacinone cereal pellets, when all indices were 0 %. In order of increasing values were pindone cereal pellets 0.51 % ± 0.23 SEM; *n*=15), brodifacoum cereal pellets (2.44 % + 0.92 SEM; *n*=16), coumatetralyl paste (4.76 % ± 1.55 SEM; *n*=5) and diphacinone blocks (5.67 % + 3.20 SEM; *n*=4) (Figure 3.12).

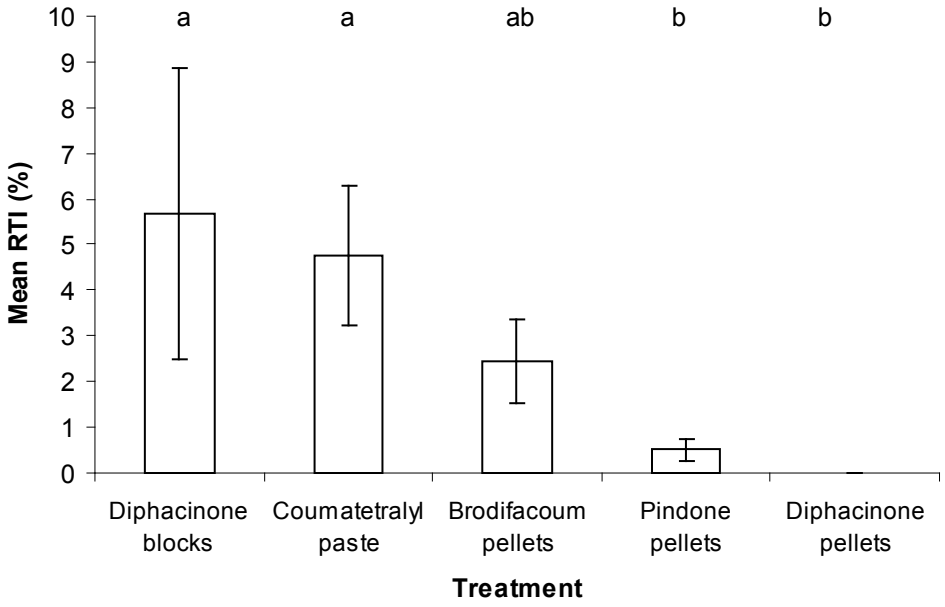

Figure 3.12: Mean RTI (%) with respect to active ingredient and bait type (± SEM). Letters above the bars indicate statistical difference at α=5 % LSD.

3.5.1.2 Season

Season did not have a significant effect on rat tracking indices during the 1996-2007 time period. However, within BSMI the RTI during summer (3.45 % + 1.44 SEM; *n*=11) and autumn (2.97 % ± 1.31 SEM; *n*=11) appeared to be higher than in spring (1.5 ± 0.54 SEM; *n*=12) and winter (0.55 % ± 0.47 SEM; *n*=8). The lowest RTI were found in winter (Figure 3.13). In the comparison sites the peak was in winter, whereas spring, summer and autumn were generally similar to each other (Figure 3.14).

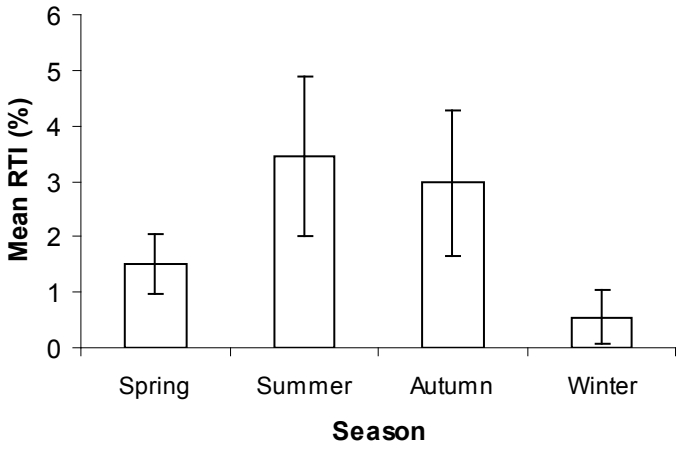

Figure 3.13: Mean RTI (%) within the treatment site with respect to season (+ SEM).

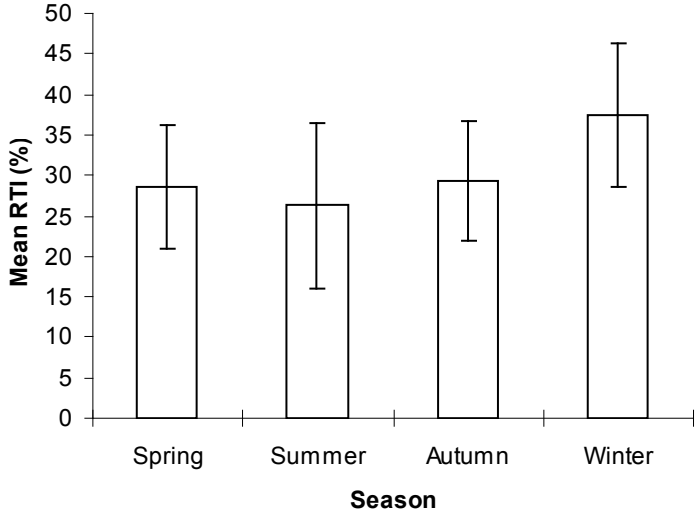

Figure 3.14: Mean RTI (%) in the non-treatment comparison sites with respect to season (+ SEM).

3.5.1.3 Change in tracking tunnel location in comparison sites

The tracking tunnel setup had a significant effect on the rat tracking indices in the comparison sites. The mean RTI until the setup change in 2001 was 42.32 % (± 2.65 SEM) and the mean RTI afterwards was 23.79 % (± 3.58 SEM) (Figure 3.15).

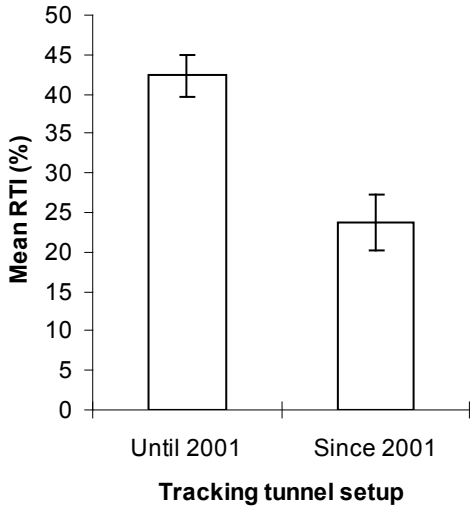

Figure 3.15: Mean RTI (%) in comparison sites with respect to tracking tunnel setup (± SEM).

Chapter 4: Discussion

4.1 Spatial analysis of bait-take

In this section, the results of the visual interpretation of the bait-take distribution maps are discussed. Where applicable, results from the statistical modelling of the bait-take are included.

4.1.1 Edge effects

Various bait-take distribution maps throughout the project time displayed highest bait-take on the edge of the treatment area. Especially in the main reserve, higher bait-take tended to be found along the treatment edge while lower bait-take was often found in the interior. This result suggests the existence of edge effects, which was also supported by statistical analysis of the bait-take, where throughout the entire research period the bait-take was significantly higher in bait stations within 150 m from the treatment edge than in the rest of the bait stations (Figure 3.8).

The bait-take distribution in Section 4 differs considerably from the main reserve. Often, highest bait-take was recorded on the southern edge or right in the centre of the area. Presumably, Section 4 is simply too small for developing a gradient from the edge to the interior. Instead, any edge effect probably affects the entire area.

4.1.2 Reinvasion

Highest bait-take was not only often concentrated along the perimeter of BSMI, but also tended to be situated in close proximity of, or adjacent to, surrounding unmanaged native forest. Unmanaged forests can be expected to have higher rat abundance than the forests within the treatment area of BSMI, with individual rats regularly ranging across the treatment edge. Since ship rats have been found to adjust their home ranges either by replacing vacant home ranges or by expansion of their own range (Innes and Skipworth, 1983), the enhanced mortality rate inside the treatment area likely results in heavily biased migration from the unmanaged forests into BSMI. The unmanaged forests adjacent to BSMI likely serve as habitat for source populations, so that the high bait-take along the treatment edge reflected a high rate of reinvasion into BSMI.

The areas identified by elevated bait-take levels as especially affected by rat reinvasion are Kakabeak, the southern treatment edge – in particular the western end of the main reserve – and Section 4. The respective source habitats with the largest influence are the native forest patches all around the Kakabeak block and Bellbird Bush, a scenic native bush reserve stretching about 3 km south-west from the treatment edge in the south-west of the main

reserve and the south-east of Section 4. Other source habitats are patches of native bush along the southern treatment edge and the native forest that is enclosed by the pine plantation.

In the following sections, these forests and their influence are discussed further.

Kakabeak

Kakabeak displayed high bait-take over virtually the entire research period. Several reasons serve as potential explanations. Kakabeak is widely surrounded by unmanaged native forest, where rat populations can be expected to occur at high densities. The long and narrow shape of Kakabeak also facilitates reinvasion from these surrounding areas, since the distance is short to any part of the treatment area. Accordingly, there will be a good supply of rats replacing any home range that becomes available after the death of a poisoned rat. The comparatively mild climate of this part – due to the lower altitude of the area – presumably further promotes rat abundance.

Furthermore, the bait station setup is not as regular and grid-like as the rest of BSMI. Half of the bait stations cuts through the habitat along the walkway and the other half is placed along the forest edge along farmland and through forested stream valleys. The coverage may therefore not suffice in providing bait to the entire resident rat population. In between is Boundary Stream and steep forest cliffs, both of which may serve as a barrier for rat movement, which may exclude some rats from accessing nearby bait stations.

Nevertheless, Kakabeak very likely serves an important role in mitigating reinvasion into the treatment area. Without any rat control there, a higher reinvasion rate from Kakabeak into the rest of the reserve could be expected.

Bellbird Bush

The entire western end of the main part of the reserve is affected by comparatively high bait-take through all seasons. Within a distance of roughly 1 km from the western edge of the main reserve, elevated bait-take was observed consistently over the years and through all seasons. Two aspects are possibly driving this phenomenon: habitat preferences and/or reinvasion from Bellbird Bush, which is a scenic native bush reserve and the largest of the native forests adjacent to BSMI.

If habitat preferences within BSMI exist, they can be expected to be largely influenced by the vegetation. The vegetation in the western end of the main reserve is largely broadleaf with a beech-dominated ridgeline in the middle of it. The bait-take in broadleaf/tawa/podocarp was indeed found to be significantly higher than in the other vegetation classes (Figure 3.9). This may be due to particular habitat preferences, but may also be caused by elevated reinvasion rates from Bellbird Bush.

On the whole, bait-take was higher in the south of the western end of the main reserve, which is adjacent to Bellbird Bush. The consistency of elevated bait-take levels in this area through the seasons as well as the years indicates that Bellbird Bush indeed plays an important role in the reinvasion into BSMI. From where Bellbird Bush is attached to BSMI, it stretches in a south-west direction for about 3 km and at its widest point is about 1.5 km wide. This provides habitat for rodents that is likely to be little affected by the continuous poisoning in BSMI. The rat density is likely to be comparable to those of the non-treatment comparison sites, and the consistently high bait-take levels suggest that Bellbird Bush served as a source population for reinvading rats for the entire project period.

Through a network of native forest, Bellbird Bush is also connected to the south-eastern tip of Section 4. Section 4 is characterised by bait-take similar to the western end of the main reserve in level as well as temporal consistency. In particular the southern half was affected by elevated bait-take in many seasons and years. Other than the Bellbird Bush extension there is no forest of considerable size adjacent to Section 4, and therefore it is the only substantial forest habitat that may facilitate reinvasion. The shape of the highest bait-take levels in various seasons or years – often displaying a corridor of elevated bait-take towards the Bellbird Bush extension – suggests that this indeed is a major reinvasion route.

Pine plantation

Inside the pine plantation along the southern edge of BSMI is a relatively large piece of native forest, which was also identified as a source for reinvasion. Where this native forest is not adjacent to BSMI, it is surrounded by the pine plantation, so that the pine plantation itself only touches the reserve at both ends. From the distribution of elevated bait-take areas, it is only the native bush area within the pine plantation that triggered notable reinvasion. Where the pine plantation touches the main reserve, the bait-take maps did not indicate any high bait-take or was often lower than the other edge areas in the south. Therefore, the native forest played a more important role in reinvasion to BSMI than the exotic forest. Ship rats are known to occur at higher densities in native forests than in exotic forests (King et al., 1996), and the bait-take distribution as found in this work supports this hypothesis.

Reinvasion from the native bush within the pine plantation was most consistent in the early years of the project. According to the bait-take distribution maps when plotted against bait types, reinvasion from the pine plantation area was most pronounced during the brodifacoum application (Figure 3.5a). No elevated bait-take was registered during pindone or diphacinone applications (including pellets and bait blocks) and partly the bait-take was actually lower than in areas towards the interior (Figure 3.5b-d). During coumatetralyl application, some

elevation in bait-take in the area was noted (Figure 3.5e). Reinvasion therefore appeared to have decreased after about four years of continuous baiting. This suggests that the poisoning operation to some extent radiated into the unmanaged surrounding area. This may have two explanations: either the breeding success in the pine plantation area did not compensate for the number of rats migrating into the treatment area in order to replace poisoned rats, and/or a large number of rats in the pine plantation were eventually poisoned by perimeter bait stations located in their home range.

Other native bush patches

Relatively high bait-take was also recorded for one small area at the northern treatment edge halfway between Kakabeak and Herries and several larger patches along the southern treatment between the pine plantation and Kakabeak. In both cases, unmanaged native bush patches can be found along the treatment edge. Similar to the pine plantation, elevated bait-take was most consistently noticeable in the first four to five years and only appeared sporadically afterwards.

At the northern boundary of BSMI, the adjacent forest is only a narrow band between the treatment edge and the adjoining farmland. The home range of any rat living here can be expected to range across the treatment edge, with a high probability including at least one bait station. It is therefore not surprising that this area was limited in providing a source for reinvasion.

The high bait-take areas on the southern treatment edge between Kakabeak and the pine plantation were adjacent to a 20 ha native forest, which is the second largest adjacent native forest after Bellbird Bush. At its widest point it is about 500 m wide and ranges slightly over 500 m into the farmland. With a rat home range of mostly < 1 ha (Dowding and Murphy, 1994; Hooker and Innes, 1995), a number of ship rats could reside there without ever encountering a bait station. It is therefore big enough to provide habitat for a rat population not directly impacted by the poisoning operation within BSMI. However, it is likely that some individuals would migrate into the treatment area, causing higher bait-take in the nearby areas. No particular season could be identified when this would most likely happen (see Figure 3.6 and Appendices 1-3). Similar to the previously described situation at the pine plantation, the poison operation presumably impacted the adjacent native bush by continuous removal of individual rats, which after invasion into BSMI were exposed to the poison.

4.1.3 Low bait-take

Areas of nil and/or very little bait-take of < 10 g were generally small in number as well as size and never repeated in consecutive seasons. Bait was taken across the reserve at all times, without any indication of 'cold-spots' with reliably low bait-take.

4.1.4 Temporal fluctuations

4.1.4.1 High bait-take in 1996/97

Bait-take was high during the first year of the poison operation in 1996/97 (Figure 3.4, Figure 3.6). This is not surprising, since by then, the rat population had only been controlled by the initial 1080 drop and not by any form of continuous baiting. The high bait-take throughout the reserve in the first year of the poisoning operation simply demonstrates that the bait stations were readily accepted as a food source from the beginning of the poisoning project.

4.1.4.2 High bait-take in 1999/2000 and 2002/2003

Extremely high bait-take was also recorded in 1999/00 and – to a lesser degree – in spring and summer 2002 (Figure 3.6). Both reflect vividly the effect of a less vigorous baiting over quite short periods of time: being the previous winter in both cases.

In winter 1999, all bait was removed from BSMI to investigate options for saving labour and poison. This 'minimum control trial' resulted in slightly increased rat tracking indices for two seasons and noticeably increased bait-take for an entire year. In reality not all bait was removed as intended. Three bait station lines (90 bait stations) remained untouched for the entire season, with the bait removed and changed when all bait stations were refilled in spring. Also, there was a one-off warfarin trial conducted in Section 4 during this time. Nevertheless the distinctly increased bait-take in the following seasons across the entire reserve and the increased RTI estimates indicate that the rat population recovered to a certain extent, which then consumed more bait than usual.

In winter 2002 – prior to the increased bait-take in spring 2002 – there was no formal rat control trial in place; bait stations were simply not serviced as normal. Only perimeter bait stations were checked and refilled and all interior bait stations were left unattended until spring. The RTI remained at 0 % during the entire year of 2002 and therefore did not indicate any increased rat activity due to the long time period of bait in the field. The unusually high bait-take during the following spring, however, suggests that there were either more rats around that ate the bait or that the fresh bait was more attractive. Possibly, the bait – pindone at the time – deteriorated in the humid and cold winter conditions at BSMI to the point that

rats preferred other – non-destructive – food sources. This hypothesis is supported by the fact that the fresh bait provided in spring was obviously readily accepted, suggesting that the pindone fabrication used at the time (Pindone Pellets®) lost palatability when left unserviced in the field over the winter period.

Both the removal as well as the neglect of bait station servicing resulted in uncharacteristically high bait-take in following seasons. A number of things can be concluded:

1. During a winter season of discontinued baiting the rat population can recover to the point where increased bait-take and RTI estimates is noted in the following season; and/or
2. Bait unattended over winter can lose palatability to rats as manifested in higher attractiveness of fresh bait in the following season; therefore
3. Baiting should be done continuously to encourage rats to consume bait all year round.

It also needs to be considered, that all bait that had remained out in the bait stations during winter was checked and refilled in spring. This means that the entire bait that was taken over winter appears in the spring bait-take. However, the average bait-take after the changeover was still higher than during the whole winter period in both years. In 1999, the average bait-take at the first servicing after winter for the 90 bait stations that had retained their bait was 130 g (±SEM), while the average bait-take in the same bait stations at the following servicing was 237 g (±SEM). In 2002, this difference was not as large, but still noticeable with an average bait-take of 136 g (±SEM; 356 bait stations) for the interior bait stations at the first bait station servicing after winter and then 158 g (±SEM; 355 bait stations) at the following servicing. Despite the longer time period out in the field, the mean bait-take during the winter was considerably lower than the mean bait-take during the following spring servicing, supporting the hypothesis that bait palatability decreased in winter. This is also reflected in the 2002 field recording sheets, which recorded that the remaining bait was found to be mouldy or crumbly in a majority of bait stations. This was not nearly as consistently recorded in 1999, but the increased bait-take in the following baiting period suggests that palatability was nevertheless impaired.

Whether the increased bait-take after neglected winter baiting has a negative effect on the ecosystem recovery is beyond the scope of this project. Further investigation into related monitoring or birds' nesting success during these seasons with 'normal' control years might reveal more information in this respect.

4.1.5 Vegetation

The distribution of the bait-take categories across the reserve and the variability over time suggests that vegetation does not play a major role in the bait-take within BSMI. Statistical modelling of the bait-take revealed that only broadleaf/tawa/podocarp had significantly higher bait-take while no statistically significant difference between the remaining kamahi/kanuka/ rewarewa, beech, and cloud-cap forest was found (Figure 3.9). The largest areas of broadleaf forest is found in the western end of the main reserve and the south-east of Section 4, both of which were characterised by elevated bait-take levels in many bait-take distribution maps. But as discussed before, this is more likely to be the result of reinvasion from Bellbird Bush than that of habitat preferences.

In pure beech forest, ship rats have previously been reported to be rare (Innes, 2005). In the middle of the western end of the main reserve, and as such repeatedly affected by elevated bait-take levels, is located a ridge line mainly stocked with beech forest. The bait-take was indeed lowest in the beech forest, but only significantly different to broadleaf/tawa/podocarp. The spatial bait-take distribution also does not indicate any noticeable decrease that could be attributed to the distribution of beech. However, since the beech patch in this area is no more than 200 m wide anywhere, the influence of the surrounding forest is likely to be strong enough to mitigate any rat-deterring effect of the beech forest.

4.1.6 Topography

According to Innes (2005), ship rats occur from the coast to the treeline, but their abundance markedly decreases at high altitude. At BSMI, both Kakabeak at the lowest altitudinal level (300 m a.s.l) and Section 4 with the highest altitude (up to 1,000 m a.s.l.) are noted with regularly occurring high bait-take. Rat activity is therefore high at both altitudinal extremes found at BSMI. In the Kakabeak area, the high bait-take is assumed to be associated with the surrounding unmanaged native forest and possibly with the comparably mild climate. Section 4, on the other hand, is not surrounded by forests to the same extent and – due to the higher altitude – the climate is considerably harsher. What Section 4 and Kakabeak have in common, however, is that both are relatively small areas with comparably short distances to the edge from anywhere within the treatment area. The edge effects in both Section 4 and Kakabeak probably affect the entire treatment area, mitigating any potential altitudinal effect on rat densities. It is also likely that the elevation as found at BSMI is simply not high enough to show the altitudinal effect as suggested by Innes (2005).

4.1.7 Other landscape features

The patchy mosaic of bait-take distributed across BSMI over time was not found to be related to any landscape features such as streams or walking tracks. In regards to streams, it can be assumed that precipitation rates suffice to make many resident animals independent from permanent water resources.

Walking tracks do not appear to be a preferred migration route for rats. Rats are probably small enough to live in any vegetation regardless of the denseness of undergrowth vegetation. Walking tracks and similar more open areas do not appear to be more attractive to them. It is possible, however, that the bait-take data as collected at the bait stations is too coarse to show any 'fine-scale' effect of features such as walking tracks.

Whether the road, which cuts through the western end of the main reserve, has any effect on the rat distribution is unknown. Any effect that the road may have is likely to be confounded by the elevated bait-take that has been attributed to reinvasion from Bellbird Bush. Accordingly, any road effect was not able to be detected.

4.1.8 Different bait products

Brodifacoum (cereal pellets)

The first impression of the bait-take distribution during the brodifacoum regime is that the highest bait-take classes were much more widely distributed than during the other baiting regimes (Figure 3.5a). This mostly reflects the fact that the brodifacoum application included the first year of the poison operation with extremely high bait-take, as well as the two other previously discussed situations where baiting was actually stopped over winter. This increased the mean brodifacoum bait-take per bait station for the entire period.

Highest bait-take was recorded on the edges, indicating firstly the generally high edge effect during the first few years of the project and secondly the effect that the adjacent unmanaged bush and forest vegetation had during the first four years of the poisoning.

Additionally, in the first year of the project, 500 g of brodifacoum bait was provided per bait station, as opposed to mostly 200-250 g later-on. With the highest bait-take class of over 150 g, this class was disproportionally bigger than during any other baiting application.

Pindone (cereal pellets)

Quite contrary to brodifacoum, the bait-take during pindone (Figure 3.5b) and coumatetralyl (Figure 3.5e) were much more uniformly distributed, with the most common bait-take class of 50-100 g per bait station during both regimes. The evenly distributed bait-take during the pindone period is probably an indication of how successfully the rat population had been reduced to low numbers across the reserve before pindone was introduced. However, pindone

did successfully maintain those previously achieved low rat densities following both 1080 and brodifacoum baiting.

Coumatetralyl (paste)

The bait-take after winter/spring 2006 tended to be uniformly distributed with rare higher and lower extremes (Figure 3.3b, Figure 3.4, Figure 3.5e). In winter 2006, the changeover from diphacinone to coumatetralyl was started and was completed in spring 2006. The application of coumatetralyl also involved a comparatively coarse recording method, with all or no bait gone and bait-take class widths of 100 g. For the purpose of this work, all coumatetralyl bait-take was set to the midpoint of each bait-class, making the range of bait-take values less variable than, for example, the cereal pellet baits, which were recorded in bait-take classes of 25 g width. The coumatetralyl bait-take was therefore less spatially detailed and consequently less conclusive than the other poisons.

The coumatetralyl application also incorporated additional baiting by two different means: first, extra bait was put in re-sealable plastic bags and were nailed on trees between bait stations. Second, after removal of the extra bags six months later, 357 extra bait stations were installed and from then on checked and refilled together with the original bait stations. None of these additional bait deliveries resulted in the lasting suppression of RTI to the desirable 5 % level. The bait-take from the re-sealable plastic bags were not included in this analysis, but the effect of the installation of extra bait stations will be further discussed in section 4.4 of this discussion chapter.

Diphacinone (cereal pellets, block baits)

The patchiest mosaic of bait-take classes were recorded during both diphacinone applications. Aside from the commonly elevated bait-take in the southern half of Section 4, the western end of the main reserve and Kakabeak, both diphacinone products indicated some areas with elevated bait-take within the interior of the main reserve. These areas were not identical during both baiting periods.

Rather than being a sign for active ingredient-specific factors driving the bait-take distribution, this stronger variability is probably a result of the relatively short application periods. The bait-take distribution varied considerably between individual seasons, indicating that a high variability was commonly found even within quite short time periods. Diphacinone cereal pellets (Figure 3.5c) were only applied for six months, while diphacinone blocks (Figure 3.5d) were applied for a year.

Despite the similar bait-take distribution, the RTI during both diphacinone applications varied markedly, which will be further discussed in section 4.3.1 of this discussion chapter.

4.2 Statistical analysis of bait-take

This section discusses the results of the statistical modelling of the bait-take for the different poisons used at BSMI. This includes those poisons that were trialled in parts of the reserve, or were applied for very short periods of time, and therefore do not appear in the above spatial analysis of the data.

4.2.1 Anticoagulants

All anticoagulants except warfarin (85 %) were taken with an average of 30-40 % per bait station and there was no significant difference between the anticoagulants (Figure 3.7). This result suggests that all anticoagulant bait formulation were accepted by rats to a comparable extent. Palatability does not seem to have made a noticeable difference. These baits were mostly put into bait stations with amounts ranging between 200-300 g, so that the absolute amount of bait-take was in a comparable range. Only brodifacoum was put out in 500 g amounts for the first year of application. It also needs to be kept in mind that the analysis for diphacinone includes both bait types (see above).

4.2.2 1080

The interesting result in this context is that the consumption of 1080 bait was also in the 30-40 % range. 1080 is a very potent acute-acting poison, with the lethal dose of only 1.2 mg/kg for ship rats (Innes et al., 1995), and only hours until death. Accordingly, either the particular product used lost its toxicity quickly after distribution, or must have been extremely palatable on first encounter. Since the bait was applied in bait stations, it is not likely that the poison degraded quickly due to exposure to moisture. Extremely high consumption of the non-toxic prefeed suggests a high bait palatability which may have led to an increase of bait-take of the 1080 bait when deployed subsequent to the prefeed. Looking at the spatial distribution of the bait-take
(Figure 4.1), however, in many cases neither the highest nor the lowest bait-take areas of both periods seemingly coincide. Although this does not seem to support the hypothesis that the high palatability of the prefeed product enhanced the take of the toxic bait, it probably reflects the fact that it does not take many rats to inflate the consumption of non-toxic prefeed. Due to the fast onset of symptoms, the rats taking the toxic compound had much less time to eat more bait and/or locate additional bait stations.

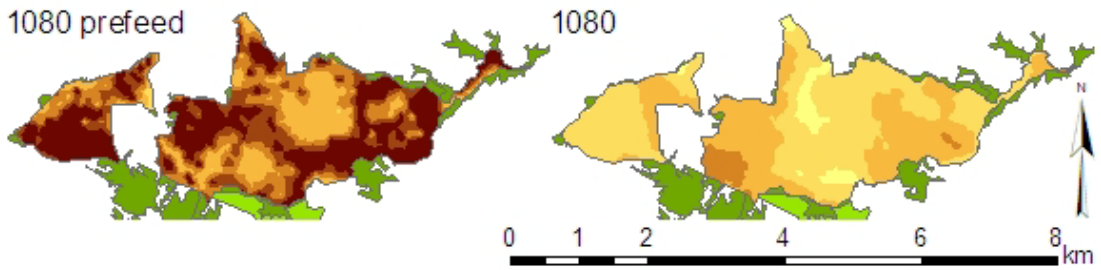

Figure 4.1: The spatial distribution of bait-take (g) of 1080 and the non-toxic prefeed, as applied in bait stations in 2005. For safetly reasons, neither compound was applied in sensitive areas, such as along walking tracks and on fence posts along cattle paddocks, which for example accounts for the bisected bait-take in Kakabeak. Interpolation method: Inverse Distance Weighting.

4.2.3 Warfarin

Apart from 1080 prefeed bait, the percentage bait-take of warfarin as well as non-toxic warfarin prefeed bait was highest (Figure 3.7). This suggests a high palatability of both products, but also seems to be an expression of the lower toxicity of this first-generation compound in comparison to the other anticoagulants. Warfarin has been found effective against – unless warfarin-resistant – Norway rats, but house mice have a high tolerance against the compound, which has been suspected also being the case for ship rats (Buckle, 1994). This is supported by the findings at BSMI where the rat population mainly consists of ship rats. The limited effect of the warfarin application becomes apparent in the bait-take distribution map for spring 1999 (Figure 3.6), where the bait-take after refilling with brodifacoum does not differ visibly from the overall high bait-take in the rest of BSMI where bait had been removed for the same time period. Physiological resistance against warfarin in the resident rat population is unlikely to have caused the high bait-take with little effect, since the application time was short and it had not been applied in this particular area before.

Interestingly, the bait-take of the toxic warfarin was also significantly higher than that of the non-toxic prefeed. Prefeed is normally applied prior to acute rodenticides to overcome any neophobic response to new foods and/or to prevent the initial food sampling in sub-lethal quantities to create bait-shyness. Bait-take of the toxic compound should therefore be lower than the prefeed, due to the consecutive death of the rats. This phenomenon happened in both other occasions where prefeed was applied at BSMI, whereby both non-toxic 1080 and cholecalciferol prefeeds were taken at a significantly higher rate than their toxic equivalent. The reason for the inverted result with warfarin is unknown, but supports the low toxicity of this compound against the resident ship rats. Interestingly, bait from the same batch that was used in a similar trial at Trounson Mainland Island; however, it achieved a significant reduction in the tracking rate (DOC, 1999, unpublished).

At the time of the warfarin bait removal, only a third of the bait stations exhibited rodent faeces. This led to the suspicion at the time, that apart from rats, it may have been possums that were responsible for a portion of the bait-take, which might explain the lack of effect against the rat population. At the time, possums were still present at low densities within the reserve (2.2/100tn; DOC, 1999, unpublished).

4.2.4 Cholecalciferol

Both toxic and non-toxic cholecalciferol baits had the smallest percentage bait-take (Figure 3.7). However, it needs to be noted that cholecalciferol was never applied in all of BSMI and was not always preceded by the application of non-toxic prefeed. In winter 2000, for example, cholecalciferol was trialled in Section 4 only, and no prefeed was applied. In 2007, cholecalciferol was started to be used in 'pulsed application' in the perimeter bait stations to target reinvading of possums. Only one of the several short applications – preceded by prefeed – occurred during the research period of this work and this may have reduced the overall efficacy of cholecalciferol bait.

4.3 Bait efficacy

In this section the results of the statistical modelling of the rat monitoring data are discussed.

4.3.1 Treatment

The bait treatment had a significant effect on the average RTI estimates. The success with which rat numbers were suppressed differed between poisons and/or bait type (Figure 3.12):

Diphacinone cereal pellets

Diphacinone in form of cereal pellets suppressed rat numbers to undetectable levels during the entire time it was used, which makes it the most effective treatment of the five poisons used at BSMI. However, this result needs to be interpreted with care because diphacinone pellets had the shortest application time. It was only applied for a period of six months as part of a national DOC trial and it appears as the prevailing poison during only two seasons. Accordingly, this result may simply reflect a unfavourable year for rats, or the high efficacy of the poison used prior to the diphacinone trial. The diphacinone cereal pellet trial was embedded in the long-term application of pindone, which was the poison with the second lowest tracking rates. By the time of the diphacinone trial, pindone had been used successfully for three years with consistently low tracking rates (mean RTI < 0.4 %, never over 2.5 %). The rat density was therefore already low when diphacinone cereal pellets were introduced.

Pindone and brodifacoum cereal pellets

Under the pindone regime, the average tracking rates were 0.5 % (± 0.23 SEM). Pindone therefore slightly exceeded brodifacoum in efficacy at BSMI, although brodifacoum – with a mean tracking rate of 2.44 % (± 0.92 SEM) – was still well within desired levels of RTI below 5 %. Since brodifacoum and pindone were both applied for a period of four years, both poisons can be regarded with confidence as having been effective regimes against rats at BSMI.

The fact that brodifacoum falls behind pindone – the potency of which is considerably lower than that of the second-generation anticoagulant brodifacoum – is surprising and the reasons for this can only be speculated about. Pindone was used following four years of virtually continuous use of brodifacoum. The rat population had therefore already been reduced to very low numbers by the time pindone was introduced. Brodifacoum, on the other hand, was only preceded by a 'one-off' 1080 aerial bait drop. While this had been effective in lowering rat numbers, it did not do so to the same effect as five consecutive years of brodifacoum in bait stations. Additionally, the brodifacoum years included 'one-off' research trials such as the removal of most poison for three winter months, which was followed by increased rat numbers for at least two seasons. However, during the pindone years the application of bait was only discontinued for six months for the above mentioned successful diphacinone trial. The pindone tracking rates therefore lack the same unusually high rat tracking indices as found during the brodifacoum years. Lastly, brodifacoum was applied in two different bait products. Identical in bait type and toxic concentration, Talon® and Pestoff® 20p were applied concurrently over the years, at times both in the same bait stations. If the palatability between both products varied, this may have had an influence on the efficacy of the overall brodifacoum application. Due to incomplete recording as to when and where which product was used, the difference between these two products cannot retrospectively be quantified.

In conclusion, whilst pindone did start with a low rat density in the reserve, it did also continue to suppress them to very low numbers, a result that none of the following poisons achieved to the same extent.

Diphacinone blocks versus diphacinone cereal pellets

After five years of pindone – including six months of diphacinone pellets – the treatment was switched to diphacinone in bait blocks. These diphacinone blocks resulted in the highest mean tracking rates of the five long-term baits (mean RTI=5.67 % ± 3.20 SEM), and these indices were significantly higher than both pindone and diphacinone cereal pellets.

The diphacinone block regime also includes a 10-day ground application of 1080, which should have aided in suppressing rat numbers. In fact, before the 1080 application the RTI

were under the desired 5 % and remained below that level after. It was not until the fundamental change in the tracking tunnel setup before the RTI increased markedly. In the first season using the new tracking tunnel lines, the tracking rates jumped to 15 % in the summer of 2005/2006, which in turn increased the mean tracking rates for the whole diphacinone block regime.

The reason for the considerably higher tracking rates with the new tracking tunnel lines is not known. Although the tracking tunnel setup as put in place in 2000 was meant to be randomly chosen, some of the lines actually followed bait station lines, which may have influenced the RTI results at the time. The locations of the new tracking tunnel lines were chosen randomly in terms of starting point as well as direction. The higher tracking rates may therefore have been a reflection of the improved new tracking tunnel setup, being more sensitive at detecting rodents. Both tracking tunnel setups 3 and 4 were run concurrently for two seasons. Only the new tracking tunnels showed the increased RTI, confirming the higher sensitivity to detect rodents (DOC, n.d., unpublished). Furthermore, the number of tracking tunnels in the reserve was increased from 80 to 120, which will have increased the precision of the RTI estimates.

Two other explanations for increased tracking rates are also worth considering. First, the new tracking tunnels may have attracted more rats due to increased curiosity, which in the face of rats' neophobic tendencies (Innes, 2005) is unlikely. Secondly, the rat population may simply have increased due to lower efficacy or palatability of the diphacinone blocks. The diphacinone blocks applied were Ditrac®, which indeed has been reported to be less palatable to Norway rats than other rodenticide products containing brodifacoum (Ross et al., 2000).

Coumatetralyl

Coumatetralyl paste resulted in slightly lower – although not significantly different – RTI levels than diphacinone bait blocks. A better result could have been expected, since it was first put out in the field not only in bait stations, but also in re-sealable plastic bags between bait stations, followed by the installation of 357 new bait stations in the interior and the Kakabeak block. Theoretically, bait should have been available to considerably more rats. However, the bait in plastic bags between bait stations did not have an immediate effect in suppressing rat numbers, since it was often non-target species such as pigs that took the bait from the plastic bags (D. Fastier, BSMI team leader, pers. comm., 2008). The increased number of bait stations also did not have a significant effect on the RTI.

The change of the poison regime from Ditrac® to coumatetralyl was a reaction to the above mentioned distinctly elevated RTI after the change to tracking tunnel setup 4. Accordingly, all results concerning the efficacy of coumatetralyl need to be interpreted with care as the RTI

estimates had considerably jumped when monitored under the new tracking tunnel setup. Consequently, comparison of the RTI estimates during coumatetralyl baiting to previous RTI estimates is highly problematic.

Although the effect of the changes between tracking tunnel setups 1-4 could not be analysed due to the lack of replication between tracking tunnel setups and all the bait types, the effect of the single change in the comparison sites proved to have a significant effect on the RTI (see below). It can therefore be assumed that each change in the treatment site also had an effect, although it was most obvious in the last one, and the difference cannot be fully quantified. Without replication with tracking tunnel setup 4 in combination with the application of each different poison, it cannot be concluded whether the higher RTI during coumatetralyl is solely attributed to the lower efficacy of the poison or the higher sensitivity of the new tracking tunnel setup.

Cereal pellets versus other bait types

Not only was diphacinone cereal pellets superior to the same active ingredient when presented in bait blocks in suppressing rat numbers. Both brodifacoum and pindone proved to be also effective in rat control at BSMI and were also presented in cereal pellets. Therefore, the three poisons with the lowest RTI estimates had in common that they were cereal baits, while the two poisons with the lowest success in suppressing rat numbers were presented in a bait block or paste.

It is possible, that the successful use of pellets coincided with high palatability of the three most successful poisons, or that the paste and blocks coincided with low toxin palatability, which may not have anything to do with the shape in which the bait is presented. The shape, in which bait is presented, however, could influence rat consumption by accommodating specific feeding behaviour. For example, rats like to carry pieces of food away to a sheltered place for feeding (Innes, 2005), for which cereal pellets may be more suitable. Ditrac® is advertised by their manufacturer (Bell Laboratories Inc.) for suitability to rats because it provides “plenty of edges to gnaw” (Bell Laboratories Inc., 2005).

The considerably higher success of the cereal pellet baits suggests that this may be the preferred bait type to ship rats. This is supported by the two previously discussed diphacinone products, which at the identical toxic concentration worked significantly better in cereal pellets than in bait blocks. However, the palatability of the toxin and/or the bait matrix will have also influenced the baiting success.

Change in tracking tunnel setup in comparison sites

The average RTI estimates in the comparison sites went from 42 % during the original tracking tunnel setup down to 23 % in the current setup that was adopted in 2001 (Figure 3.15). This may be due to a decrease in the rat population in the years since 2001 due to unknown external factors such as low breeding success. This conclusion is supported by the relatively high variability within the RTI since 2001, with relatively low RTI between the years 2002 and 2004 before recovery of the population to levels similar to 1996-2001 (Figure 4.2).

However, the number of tracking tunnels in the comparison sites also decreased from an original 50 per site to 30 per site since, which may have decreased the sensitivity to detect rats. Also, due to the small size of the comparison sites, a completely random placement of tracking tunnel lines was not always possible. Some of the current lines are placed in grassy areas alongside the bush edge. Those grassy forest edges tend to be more inhabited by mice than by rats (King et al., 1996), and may not have accurately detected the rat population inside the forest. Furthermore, in January 2003, a buffer trap line was installed alongside one of the comparison sites (Thomas Bush), coinciding with one of the tracking tunnel lines. Although this was part of the pest control targeting mustelids, fenn traps are also known to catch rats. This may have influenced the rat tracking data either by removing trapped rats or by increasing them with additional rats being attracted by dead bodies caught in the traps (D. Fastier, BSMI team leader, pers. comm., 2008). Since the RTI includes all tracking tunnels in both comparison sites, it is not possible to quantify the effect of the trap line. A comparison of the tracking rates for this particular tracking tunnel line over time may reveal more information, an effort that lies beyond the scope of this research project.

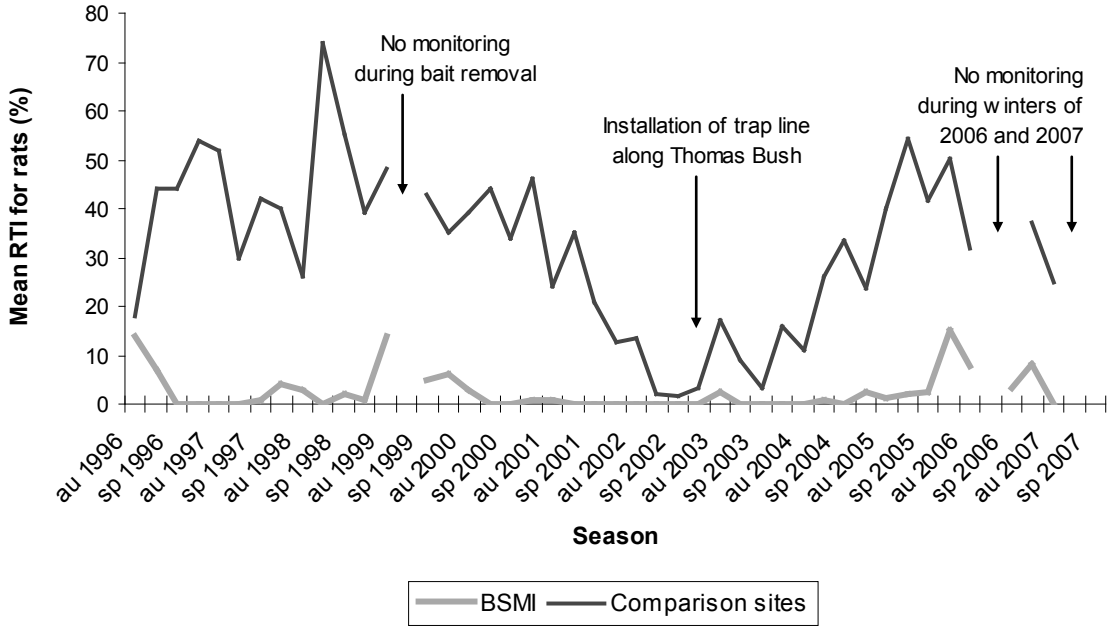

Figure 4.2: Mean RTI (%) at BSMI and comparison sites between 1996 and 2007.

From a management perspective, the significant effect of the tracking tunnel setup is important. Since it is difficult to quantify the difference between the monitoring setups, the comparison of the RTI from the changing sampling techniques is problematic.

4.3.2 Season

Season did not have a significant effect on either RTI – both within BSMI and the comparison sites – or on the bait-take at BSMI; however, they did indicate some interesting patterns. With respect to seasonal variations in RTI, there was a greater variability in the baiting treatment area. RTI estimates were lowest in winter, raised slightly in spring and were highest in summer and autumn. The highest baiting efficacy therefore seemed to happen in winter, with the rat population slightly increasing in the following seasons. Despite the peak over summer it needs to be kept in mind that the differences between seasons were not significant and that most RTI values were extremely low and below the 5 % RTI threshold during all seasons.

The RTI in the comparison sites were very similar between seasons, the only peak was found during winter. The range in which the RTI in the non-treatment sites were found, points out the overall success of the poisoning operation in the treatment area. While generally below 4 % every season at BSMI, the average RTI in the non-treatment sites ranged between 40-50 %.

Also contrary to the RTI at BSMI, the peak in the non-treatment site was found in winter. Both extremes were therefore found in the same season, indicating the importance of winter

baiting. Having the biggest impact in winter, baiting serves an important role in reducing the rat population in preparation for the breeding seasons in the subsequent spring.

Interestingly – although also not significant – the peak in seasonal bait-take was in autumn, while spring, summer and winter were very similar to each other. Possibly it was the high bait-take in autumn that led to the low RTI in winter. The small differences between bait-take in the different seasons, however, do not allow any meaningful interpretation.

The fact that seasons did not have a significant effect on either bait-take or rat monitoring data in this work is an interesting result in itself. Apparently, the rat population in the whole area was not influenced by any seasonal changes, which is consistent with Innes (2005), who reported that seasonal changes were small in comparison to annual changes. Possibly the winters are not cold enough to be responsible for increased mortality, and summers are not warm and dry enough to cause any heat-influenced problems, and food is mostly available all year round.

4.4 Effect of installation of extra bait stations

The installation of 357 extra bait stations at BSMI in 2006 not only decreased the bait station grid size from 150 x 150 m to 150 x 75 m, but also considerably increased the workload and staff hours involved in the servicing of the interior bait stations. In the light of noticeably higher RTI estimates since the extra bait stations were installed, it is worthwhile investigating whether the extra installation had been a successful move or not.

The sudden increase of RTI with installation of the tracking tunnel setup 4 also raised the question of whether the previous bait station grid was sufficient to provide bait to all resident rats (DOC, n.d., unpublished). The decrease of the grid size was therefore meant to provide bait to those rats that previously may not have had a bait station within their established home ranges. An increase of bait-take would support this hypothesis. On the other hand, the decrease in the grid size may also simply have placed additional bait stations where the old setup had already done the job, which may have led to rats dividing up their bait-take between two or more bait supply points, thus causing a more evenly distributed bait-take, but no overall bait-take increase.

Between all anticoagulants, coumatetralyl had the smallest percentage bait-take per bait station (Figure 3.7), but was only significantly different to warfarin. Figure 3.1 also shows that the mean bait-take per bait station in grams largely remained at a consistent level after the extra bait stations were installed. This suggests that indeed the demand for bait at each bait station remained largely unchanged after installation of new bait stations, supporting the

thought that rather than rats spreading their bait consumption between bait stations, more rats were possibly eating bait. This is also supported by the overall bait-take during the same period, which showed an increase for the first three seasons after installation. The decrease during the last two seasons could hint at the increased kills due to the previous overall increase of bait-take, but could also reflect the fact that in the end of autumn 2006 the amount of bait put into bait stations was reduced to 200 g from previously 300 g.

Why the mean bait-take per bait station with the extra bait stations largely remained the same while overall bait-take first increased and then decreased, is interesting. The bait-increase in some bait stations must have been compensated by decrease in others. However, this is not obvious from Figure 4.3, where the areas with bait-take of below 100 g first decreased in size and then disappeared in autumn 2007, but then reappeared again with an increase in both number and size. This would indicate an overall increase in mean bait-take per bait station rather than an unchanged mean bait-take. The variation in bait-take must have occurred at a level that is not detectable with the interpolation method or categorisation of bait-take used here. Further spatial analysis at a finer scale would be necessary to detect ‘small-scale’ changes, which due to time constraints cannot be done as part of this project.

Accordingly, with the interpolation method used in this work, the question whether the installation of extra bait stations improved the poison operation cannot be fully answered.

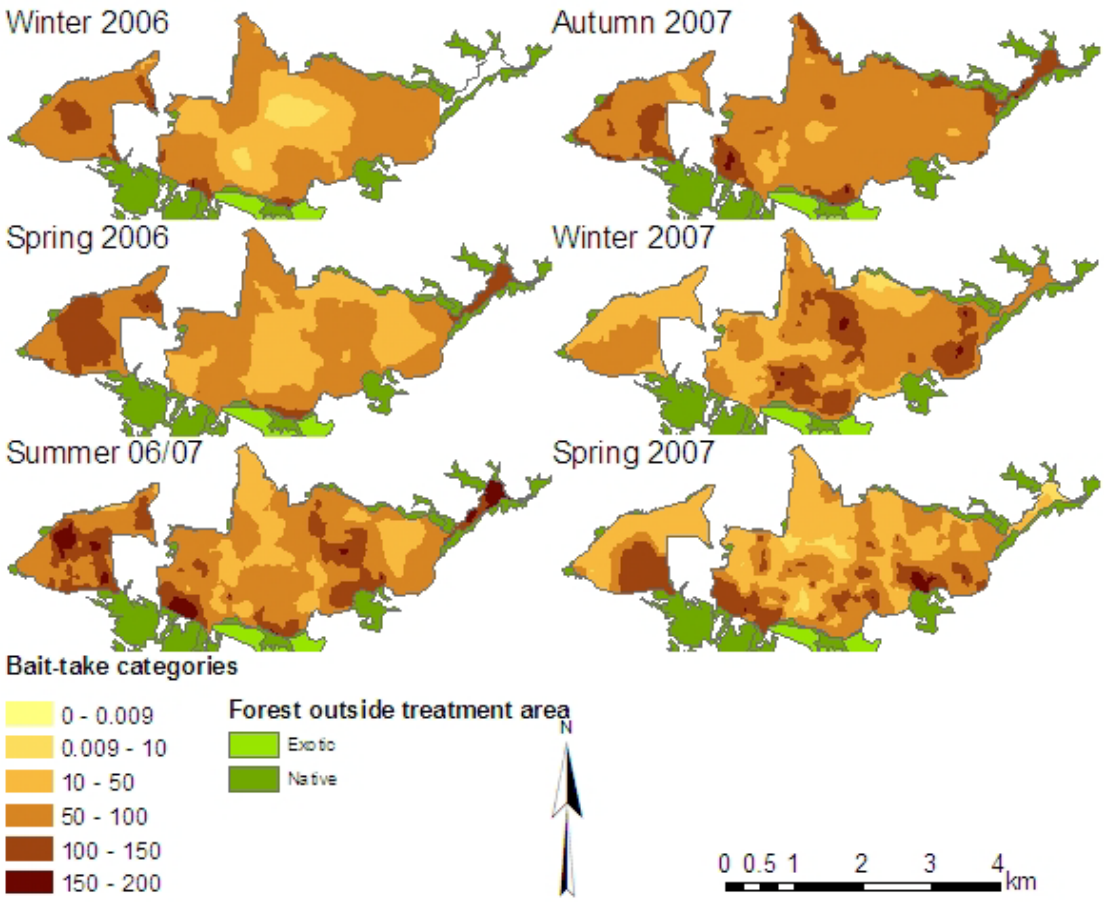

Figure 4.3: Bait-take distribution after the installation of extra bait stations. The installation started in winter 2006, but the first bait-take recordings from those new bait stations were collected in spring 2006.

4.5 Bait-take versus tracking index as an indicator of rat activity

Most poisons investigated from a spatial perspective in this work were anticoagulants. Since the onset of poisoning symptoms is delayed after ingestion of anticoagulants, rats can continue consuming bait for several days after ingesting a lethal dose. Bait-take therefore does not allow any quantification of actual rat numbers living in a particular area. Indeed there is no obvious linear correlation between bait-take and RTI, neither in absolute bait-take across the reserve (Figure 4.4), nor in average bait-take per bait station (Figure 4.5).

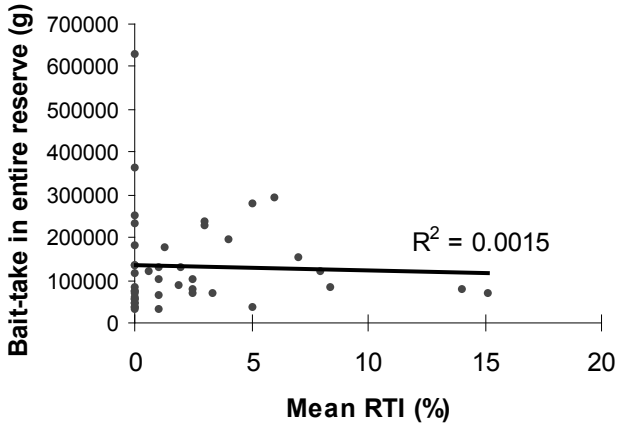

Figure 4.4: Correlation between RTI (%) within BSMI and absolute bait-take for every season.

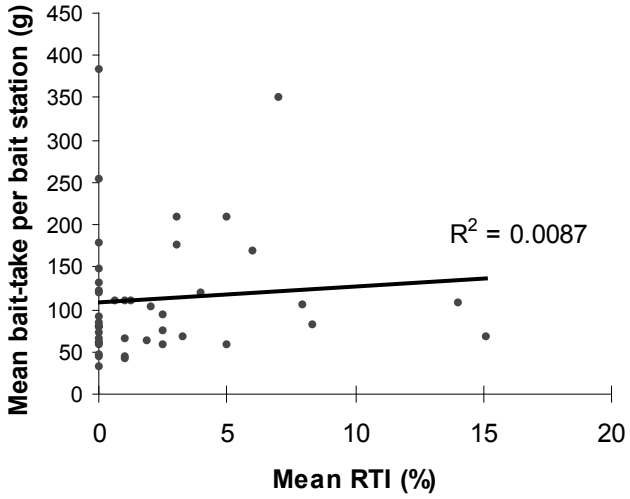

Figure 4.5: Correlation between RTI (%) within BSMI and average bait-take per bait station for every season.

Bait-take therefore cannot – as expected – replace direct rat monitoring. It simply is an indicator of rodent activity and any changes in bait-take do not allow quantifiable differences in rat abundance to be estimated, but they do allow us to speculate with regards to differences in bait-take activity. Changes in bait-take activity may be due to differences in other available food sources or differences in rat abundance, but it may also indicate differences in bait palatability due to locally and/or temporally variable conditions influencing the bait quality and/or palatability.

In conclusion, RTI are a more accurate measurement of relative rat densities or abundances than bait-take measures, especially when bait-take is based on the use of anticoagulants. However, due to the much better coverage of the entire reserve through bait stations, the bait-take data allow an interesting insight into the spatial distribution of rodent activity at BSMI and highlights centres of reinvasion.

4.6 Recommendations

- Of the first-generation anticoagulants, pindone and diphacinone – provided a palatable bait product was chosen (Pindone Pellets® for pindone or Pestoff® 50D for diphacinone) – showed the best results and could be used again for reliably suppressing, and maintaining low, rat numbers. Brodifacoum (Pestoff® 20p, Talon®) could also be applied if rat numbers need to be suppressed quickly, but considering the high persistence in the environment should only be used in a pulsed fashion.
- Non-anticoagulant pulses should be carried out on a regular basis to prevent build-up of resistance to anticoagulant products.
- The consistent success of toxic formulations presented in cereal pellet baits cannot be put down to the bait type alone with any degree of certainty. A trial involving an identical bait formulation in cereal pellets and in a paste and/or block shape might improve future decision making.
- Both brodifacoum (Pestoff® 20D, Talon®) and pindone (Pindone Pellets®) were applied in cereal pellet baits, but they proved to be not practical for leaving in the field for three months at a time, especially not over winter. Unless bait products are found that reliably retain their toxicity and palatability in the often adverse weather conditions at BSMI, it is advisable to change bait regularly, regardless of whether the bait is presented in cereal pellets or any other bait type.
- The effect of neglected winter baiting on the general forest restoration should be investigated. E.g. bird's nesting success of the years 1999/2000 and 2002/2003 compared to other years might reveal interesting insights into the interaction between bird and rat populations.
- Edge effects influence the treatment area, but the irregularities with which they are manifested do not allow the development of more efficient baiting strategies. All bait stations need to be serviced consistently, but if time constraints prevent a complete servicing, perimeter bait stations and interior bait stations close to the treatment edge (e.g. < 150 m) should have high priority, particularly if close to adjacent unmanaged native forest. Especially the Kakabeak block and the western end of the main reserve should always be serviced with fresh bait.
- The poison operation showed the greatest impact on the rat population in winter. Therefore, care should be taken to make bait available in sufficient quantities and kept in a palatable condition during this season especially.

- Uniformity in time periods for which the same bait is applied would greatly enhance possibilities for future analysis of, and comparison between, different baiting strategies. A time period of two years – corresponding with the application period of coumatetralyl – would provide a substantial data set for future analyses.
- The current tracking tunnel setup within the treatment site should be retained to allow viable comparisons between poison efficacies in the future. However, the tracking tunnel setup in the comparison sites should be reviewed. The tracking tunnel line along the forest edge of Thomas Bush should be relocated to exclude any effects the grassy habitat and/or the nearby mustelid trap line may have on the RTI.
- The simultaneous monitoring in the treatment site and the comparison sites has clearly established the overall efficacy of the poison operation through the years. For this purpose alone, no more monitoring in the non-treatment site is necessary. However, to allow further analysis of the relationship between population fluctuations in both areas, monitoring in both areas should continue into the future.
- Due to the overall efficacy of the poison operation against rats in the past, the future management decisions could focus on also improving mouse control strategies.

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Appendices

Appendix 1. Bait-take distribution in individual summers

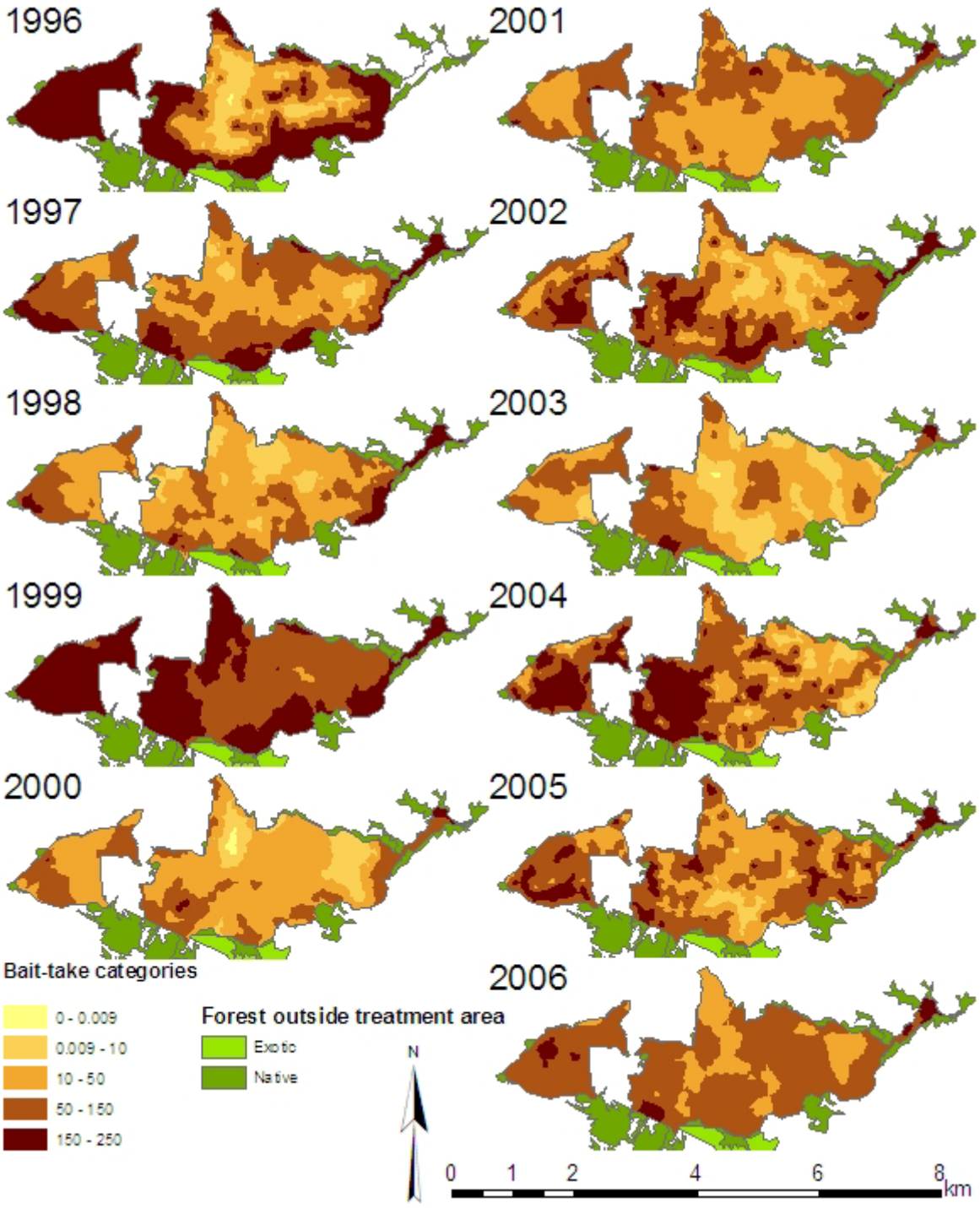

Figure A. 1: Mean bait-take during each summer season interpolated across the entire treatment area. Interpolation method: Inverse Distance Weighting. See Appendix 4, Table A.5 for statistics.

Appendix 2. Bait-take distribution in individual autumns

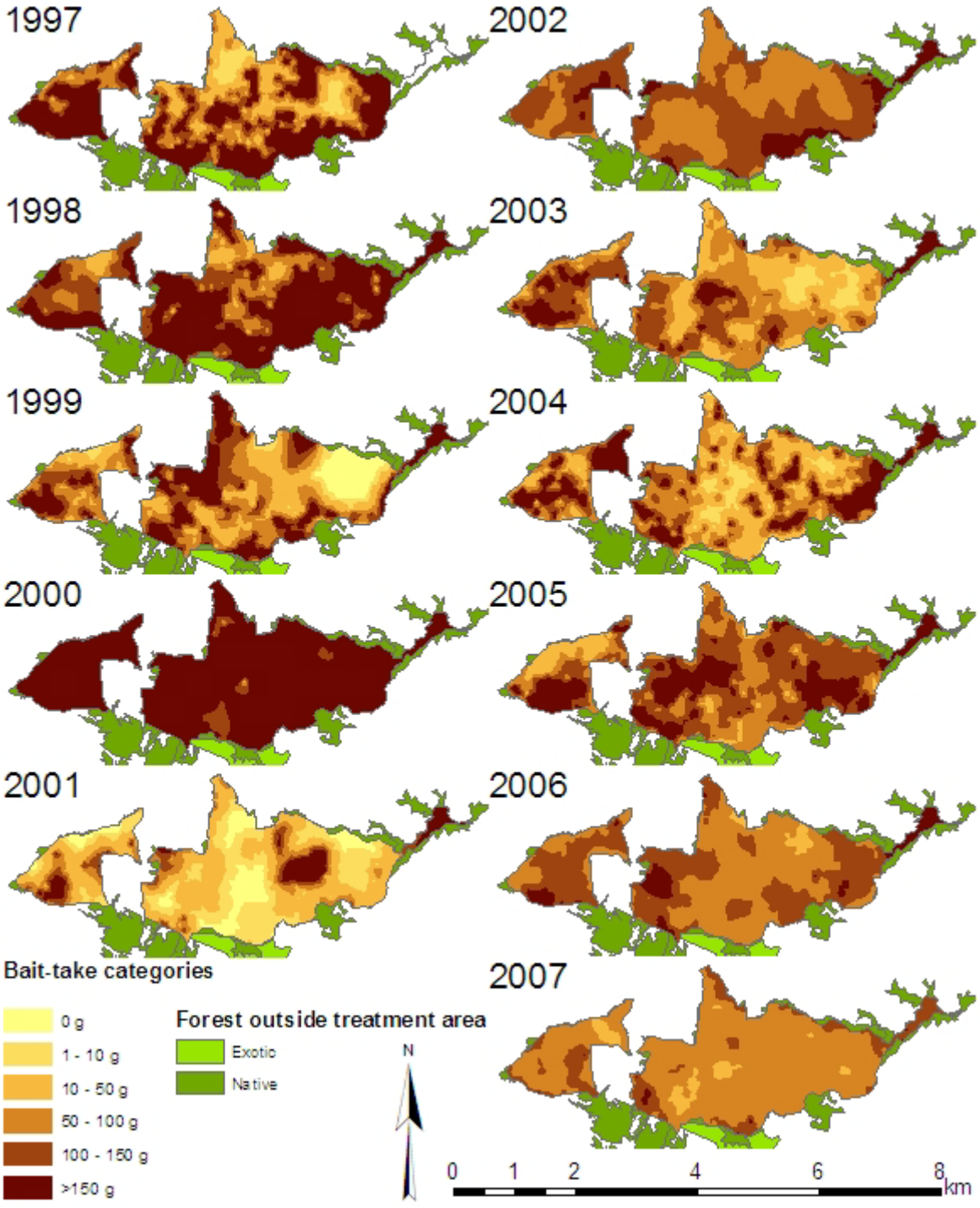

Figure A. 2: Mean bait-take during each autumn season interpolated across the entire treatment area. Interpolation method: Inverse Distance Weighting. See Appendix 4, Table A.6 for statistics.

Appendix 3. Bait-take distribution in individual winters

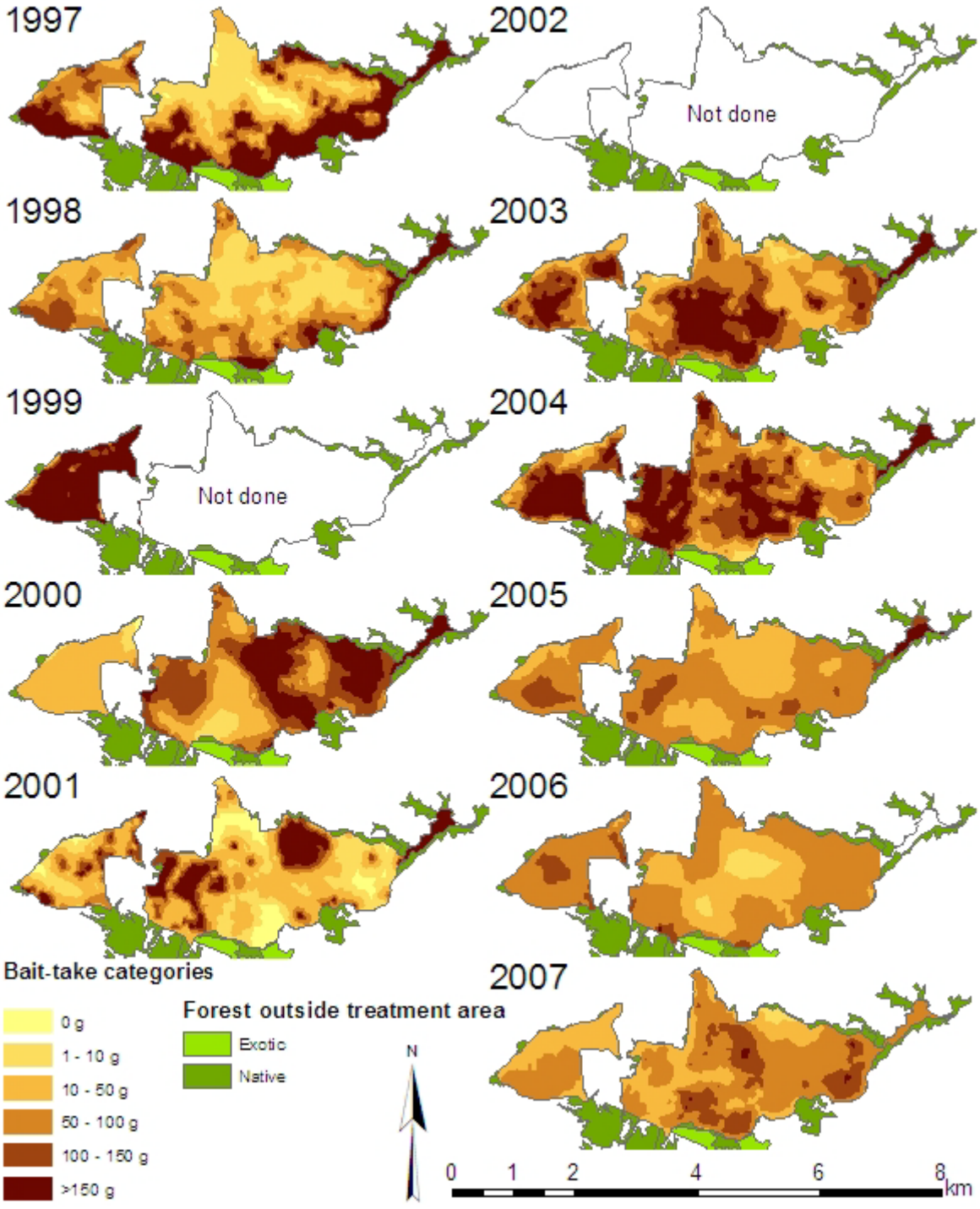

Figure A. 3: Mean bait-take during each winter season interpolated across the entire treatment area. Interpolation method: Inverse Distance Weighting. See Appendix 4, Table A.7 for statistics.

Appendix 4. Statistics for interpolations

Table A. 1: Statistics for Figure 3.3. Mean bait-take by season.

Interpolation period	Bait stations *	Neighbours used (at least)	Optimised power value	Prediction errors:	
				Mean	Root-mean-square
Spring 1996-2006	587	12 (10)	1.4819	0.2426	28.11
Summer 1996-2006	587	12 (10)	1.5657	0.7643	29.85
Autumn 1996-2006	587	12 (10)	2.7272	0.3937	36.05
Winter 1996-2006	587	12 (10)	2.0706	0.8911	34.71
Spring 2006/07	897	18 (15)	1.3728	-0.3202	40.4
Summer 2006/07	941	19 (16)	1.6249	0.1296	50.09
Autumn 2006/07	846	17 (14)	1.0	-0.9287	40.62
Winter 2006/07	932	19 (16)	1.0	1.277	43.46

* Number of bait stations with bait-take values during the period

Table A. 2: Statistics for Figure 3.4. Mean bait-take by year.

Interpolation period (spring-winter)	Bait stations *	Neighbours used (at least)	Optimised power value	Prediction errors:	
				Mean	Root-mean-square
1996/97	586	12 (10)	2.0544	1.092	68.58
1997/98	586	12 (10)	2.3944	0.6185	42.06
1998/99	586	12 (10)	2.0541	0.8594	47.98
1999/2000	586	12 (10)	2.0649	0.4224	31.57
2000/01	587	12 (10)	1.803	0.172	37.02
2001/02	587	12 (10)	1.4037	0.1909	30.99
2002/03	587	12 (10)	1.9319	0.1125	41.53
2003/04	587	12 (10)	1.869	0.8458	41.0
2004/05	587	12 (10)	2.3131	0.2339	37.14
2005/06	588	12 (10)	2.0998	0.7042	38.65
2006/07	941	19 (16)	1.2552	0.5748	23.77

* Number of bait stations with bait-take values during the period

Table A. 3: Statistics for Figure 3.4. Mean bait-take by poison.

Bait	Bait stations *	Neighbours used (at least)	Optimised power value	Prediction errors:	
				Mean	Root-mean-square
Brodifacoum	586	12 (10)	2.2693	0.7766	34.85
Pindone	587	12 (10)	1.6674	0.4016	26.74
Diphacinone pellets	587	12 (10)	2.4421	0.4495	52.14
Diphacinone blocks	587	12 (10)	2.4827	0.04757	41.62
Coumatetralyl	941	19 (16)	1.2193	-0.317	23.05

* Number of bait stations with bait-take values during the period

Table A. 4: Statistics for Figure 3.6. Mean bait-take by individual seasons (spring).

Spring	Bait stations *	Neighbours used (at least)	Optimised power value	Prediction errors:	
				Mean	Root-mean-square
1996	556	12 (10)	1.8865	0.6872	79.33
1997	586	12 (10)	2.0965	-0.1112	79.57
1998	586	12 (10)	1.5929	0.1114	68.29
1999	586	12 (10)	1.9471	0.197	44.77
2000	583	12 (10)	1.5168	-0.6357	81.28
2001	586	12 (10)	1.6906	-0.0579	42.14
2002	586	12 (10)	1.8065	0.2993	47.47
2003	584	12 (10)	1.3877	0.319	69.93
2004	583	12 (10)	2.2558	0.4614	75.89
2005	587	12 (10)	2.3469	0.4597	58.08
2006	809	18 (16)	1.1955	-0.1996	42.17
2007	618	13 (10)	1.6597	-0.7231	52.92

* Number of bait stations with bait-take values during the period

Table A. 5: Statistics for Appendix 1. Mean bait-take by individual seasons (summer).

Summer	Bait stations *	Neighbours used (at least)	Optimised power value	Prediction errors:	
				Mean	Root-mean-square
1996	556	12 (10)	2.2257	1.863	102.3
1997	586	12 (10)	1.5621	-0.2318	65.02
1998	586	12 (10)	1.7176	0.7815	55.51
1999	586	12 (10)	1.5896	0.7574	53.04
2000	584	12 (10)	1.4133	0.2486	47.08
2001	585	12 (10)	1.7825	0.2077	48.13
2002	586	12 (10)	2.0455	-0.4098	75.91
2003	587	12 (10)	1.1307	1.078	53.78
2004	580	12 (10)	2.3542	-0.0564	84.46
2005	586	12 (10)	2.1598	0.5921	74.22
2006	846	17 (14)	1.5487	0.1655	50.08

* Number of bait stations with bait-take values during the period

Table A. 6: Statistics for Appendix 2. Mean bait-take by individual seasons (autumn).

Autumn	Bait stations *	Neighbours used (at least)	Optimised power value	Prediction errors:	
				Mean	Root-mean-square
1997	557	12 (10)	2.1151	1.803	132.5
1998	583	12 (10)	1.53	0.9207	79.62
1999	466	12 (10)	2.0085	0.4549	85.09
2000	584	12 (10)	1.6518	0.4054	53.02
2001	583	12 (10)	1.463	0.2816	64.23
2002	584	12 (10)	1.0	0.3467	57.38
2003	585	12 (10)	1.9659	0.3049	62.73
2004	581	12 (10)	2.1828	0.983	83.49
2005	585	12 (10)	2.2549	0.2018	54.87
2006	586	12 (10)	1.1621	0.9532	61.15
2007	911	19 (16)	1.6238	-1.27	41.24

* Number of bait stations with bait-take values during the period

Table A. 7: Statistics for Appendix 3. Mean bait-take by individual seasons (winter).

Winter	Bait stations *	Neighbours used (at least)	Optimised power value	Prediction errors:	
				Mean	Root-mean-square
1997	586	12 (10)	1.9631	0.813	101.5
1998	586	12 (10)	2.3141	0.898	48.5
1999	123 **	12 (10)	2.695	-0.0394	109.1
2000	571	12 (10)	1.0	-0.7756	76.47
2001	552	12 (10)	1.8952	-0.1369	83.31
2002	229 ***				
2003	583	12 (10)	1.4168	1.2	77.74
2004	587	12 (10)	1.9974	0.3059	76.05
2005	587	12 (10)	1.0	0.8384	46.47
2006	346	12 (10)	1.1305	0.1597	45.34
2007	931	19 (17)	1.5172	2.053	46.2

* Number of bait stations with bait-take values during the period
** Only bait stations in Section 4 (warfarin trial).
*** Only perimeter bait stations done. Season was not interpolated.

Appendix 5. Bait product specifications

Table A. 8: Trade names and manufacturers of anticoagulant products used at BSMI.

Active ingredient	Trade name	Manufacturer
Brodifacoum	Pestoff® 20p	Animal Control Products Ltd., NZ
Warfarin	Wanganui No. 7	Animal Control Products Ltd., NZ
Diphacinone	Pestoff® 50D	Animal Control Products Ltd., NZ
Pindone	Pindone Pellets®	Pest Management Services, NZ
Diphacinone	Ditrac®	Bell Laboratories Inc., USA
Coumatetralyl	Racumin®	Bayer AG, Germany