Management and predator control in a 'Mainland Island' ecosystem : Assessment of rodent control efficiency

Ship rat eating fantail chicks
D. Mudge

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And finally thanks to the bush, for its magnificent Kauris, Ratas, KieKie, Supplejack, Cutty grass and for all of these beautiful walks during my six months in New Zealand.

Sorry for all the people I forgot, but it would add at least 20 pages to my report !

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I. Introduction

New Zealand has developed a distinctive flora and fauna dominated by bird species due to its geographic isolation. Since human settlement, invasive pests and weeds were introduced threatening this unique endemic flora and fauna. Today, many conservation programmes manage and remove plant and animal pests in order to save New Zealand's species and ecosystems. Ark in the Park is one of these projects, it started in 2003 and after one year of predator control translocations of endemic bird species started. It is a project jointly managed by the Royal Forest and Bird Society of New Zealand and the Auckland Regional Council.
My main goal during this internship was to assess the efficiency of the rodent control since the beginning of the project. The aim of this research was to have a more precise idea of how predator control techniques have been working and to gather more information on the effects on the targeted species. With these results, the project can improve baiting and work effort depending on where rodents are persistent and lessen effort with low or no rats. Spatial analyses were undertaken of rodent bait eaten at more than 2000 bait stations from 2004 to 2010 in 1100ha of the Ark in the Park sanctuary. This will allow the project managers to better understand rat behaviour and determine why some areas are more likely to be infested than others, and how to control them more efficiently.

Since the late 1800's, New Zealanders have been concerned about protecting and preserving the native fauna and flora, despite a history of unintentional and deliberate introductions of invasive species into this country (Ji & Clout, 2006). Most of the earlier ecological restoration projects were focused on off-shore islands where ecosystems tended to be less modified in comparison to the mainland due to isolation from other terrestrial habitats (Saunders, 1990). Predator control allowed native species to recover and has provided opportunities to translocate native populations that are endangered. Since eradicating invasive mammals on islands has been of considerable success (Veitch & Bell, 1990), attention focused on mainland ecosystems where invasive species are controlled rather than being eradicated (Saunders, 1990). This brings forward the concept of 'Mainland Islands' where borders can be physical structures such as predator-proof fencing, or such as geographical features like for example open pasture surrounding a significant ecological area.
There are many individuals, community groups and organisations involved in ecological restoration projects involving predator control throughout New Zealand.

1.1) Royal Forest and Bird Protection Society of New Zealand.

Royal Forest and Bird Protection Society of New Zealand was formed in 1923 in order to protect the native forests and birds and natural landscapes. It is New Zealand's largest independent conservation organisation, which works with other environmental organisations such as BirdLife International, on environmental issues in New Zealand's Exclusive Economic Zone, the wider Pacific and in Antarctica. Their role has grown since 1923 to include protection of all native species and wild places. Forest & Bird is a non-government organisation and relies on donations and bequests to carry out their conservation work.

1.2) Study area :

1.2.1) Waitakere Ranges Regional Park:

The Waitakere Ranges Regional Park contains more than 18,000 hectares of native forest, beaches and cliffs to the west of Auckland on the North Island of New Zealand. It includes 250km of trampling tracks and is administered by the Auckland Regional Council. Before the arrival of Maori in New Zealand, about a thousand years ago, the region of Waitakere was covered with virgin forest containing extensive groves of kauri. As the Maori population grew, some of this forest was cleared for habitation and cultivation. They would usually break down the undergrowth and once dry it would be set alight. Then the large trees would be cut down and the land prepared for planting. Another main impact on the forest were the timber millers. They cut down the vast majority of the Kauri trees in the area and caused a lot of damage to the remaining forest getting the Kauri logs out of the rugged hills and down to the mills. By the 1920s, very little virgin forest remained in the Ranges. But fortunately that which remained was preserved and became park land and water catchment area. The wildlife of the Waitakere Ranges is strongly influenced by the climate and topography as well as by the marine coastal environment. The Waitakere Ranges were formed by an ancient uplift of hard volcanic basalt creating an elevated plateau with a cool climate, therefore the rainfall is twice that of Auckland.

Plate 1 : Location of the Waitakere Ranges in New Zealand

1.2.2) Ark in the Park :

The conservation strategy of removing mammalian predators from offshore islands has been really successful in New Zealand. The success of this strategy has led to the development of open sanctuaries on the mainland referred to as ‘Mainland Islands’. The aim is to protect and restore habitats on the mainland throught intensive management of introduced pests. ‘Mainland Islands’ are manageable areas, isolated by means of fencing, geographical features or more commonly intensive management. Unlike islands which are surrounded by sea, ‘Mainland Islands’ are subject to continual re-invasion pressure from pests in surrounding areas, it therefore requires specific management techniques.

Ark in the Park is the largest of these eco-restoration project located in the Waitakere Ranges Regional Park. The aim of the project being to restore sustainable mainland populations of endemic New Zealand species throught intensive pest control. It represents an area of approximately 2500 hectares (2000 ha of parkland and 500 ha of private land). My study area was the 1100 ha where pest control was established from 2002. The Ark in the Park project is a partnership between the Auckland Regional Council and the Waitakere branch of the organisation Forest & Bird. Since the beginning of the project in 2003, a grid of bait stations and mustelids traps were set over the area of Ark in the Park. To measure and assess pest abundance, monitoring tunnels were also placed inside and outside the borders of the Ark in the Park area. When the bait stations are rebaited every six months, volunteers record how much bait has been eaten at every station.

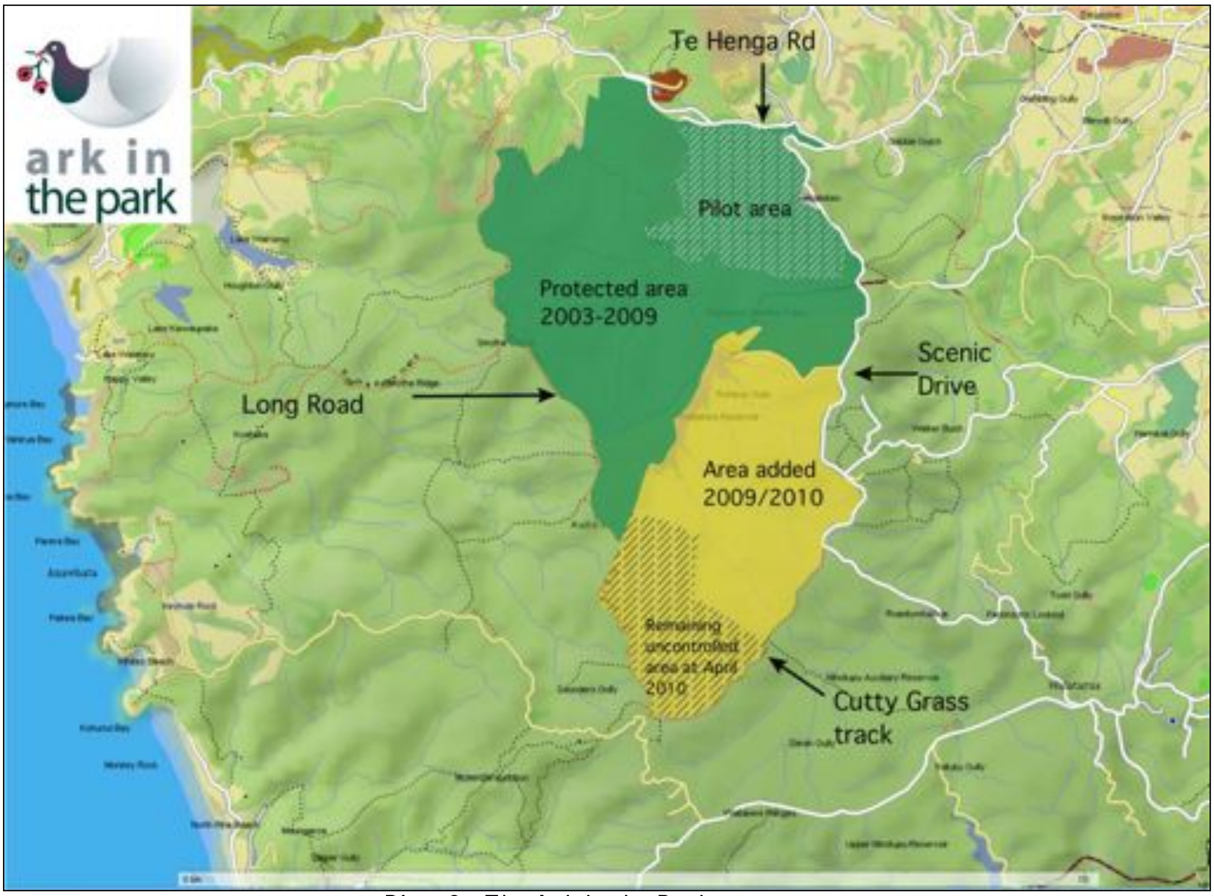


Plate 2 : The Ark in the Park sanctuary

1.3) Animal pests

1.3.1) Rats and mice


Plate 3 : Norway rat

Originally, New Zealand has no native rat species, three rat and one mouse species arrived with early sailors. The first one to invade was the kiore (*Rattus exulans*) introduced by the first polynesians (1250-1300 AD) when they settled in New Zealand. They have had an important impact on native wildlife and are thought to have wiped out some species like the snipe-rails, some small petrels, native frogs and tuatara on the mainland. Today kiore survive on offshore islands since more aggressive European rodent species have replaced them.

Norway rats (*Rattus norvegicus*) and ship rats (*Rattus rattus*) arrived in New Zealand with the first European explorers in the late 1700s. Today, Norway rats live from North Cape to Stewart Island. They are ground dwellers and threaten animals living, roosting or nesting near the ground, but are uncommon in native forests. The ship rat is present throughout the country, and abundant in kauri and rimu-rata forest. Since they mostly live and nest in trees, the spread of ship rats caused the decline of many native bird, insect and bat species. In the bush, they feed mainly on fruit, berries and fallen seeds during autumn and winter, and on other animals in spring and summer like wetas, stick insects, cicadas, beetles, caterpillars and grubs, spiders, native slugs, snails and lizards.

House mice (*Mus musculus*) is found throughout New Zealand's forests, sometimes in plague numbers. They deprive many native ground- feeding animals of food by eating their resources like insects and fallen seeds and berries. Another major problem is that when mice populations explode, stoat numbers may also increase as they prey on mice. The stoats, once most of the mice are eaten, will turn their predatory attention to native birds.

1.3.2) Mustelids

Stoats (*Mustela erminea*) and the less common weasel (*Mustela nivalis vulgaris*) and ferrets (*Mustela furo*) are all invasive species in New Zealand. Stoats were first brought from Britain in the 1870s to control rabbits. They quickly spread into the bush preying on native animals. Together with rats and cats, they are mainly responsible for the extinction of many bird species including huia, bush wrens, native thrushes, laughing owls and quails. Stoats have also exterminated stitchbirds, saddlebacks, kakapo and little spotted kiwi from the mainland. In the bush, their diet consists mainly of birds, rats and mice, rabbits, possums, hares, lizards and insects. Their population can rapidly increase when food becomes abundant.

Plate 4: Mustelids

1.3.3) Possums :

Plate 5 : *Trichosurus vulpecula*

The brushtail possum (*Trichosurus vulpecula*) is a nocturnal, semi-arboreal marsupial of the family Phalangeridae. It is native to Australia and has been introduced in New Zealand in the 1800s for its fur. The native vegetation of New Zealand has evolved in the absence of mammalian omnivores, therefore possums are a major conservation pest. They selectively browse native vegetation causing particular damage to broadleaved trees. This leads to changes in forest composition and eventually canopy collapse, as well as competition for food with native forest birds. Possums are opportunists, so they will also eat the eggs and chicks of nesting native birds, they are referred to as 'reluctant folivores' in that they eat foliage to survive but prefer other foods. They are also a threat to the dairy, beef and deer farming industries, since possums are vectors of bovine tuberculosis.

1.4) Management and predator control :

Ark in the Park is not a suitable site for a predator exclusion fence, considering the terrain and costs. As well, Ark in the Park has always intended to extend the area making the use of a fence incompatible. Therefore, the park will continually be invaded and reinvaded by pest species, so an intensive predator control is necessary. The main targets are rats, possums and mustelids. The Waitakere Ranges are currently free of deer and goats.

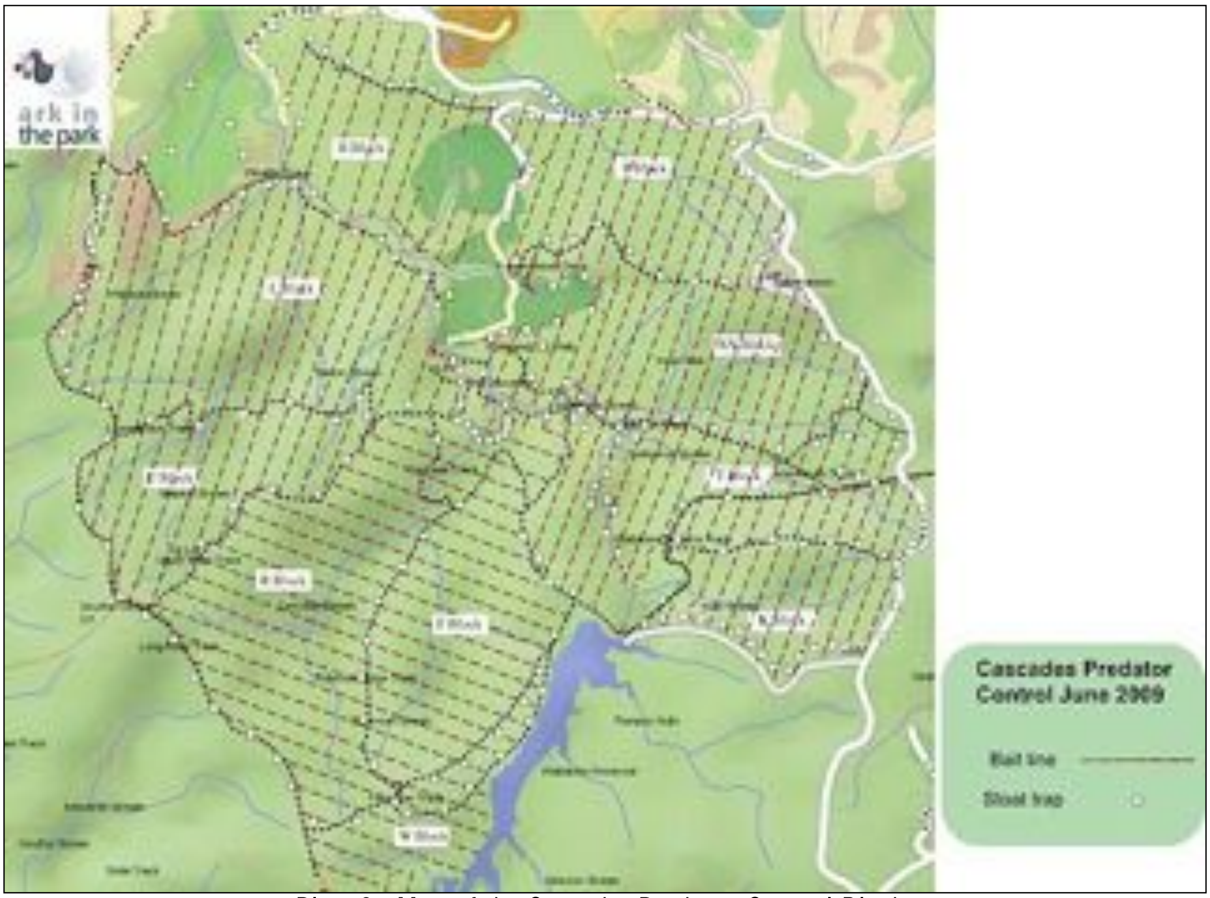


Plate 6 : Map of the Cascades Predator Control Blocks

1.4.1) Bait stations

A grid of bait stations has been set throughout the managed area. The baitlines are a hundred meters apart from one another, and bait stations are set every fifty meters along those baitlines. The poison used are brodifacoum baits 'Pest Off' (in a cereal bait manufactured for rats and possums), they are provided by the Auckland Regional Council and are contained in 150g doses in sealed plastic bags, keeping bait fresh for longer and avoids bait dispersal. The main target are rodents, the aim being to reduce rat numbers to under a 5 percent index over the period September to February. The bait is renewed twice a year, in winter and early summer, with late summer baiting around the borders. Using bait stations has the following advantages:

- Bait is kept dry, so the operation is not weather dependent
- Bait take can be monitored and unused bait can be removed
- Most bait taken from the bait stations has been eaten by rats and possums
- There is a lower risk of non-target poisoning

My analysis of the efficiency of rodent control required me to locate and GPS 2193 rodent bait stations and attach the bait take data for each bait station to that point.

Plate 7 : Pink triangle **with bait station's name**

Plate 8 : Bait station

1.4.2) Snap Traps

Cordons of mustelid traps are placed throughout the Ark in the Park area. Either Fenn or DOC 200 traps enclosed within tunnels are used, and these are baited with rabbit meat or eggs. The main targets are mustelids (althought rats also get caught in these traps), the aim is to have the managed area encircled by traps, with additional trap lines running throught the interior. They are set 200 meters apart from one another along the existing track network to facilitate their accessibility. The mustelid traps are checked and re-baited once a week in summer, and every one to two weeks in winter. Another cordon of cat traps are placed at 500 meters intervals with the mustelid trap network. These traps are checked at the same frequency as the mustelid traps.

Plate 9 : Fenn trap

Plate 10 : egg bait and Fenn trap

1.4.3) Monitoring tunnels

Tracking tunnels are placed in various areas of Ark in the Park with pest control, and in other areas without pest control in order to assess the efficiency of the pest management (Appendix 1). This method for monitoring small mammals was first described by King and Edgar (1977). The technique uses a 'run-throught' tunnel containing pieces of paper with ink on it. As the mammal walks over an inkpad to eat peanut butter in the tunnel, as it departs it leaves its footprints on the paper. Therefore, information can be gained for any species passing throught the tunnel. This non-destructive sampling technique doesn't affect the target population or any non-target species. Tracking tunnels only provide a coarse index of relative abundance, it's not a direct measure of population density, but a measure of activity. The tracking index of relative abundance for rodents is expressed as the mean percentage of tunnels tracked by rodents per lines (Gillies, 2001). With the decline of rodents, it has recorded the growing population of large ground insects.

Plate 11 : Tracking tunnel with peanut butter bait

Plate 12 : Ink pad

1.5) Brodifacoum

The toxin used at Ark in the Park is the second-generation anticoagulant brodifacoum. It is produced as compressed cereal pellets containing 0.02g/kg of the toxin. The pellets are dyed green and have cinnamon flavour to make them less attractive to birds. Brodifacoum is absorbed and acts by interfering with the synthesis of vitamin K dependent clotting factors in the liver, which causes death by haemorrhaging. It is extremely toxic to rats, the consumption of a single bait is enough to kill a rat (Eason and Wickstrom, 2001). The first symptoms appear several days after poison consumption, and bait shyness is therefore unlikely to happen. Rats gradually become weaker before they die, so many animals die underground or in cover, thereby reducing the risk of secondary poisoning of scavenging birds. Brodifacoum is insoluble in water and when released it binds onto organic matter, becomes inert and is slowly degraded by soil microorganisms over a period of 3-6 months. Ark in the Park have their rat baits in sealed plastic bags in bait stations, rather than spreading the baits in the forest. This reduces bait spread and bait becoming mouldy and unpalatable to rats with the damp climate.

Plate 13 : Brodifacoum pellets in sealed plastic bag

Many studies have been done concerning the assessment of the risk of secondary poisoning on non target species. Fraser & Hauber (2008) have done a study on the morepork (*Ninox novaeseelandiae*) which is a small species of owl at risk of secondary poisoning through ingestion of poisoned invertebrates and rodents. They have collected data on morepork calls inside the Ark in the Park and compared it with contol locations in the Waitakere ranges where no poisoning was conducted. Their results show that there is a higher quality of foraging habitats and breeding grounds inside the controlled area following the reduction in population sizes of mammalian pests. At Ark in the Park, the risk of secondary poisoning is most likely to affect stoats and cats which predate on rats and mice. It is therefore not a problem since they are also targeted species.

1.6) Translocation projects:

In total, four endemic species have been translocated to the Ark in the Park since the beginning of predator control in 2002. One of the crucial issuesfor reintroduced threatened species is to understand the factors responsible for their disappearance, and therefore eliminate or control them. Intensive monitoring of the reintroduced species is necesary in order to see whether these factors have been eliminated. In addition to that, the purpose of this study was also to understand how the reintroduced species are affected by the predator control program and to see if their dispersal is influenced by the pest control efficiency.
As the environmental restoration of the Ark in the Park takes effect, key bird species are returning, either actively as the result of translocations from remnant populations elsewhere, or by natural recovery of residual small local populations.

Plate 14 : Hihi (stitchbird) feeding chicks
Picture Laurence bechet

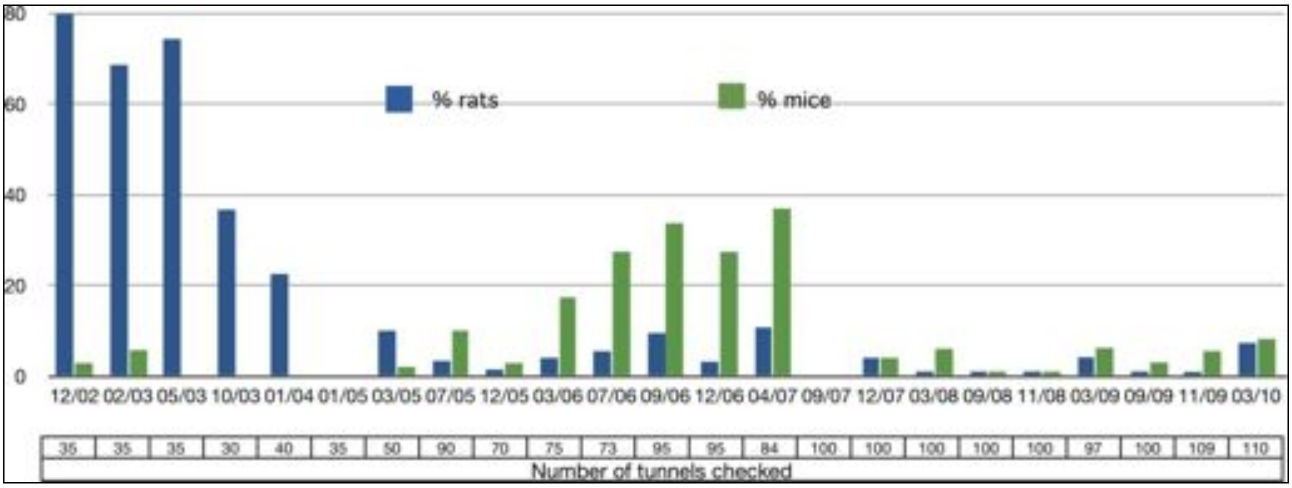
Plate 15 : North island Robin

Plate 16 : Kokako

During my internship the translocated Kokako shifted from predator-controlled forest to an adjacent area with no predator control. Consequently, the Ark in the Park project started a 800ha expansion of their predator control, trialling bait stations on a 100m by 100m grid. In this new added area, a study is actually being carried out to see if the predator control is as efficient with bait stations being a hundred meters apart from one another. The first results seem promising.(appendix 3)

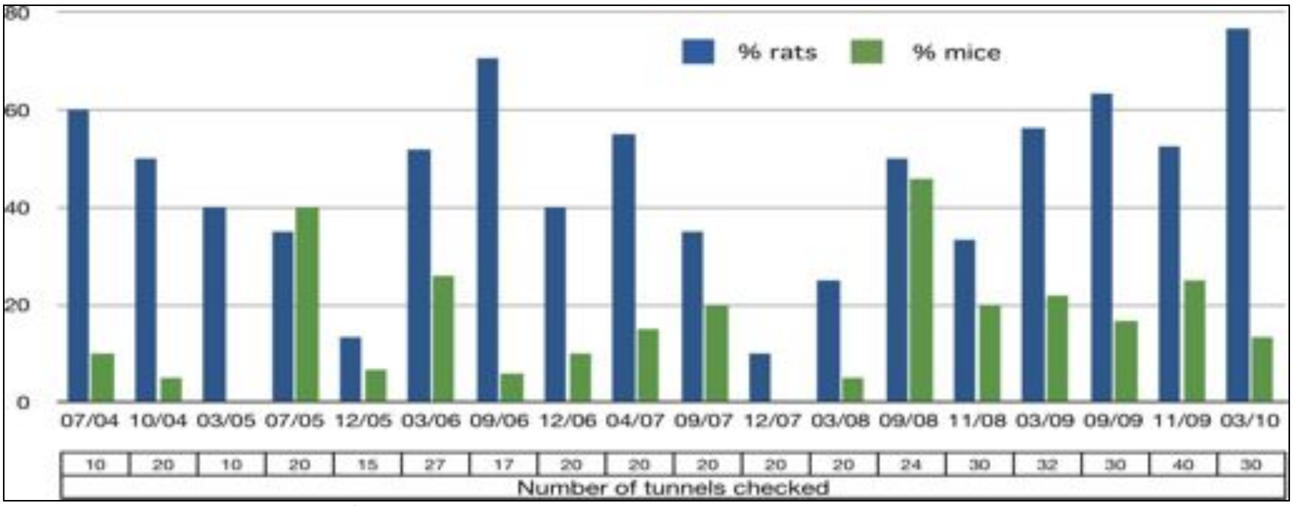
1.7) Rodent monitoring tunnel :

To assess the efficiency of the predator control, the data recorded by the volunteers from the monitoring tunnels had been analysed and the following results in graph 1 show rat (ship rat) and mouse activity at monitoring tunnels in the predator controlled areas and since 2003.



Graph 1 : Monitoring results in pest controlled areas

Predator control started early in 2003 in 250ha of the Cascades Park. Since then, the reduction in rat numbers has been spectacular. The average result of monitoring since 2007 is to find just one visited tunnel out of the 100 placed throughout the Ark (1% of tunnels). We can see on the graph 1 above that there was an initial increase in mouse numbers, certainly due to the absence of rats, but since 2006 their numbers have also dropped and have been sustained up to today, mainly by making it easier for mice to access bait in the bait stations. It seems clear that the combination of brodifacoum pellets and a 100m by 50m grid of bait stations is efficient in reducing mouse numbers.



Graph 2 : Monitoring results in an uncontrolled area

The graph 2 shows the monitoring results of the uncontrolled area. The comparison between this one and the results from within the controlled area (graph 1) shows the effectiveness of the rodent control. The variability of the rodent numbers can be explained in terms of the normal cycle of rodent populations and food availability. There is a large decrease in numbers during the winter and a steady build up during the summer to a peak in late summer and autumn.

II. Materials and Methods :

2.1) Gps locations :

The first step for the spatial analyses was to get a relatively accurate position for each bait station. Therefore, each line of bait stations was located with a Garmin GPS in a projected coordinate system, New Zealand Transverse Mercator (NZTM). Most locations had an accuracy of ± 10 meters, and on ridges and cleared areas ± 5 meters. In valleys or under dense forest canopy, the accuracy was around 12-13 meters. A total of 2193 bait stations were located. (Appendix 2)

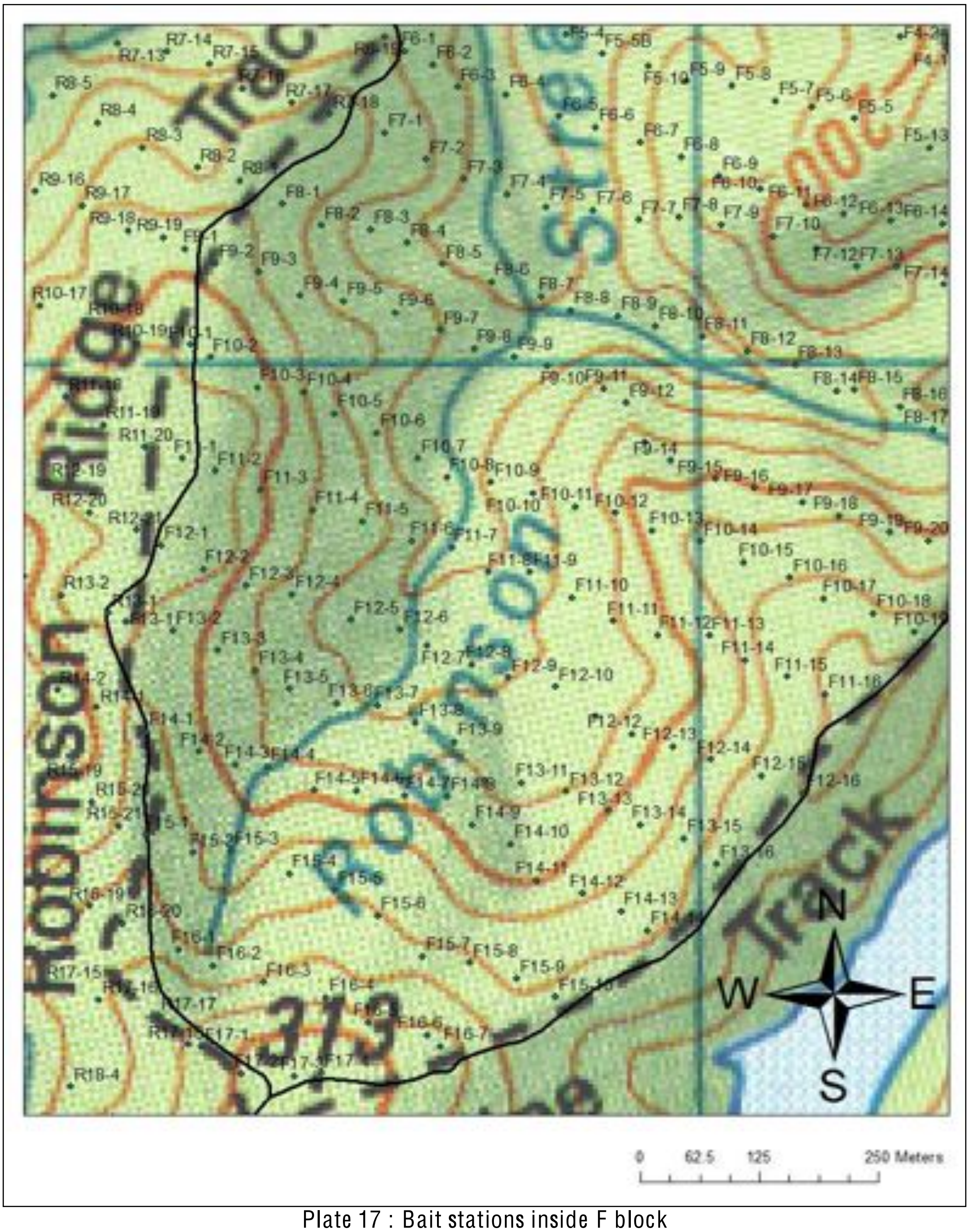


Plate 17 : Bait stations inside F block

2.2) Rodent Bait database

When the rodent bait is renewed, volunteers and contractors fill in a datasheet estimating the amount of bait that has been eaten or not. Data has been gathered for each baiting season since 2006. The next step was to sort all of this data by seasons in a main database.

Table 1 : Example of a bait take data card

Bait Line:				Date:	Name:	
Station	Bait not eaten	Bag nibbled	½ gone	More ½ gone	Bag pulled out	Category
1	✔					1
2	✔					1
3			✔			3
4		✔				2
5					✔	6
6				✔		4
7				✔	✔	5
8				✔		4
9		✔				2
10	✔					1

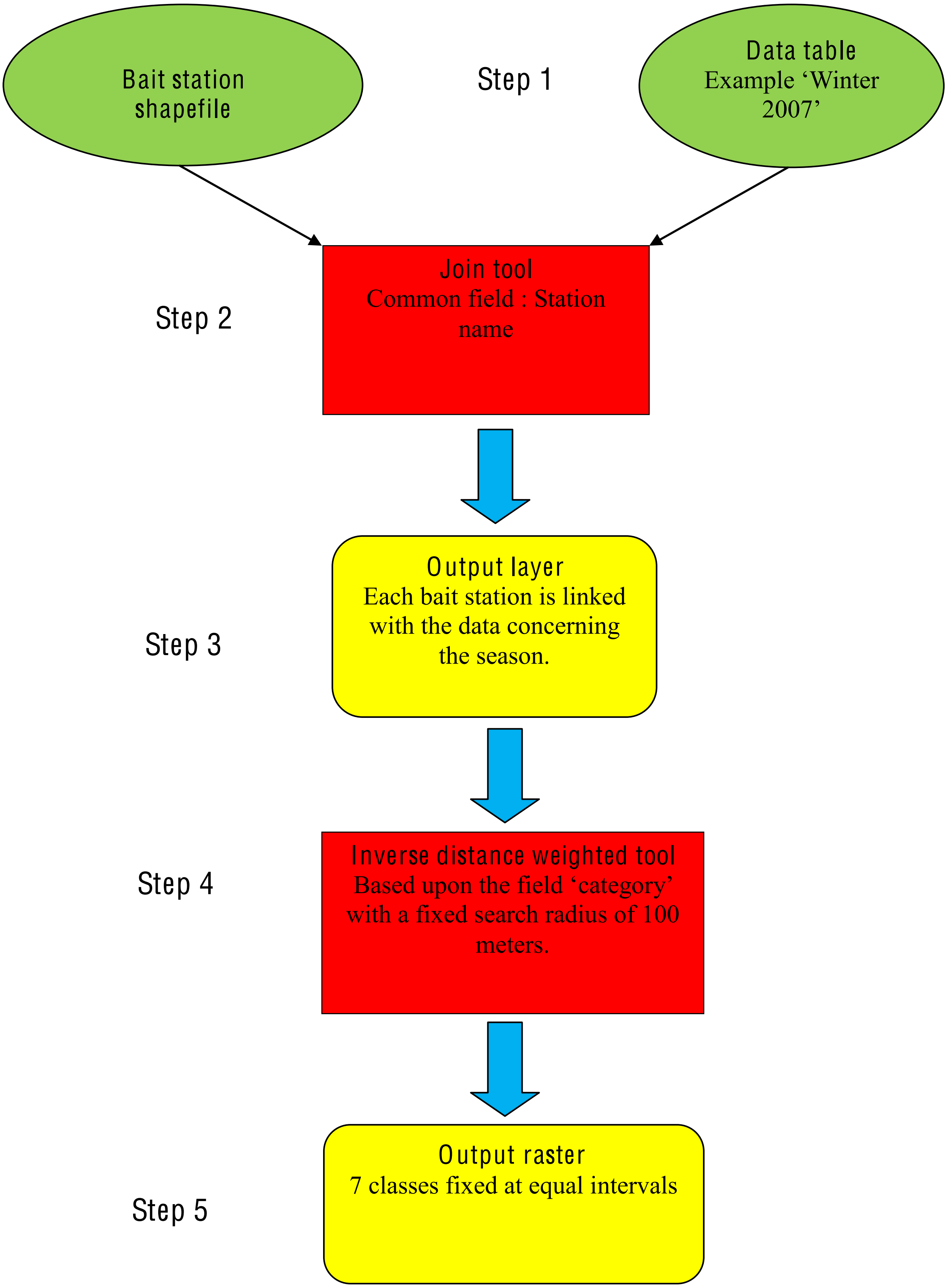
In order to analyse the data, each result of bait taken for each station has been classified into categories :

- Bait not eaten : 1
- Bag nibbled : 2
- Less than half bait gone : 3
- More than half bait gone : 4
- All gone : 5
- Bag pulled out : 6

2.3) Map creation with ArcGIS 9.3

The next step was to link the data cards gathered since 2006 with the bait stations. The aim was initially to produce visual maps, so the project managers could identify any patterns of bait eaten and 'hotspots' of baiting, where rats persisted with on-going rat baiting. A map for each baiting season has been created. The ESRI software ARCGIS v9.3 has been used for this project. The figure 1 shows the method for computing the data and creating these maps :

Figure 1 : Method for creating pest control data maps



Step 1 : The bait station shapefile and the database concerning the studied season are added
Step 2 : The joining tool is used, with the common field in the two tables being the name of the bait station. Stations are all named the same way, containing the block's name, the line's name and the station's number. For example 'AN12-6' means that we're in the AN block, line 12 and station 6.
Step 3 : Now the data is linked to the appropriate bait station and by using a thematic analysis, giving an idea of where the bait is the most consumed. (Plate 18)

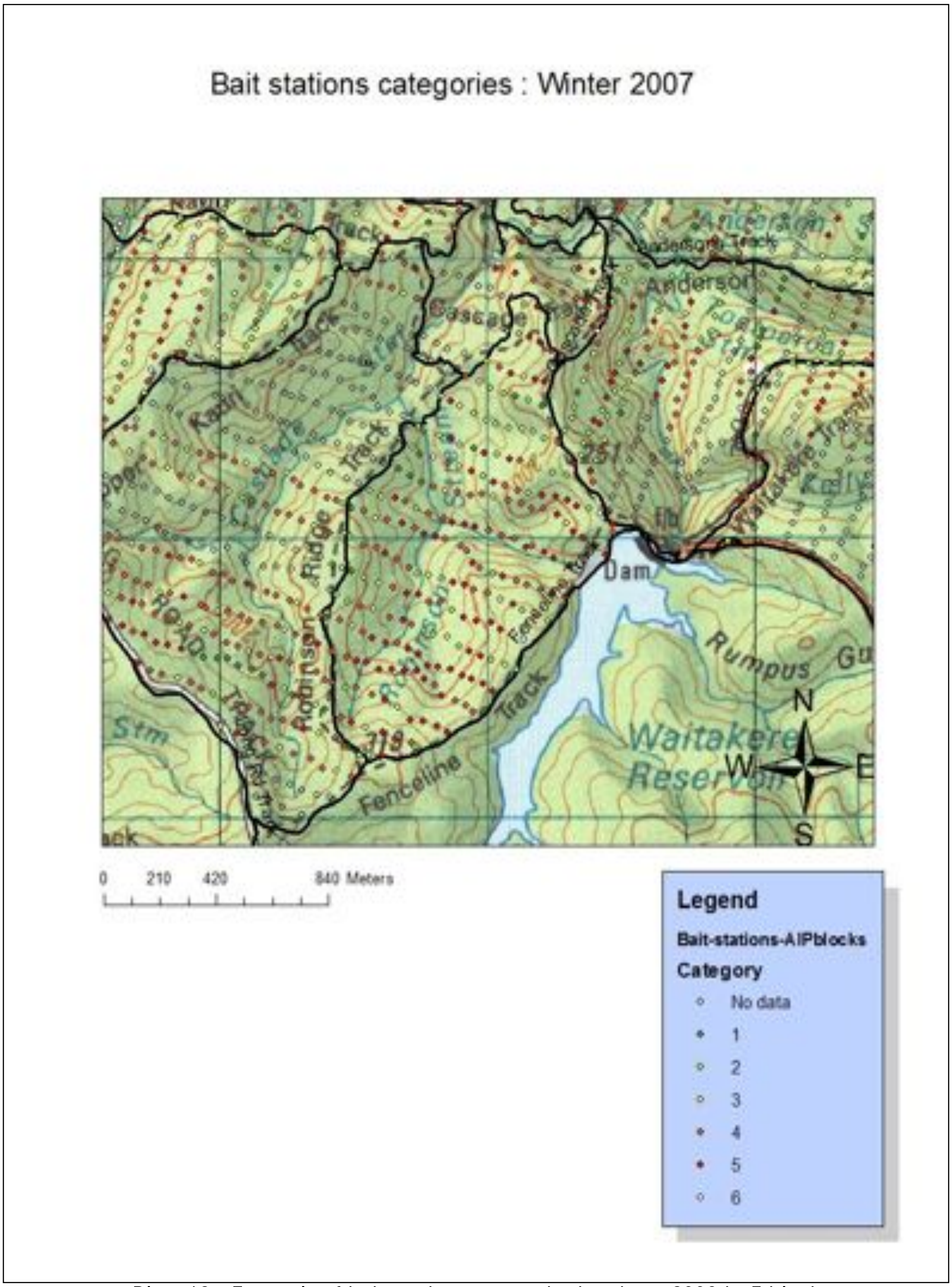


Plate 18 : Example of bait stations categories in winter 2006 in F block

Step 4 : The Inverse Distance Weighted tool (IDW) estimates cell values by averaging the values of sample data points (in this case the bait stations) in the vicinity of each cell. The closer a point is to the centre of the cell being estimated, the more influence, or weight, it has in the averaging process. The idea is to get a map that assesses bait consumption between baitlines and not bait stations. The value field is the category, and the fixed search radius is of 100 meters.
Step 5 : The IDW tool creates an output raster. The classification is divided into 7 classes, limits of these classes being at equal intervals. (Plate 19)

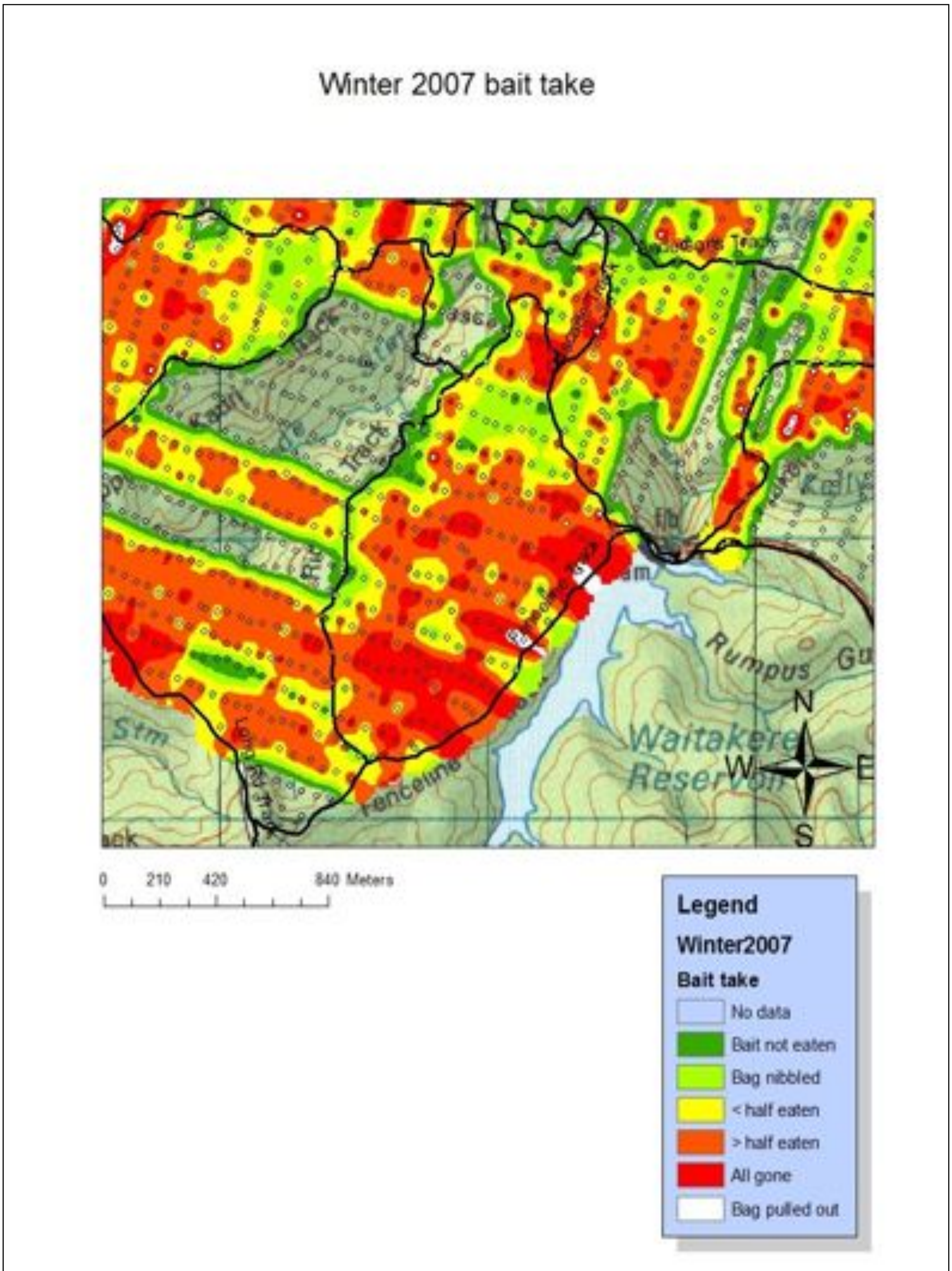


Plate 19 : Final map, example winter 2007 bait take in F block

2.4) Spatial analysis

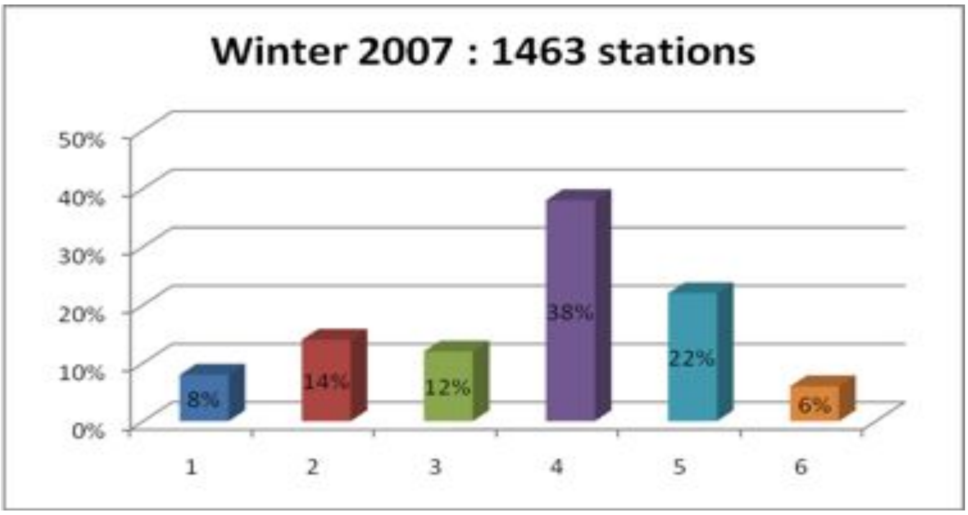
Spatial analysis have then been done in order to determine if the bait take is related to ecological parameters. The first analysis concerned the proximity to rivers, as it was proposed that bait stations in valleys could be in sites with higher fertility soils and therefore more insects, flowers and fruit could be available to rodents, than on ridges. The second analysis concerned the distance of the bait station to the boundaries of the Ark in the Park. As the closest a bait station is to the borders of the sanctuary, the more likely that rodents could reinvade and regularly consume the bait. Data of other parameters (for example the habitat caracteristics) were not precise enough to be able to run analysis on them. Further studies could therefore include these factors after having gathered more data about them.

Plate 20 : Anderson Stream

III. Results

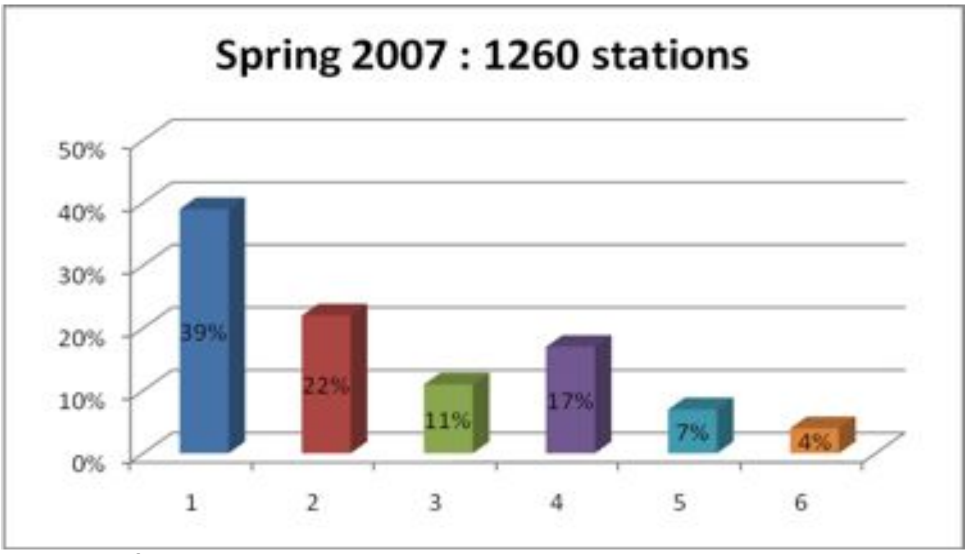
3.1) Maps of bait take for each season :

A map has been produced for each major baiting season since 2006 (appendix 4-14*)*. One of the main problem while computing the data is that for some seasons, there is no information. Either the bait card has been lost, or is unreadable. And in some cases, the names on the bait stations have been changed throughout the years. The table in appendice 15 shows the percentage of bait stations per category and per season. Taking that into account, baiting seasons can be compared with one another. The graphs (appendix 16) show the percentage of bait stations belonging to each category for winter seasons and spring seasons. Summer seasons should be assessed carefully since there are many stations with no data. These first results show that during the winter period the most bait is eaten (category 4+5+6 >50%). During the spring period, less bait is consumed (category 4+5+6<50%) except for spring 2006 which was the beginning of the decrease in rodent numbers at Ark in the Park.



Graph 3 : Percentage of bait stations per category, winter 2007

- Category 4+5+6 = 66%



Graph 4 : Percentage of bait stations per category, spring 2007

- Category 1+2+3 = 72%

This difference between winter and spring seasons can easily be explained. During winter seasons, the bait is not renewed for 8 months as for spring seasons it stays for 4 months. Therefore the bait is more likely to be completely eaten during winter since it is available to rats in the bush for a longer period. There might also be the fact that less natural food is available in winter, so rats are more likely to eat the bait.

Plate 22 on the next page shows the different maps of bait take for the winter baiting seasons. Althought the missing data is different from one year to the other, we can still see the effect of rodent control over this period. During winter 2006, a lot of bait was eaten, since it was the early years of the Ark in the Park project. The amount of bait taken decreases throughout the years and in winter 2009 a lot of areas that used to have a high rodent presence have now a low amount of bait take. This shows the rodent control efficiency. This map also shows some areas where the bait take is especially important. Therefore it is possible to focus on these ‘ hotspots’ to understand the factors responsible for a high rate of bait taken. Categories have to be studied for these areas on a more local scale, as they show the amount of bait taken but they can also explain other factors. For example categories 2 and 3, which are respectively the bag nibbled and less than half of the bait eaten, may indicate the presence of mice, since rats are more likely to eat all the bait or to hoard it away. Winter and spring seasons can also be compared with one another. The effect of a high baiting season in winter is noticed during the following spring season. Plate 21 shows the impact of a high baiting season during the winter 2007 inside F block, located between Fenceline track and Robinson ridge track, on the spring 2007 baiting season.

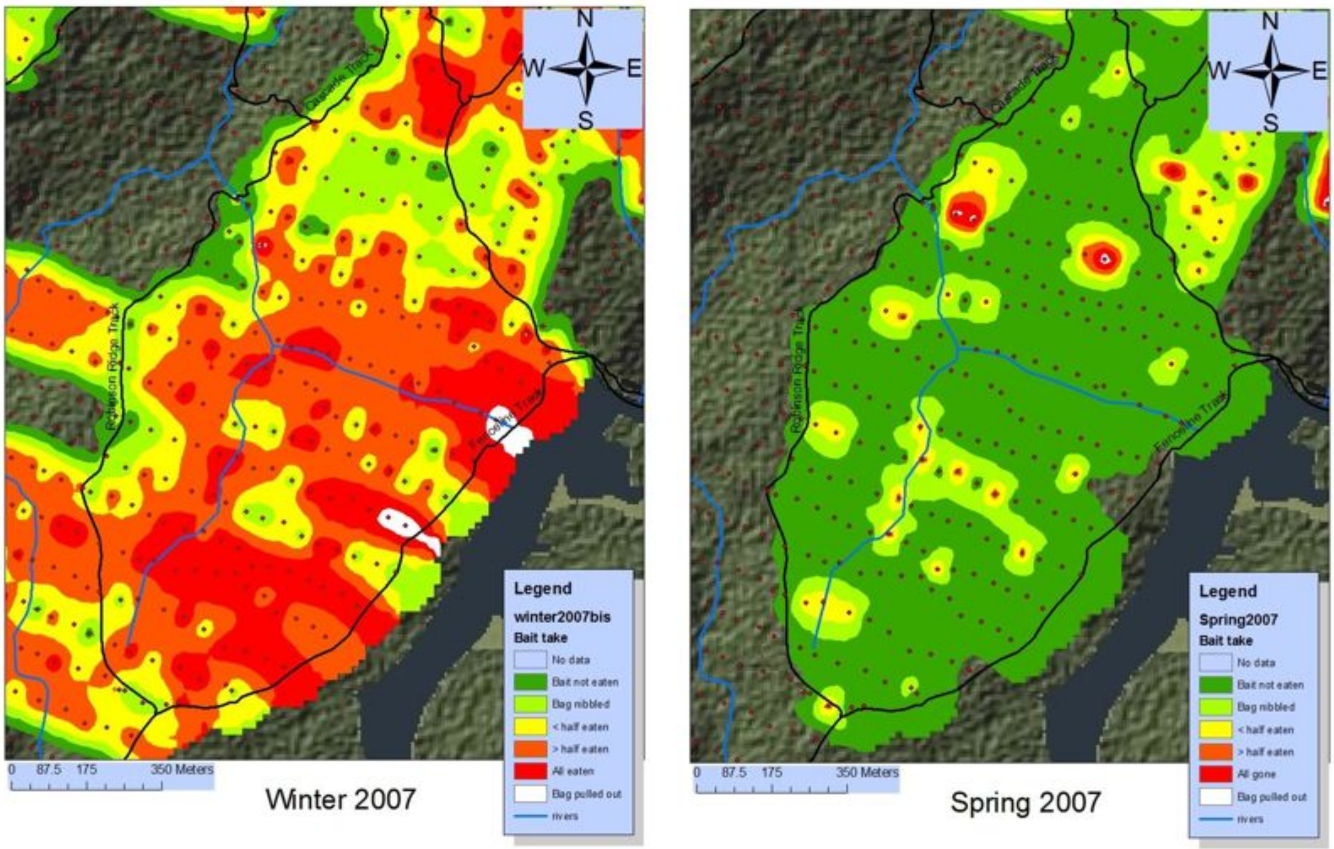


Plate 21 : Winter 2007 and Spring 2007 baiting season inside F block

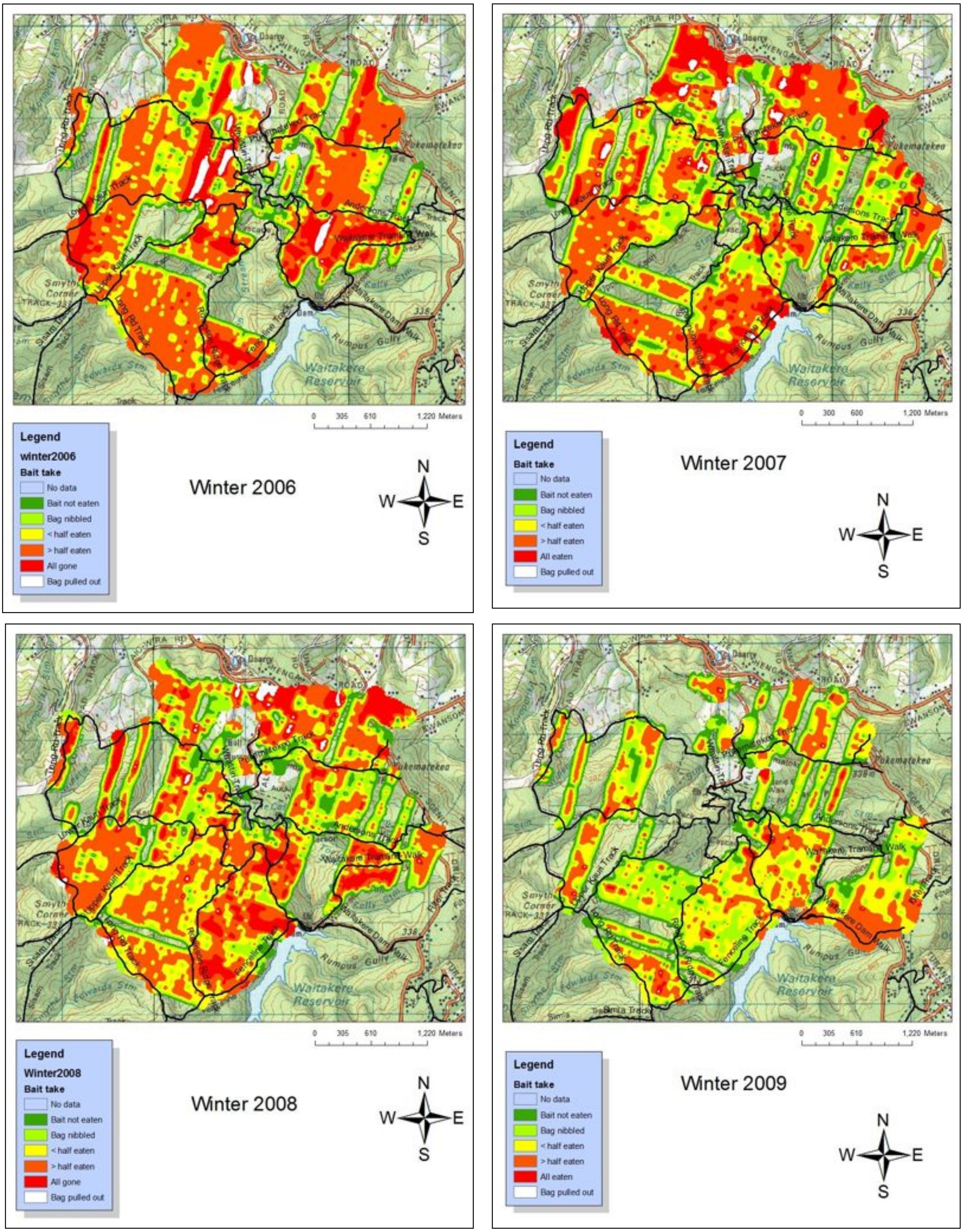


Plate 22 : Comparison of winter baiting seasons since 2006

3.2) Results of spatial analysis

Results show that there is no relationship between the proximity of bait stations to streams and the amount of bait taken (plate 23). The rodent bait take for winter seasons or spring seasons was similar in relation to proximity to streams:

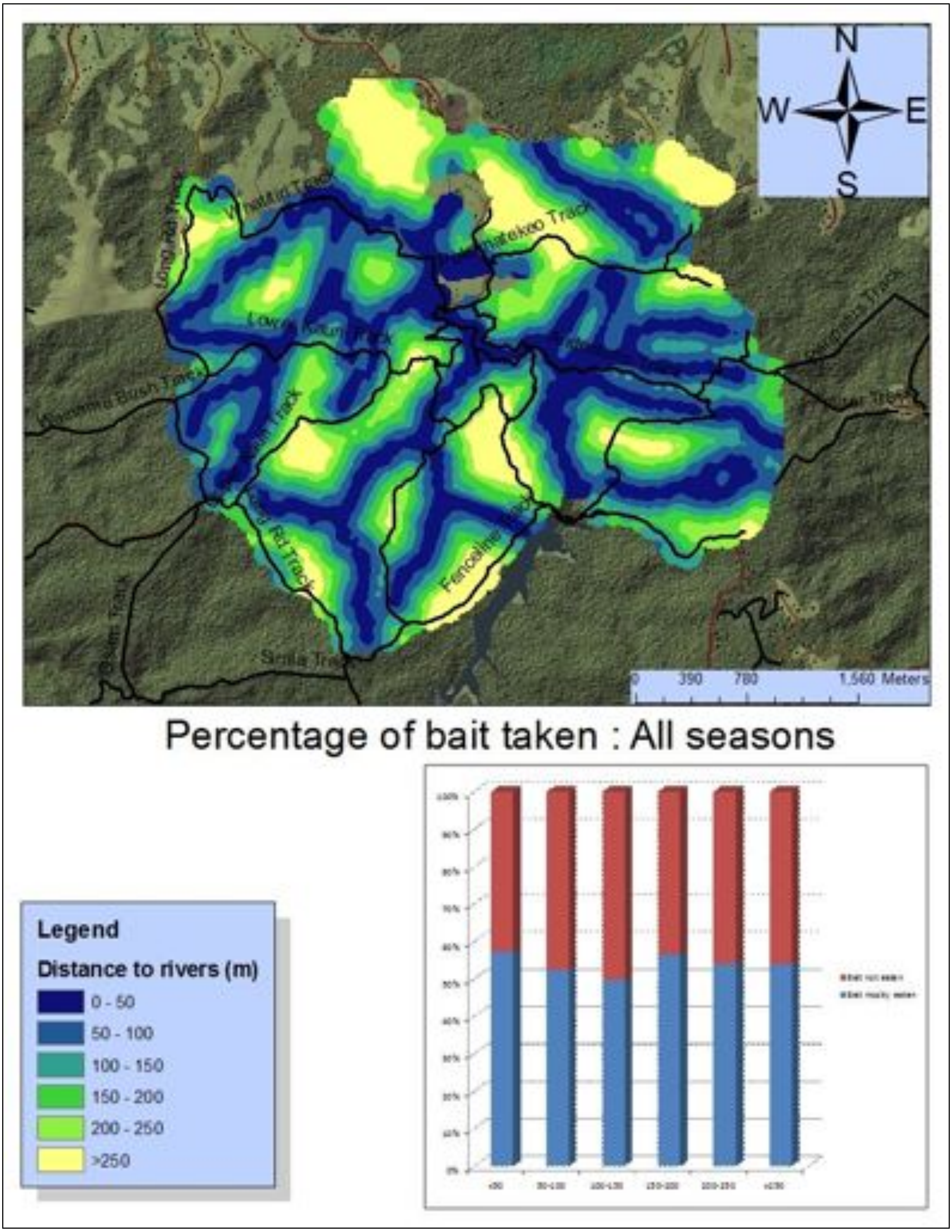


Plate 23: Map of the distance to streams

With the distance to the boundaries, no significant correlation was found over the entire area of Ark in the Park. The first results looked promising (appendix 16 & 17) as it seemed that the amount of bait taken was greater next to the boundaries of the Ark in the Park. However, statistically it has no correlation (table 2). Since the bait stations are randomly distributed over the area of Ark in the Park, a linear correlation showed no influence of the distance to the borders with the amount of bait taken.

Table 2 : Linear correlation table :

	Dist-rivers	Dist-borders	Category
Dist-rivers	0	1,22E-41	0,01
Dist-borders	-0,13	0	8,26E-66
Category	-0,02	-0,16	0

However when individual blocks are analysed, there appears to be a boundary effect. These hotspots should be assessed individually and on a more local scale.

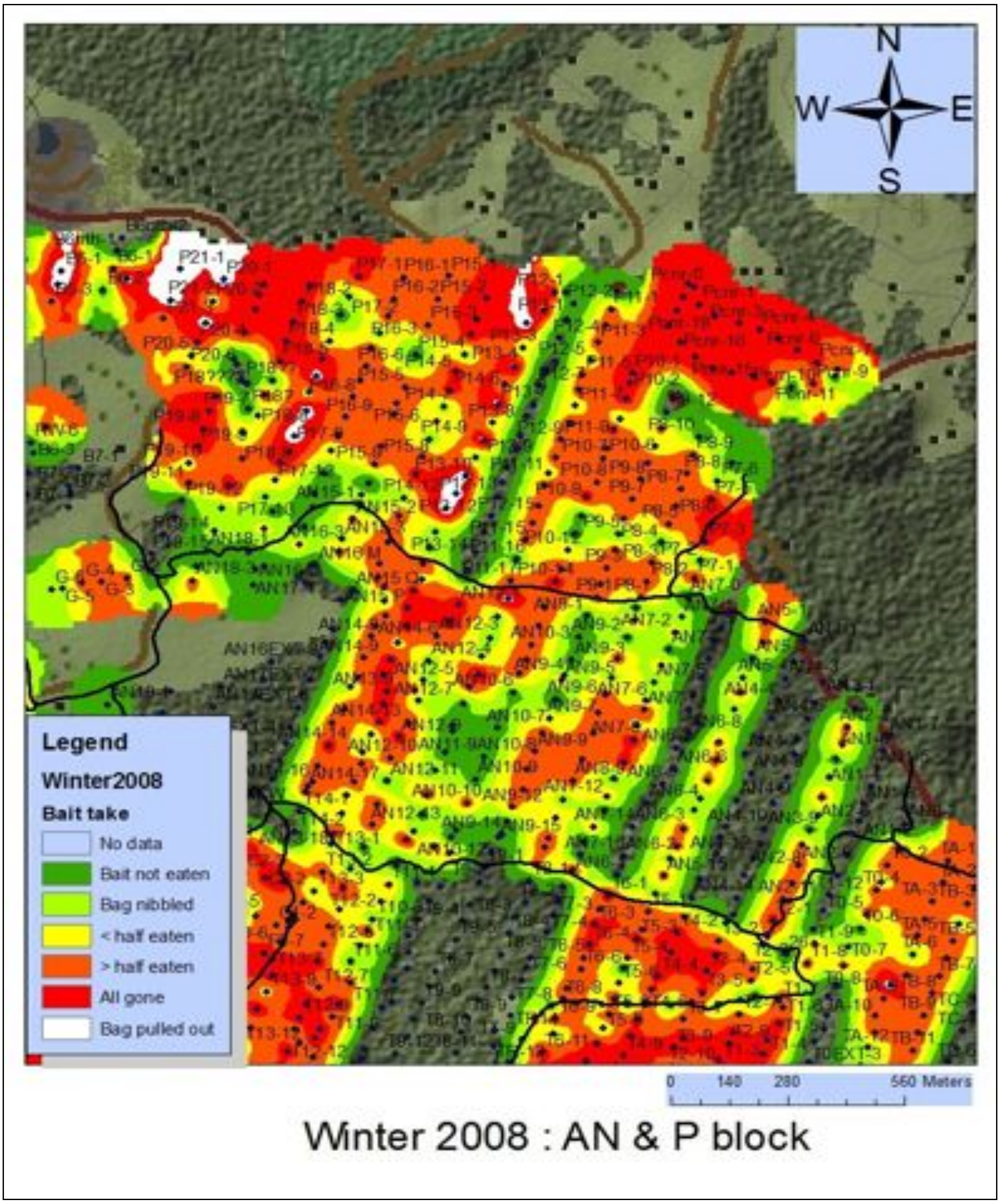


Plate 24 : Winter 2008 bait take, AN & P block

Plate 24 is a map showing the bait take during the winter 2008. AN & P block are located in the north-eastern part of the Ark in the Park. The northern limit of the area is a hotspot of rat invasion, especially where the boundaries of the park are. These results imply that these bait stations could be re-baited more often to be even more efficient. Baiting effort can therefore be aimed at these critical areas.

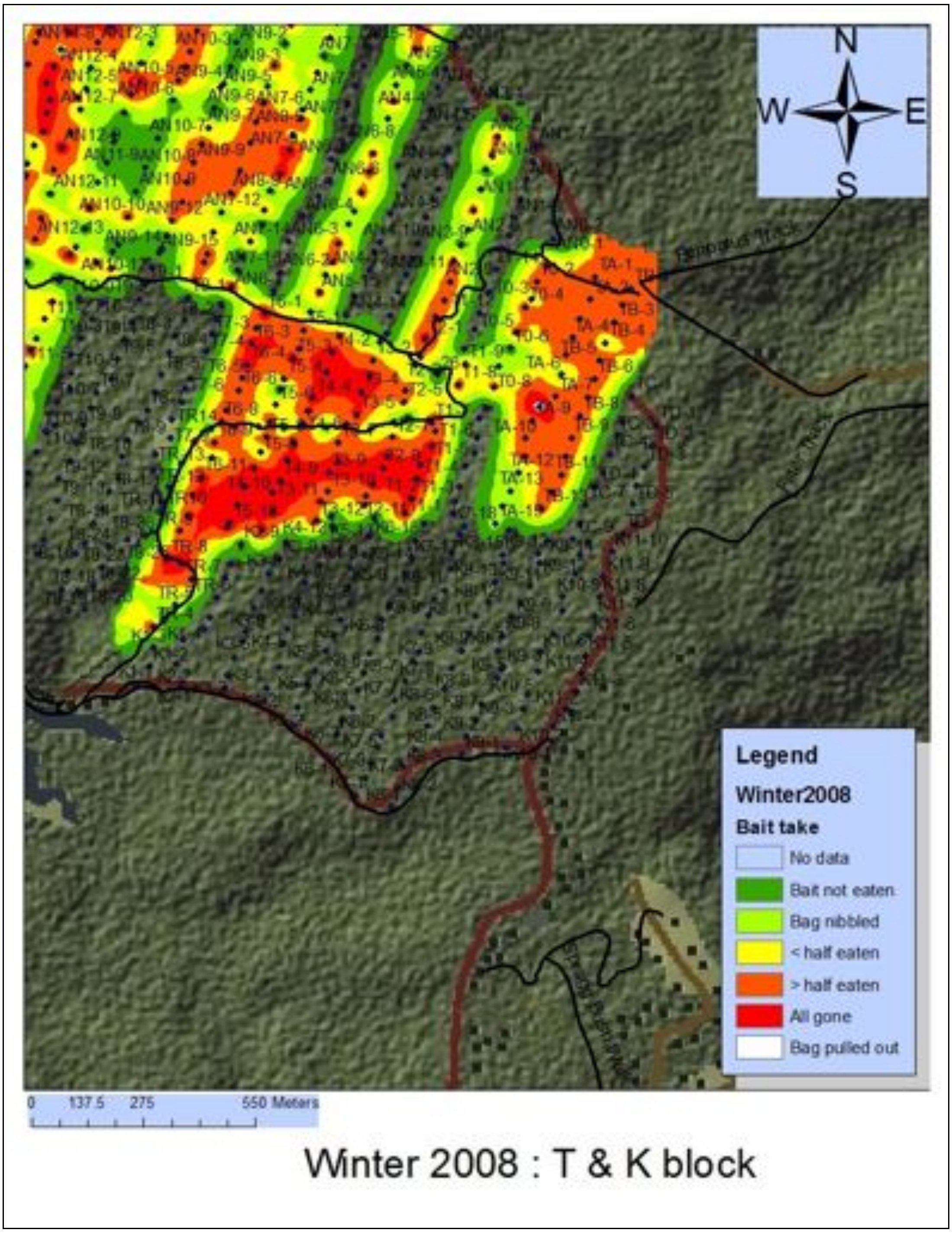


Plate 25 : Winter 2008 bait take, T & K block

Plate 25 is a map showing the bait take during winter 2008. T & K block are located in south-eastern part of the Ark in the Park. At that time, K lines were not created yet, therefore bait take inside T block was relatively high.

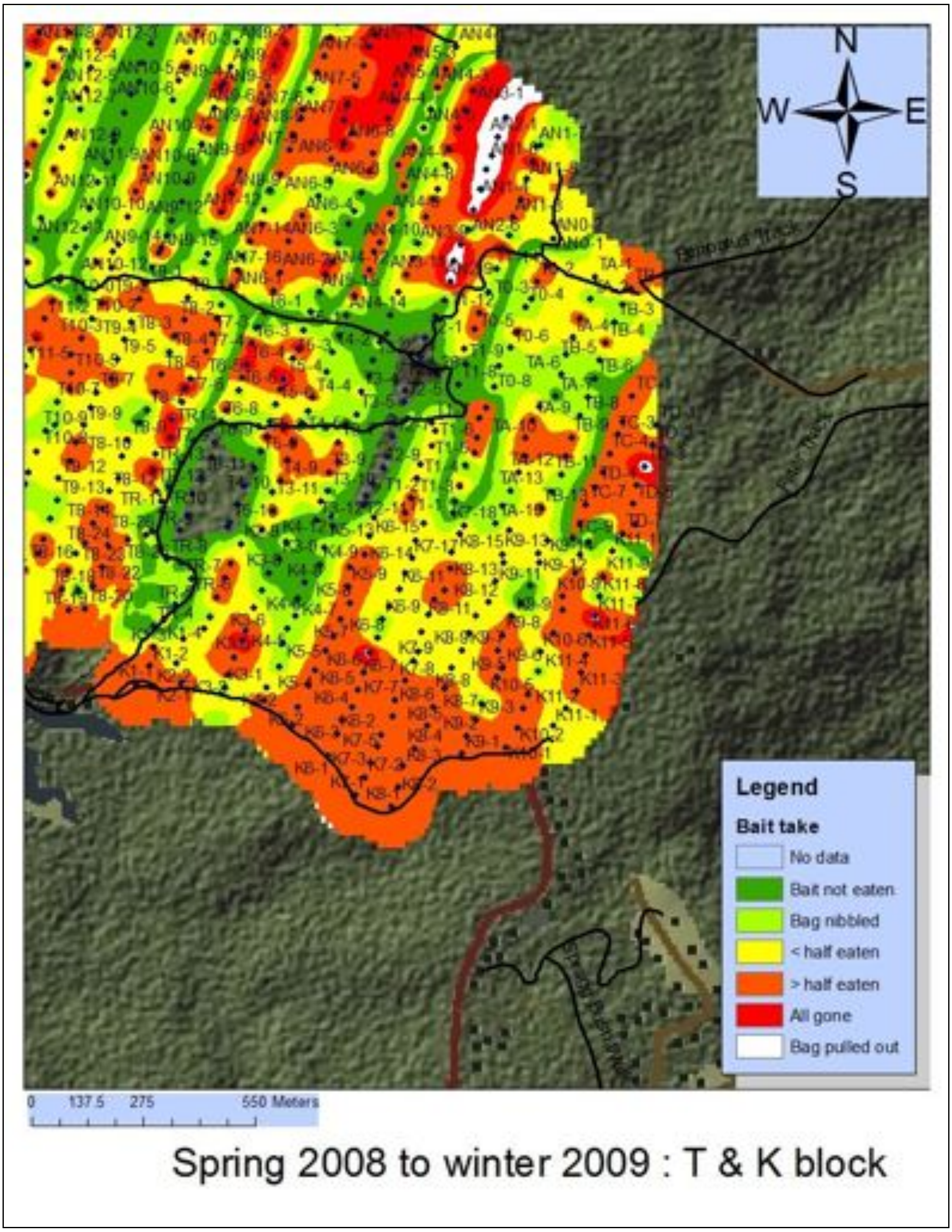


Plate 26 : Bait take from spring 2008 to winter 2009

Plate 26 is a map showing the bait take throught spring 2008 to winter 2009. It shows the effect of expanding the baited area on the inside blocks. After K block lines were navigated and baited, pressure inside T block became lower, as most of the bait eaten were at the boundaries where the new bait lines were created.

IV. Discusion :

Improved understanding of rodent behaviour is vital for planning eradication of long established rat populations on New Zealand islands and for rodent control on the mainland. A vast literature on the biology and behaviour of rodent is available (reviews by Ewer 1971; Rowe 1973; Berry 1981; Mackintosh 1981; Meehan 1984; Barnett 1988; Prakash 1988; Buckle & Smith 1994; Macdonald & al. 1999; Singleton & al. 1999). Their feeding and social behaviour is a major factor for the pest control efficiency. Wolff (2003) described rodent behaviour systems as complex, variable and adapted to high reproductive rates and marked changes in density. Rodent behaviour is highly variable between species but even between individuals. Territoriality of rodents varies from species to species and with ecological conditions. The ability of individuals in a population to access bait stations may also vary with population density, or food supply. Other issues such as bait shyness and other forms of behavioural resistance play a major role in the success of ongoing rodent control operations and is also highly variable between species and individuals. The movements of wild rats are mainly the result of two inherent tendencies to explore and to avoid (Barnett 1956) and placing of control devices should be determined according to the socio-ecological characteristics of the population in question.

Mice may visit many feeding locations during a single trip and they appear to feed quite randomly (Crowcroft & Jeffers 1961). They have been described as light and erratic feeders which makes it difficult to ensure that each individual receives a lethal dose of poison (Rowe 1973).
Ship rats are very adept at manipulating food particles, and perching on their haunches or clinging to branches (Ewer 1971). There have also been many studies of social facilitation of feeding in rats. For example, Norway rats follow trails left by other rats to find food (Galef & Buckley 1996) and mice learn food preferences from observing other mice feeding (Valsecchi et al. 1996). Hoarding is another aspect of feeding behaviour that can influence bait take. Ship rats do not like to feed far from their shelter and will hoard food more frequently than other rodent species (McCartney 1972) . All of these different aspects and variability of rodent behaviour strongly affect the choice of management techniques. The rodent's behavioural ecology, such as the propensity of Norway rats to dig (Spurr & al. 2006), ship rats to climb (Morris 2002), or invasive rats to jump (Baker & al. 1994) should be exploited to improve pest control efficiency.

Further research should be undertaken to improve knowledge on rodent behaviour inside the Ark in the Park sanctuary. For some bait stations where the bait is often fully eaten, we don't know how many rodents have had access to it. It could be more than one, but it also could only be one rat that has carried the bait away to store it for later. Monitoring papers could be placed in front of some bait stations so we could assess the number of rats that are actually eating the bait. Another project could be of releasing rats in different places at Ark in the Park and monitor them using radiotelemetry techniques. We could then determine ‘ pathways ‘ that rodents mostly use depending on food ressources and habitats at Ark in the Park. Such research has already been done (Russel & al. 2007) concerning the reinvasion of offshore islands in order to test the biosecurity system.

V. Conclusion :

Introduced pests have had a devastating impact on a range of unique habitat types on the New Zealand mainland and offshore islands. Many native and endemic species are now extinct, some have been shifted to predator-free islands for a chance of survival, while others are still trying to hold on in their predator modified environment. Important advances have been made in recovering threatened species and restoring damaged habitats on offshore islands, but effective conservation management needs to be developed for 'Mainland Islands'. However the recent initiation of 'Mainland Island' projects and the intensity of pest control undertaken could be improved with better monitoring of results and applying this to the conservation outcomes.

Althought no correlations have been found concerning the distance to the park limits or the distance to the streams and rivers, results have shown that in areas 'hotspots' of bait take can be assessed in order to improve the predator control efficiency. These areas should be focused on so that we can better understand the factors responsible for a high bait take and reduce high rodent numbers when and where they occur. Then we could apply more efficient management techniques depending on the pest presence, these results should also be linked with the bird sightings and nesting sites in order to see whether their distribution is influenced by the presence of rodents or not. Eventually, higher baiting efficiency is needed in places where the translocated birds have territories and especially their breeding sites.

These results should also be linked with the mustelid trap catch, as for in areas, the presence of the different species of mustelids can be linked with the predator control bait take. For example weasels tend to feed mostly on mice so the presence of weasels may indicate a high mice population. At Ark in the Park, most of the mustelids traps catch stoats, however in the north-western part of the Park weasels have been caught. Pastures are present in this area which may explain a high number of mice, and so of weasels. Bait stations could therefore be set more efficiently in this area in order to mainly kill mice.

One of the major problem encountered during this research project was the data quality. Some bait cards of the early years of Ark in the Park have either been lost or the bait station's numbers had changed. It would be useful to enter the bait cards into a main computer database as soon as possible after the survey in order to avoid data loss. That database should also include the different changes that have been made on the stations (change of station name, station added/removed…)

Predator control at the Ark in the Park sanctuary has shown to be very effective. Nevertheless, it requires a great deal of work effort in order to keep the project going. This study has shown that hotspots of pest presence, can be easily identified with basic monitoring methods, and this can make rodent control in Ark in the Park more efficient and effective.

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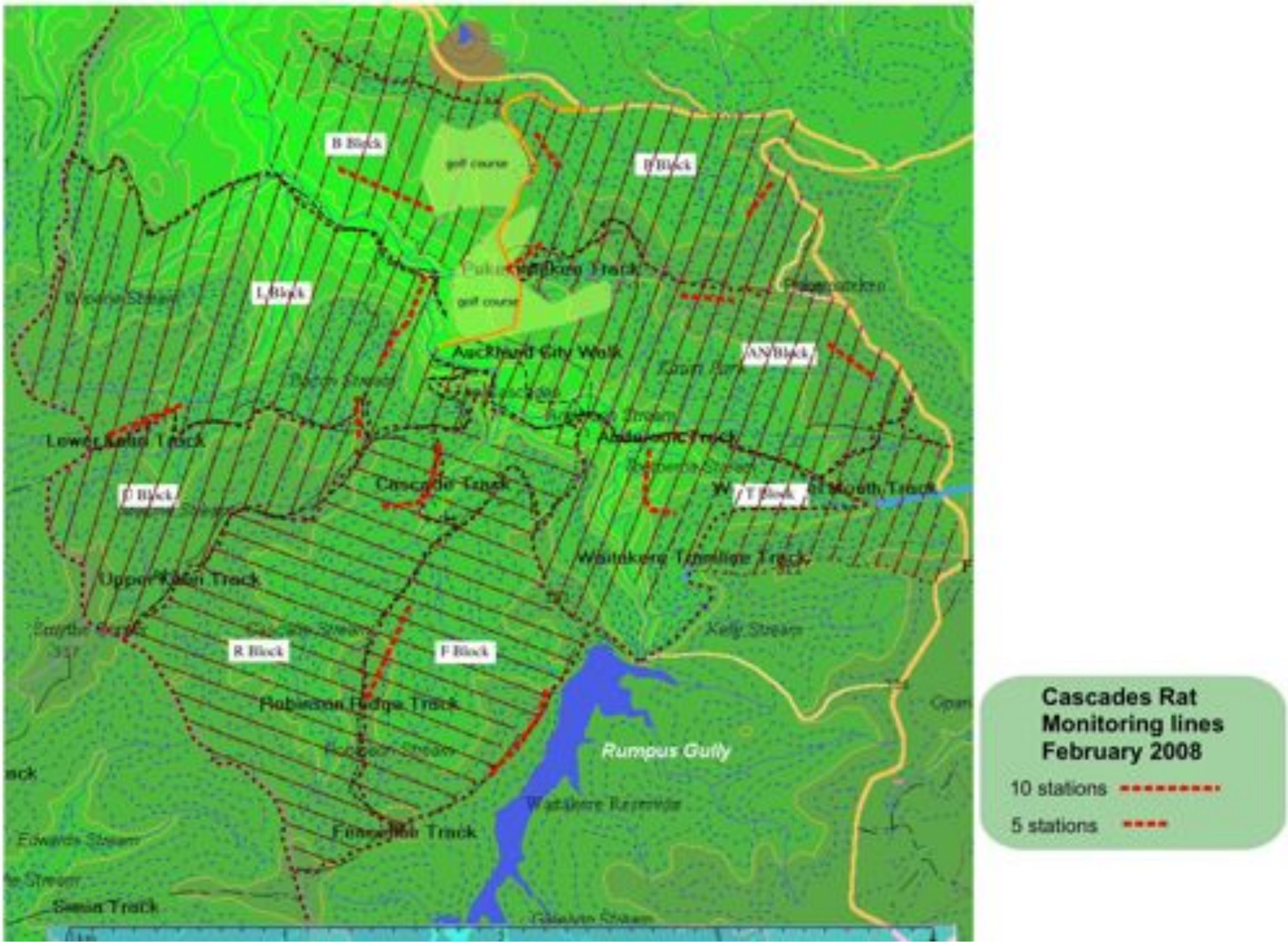
VI. Appendices

List of graphs, figures and tables:

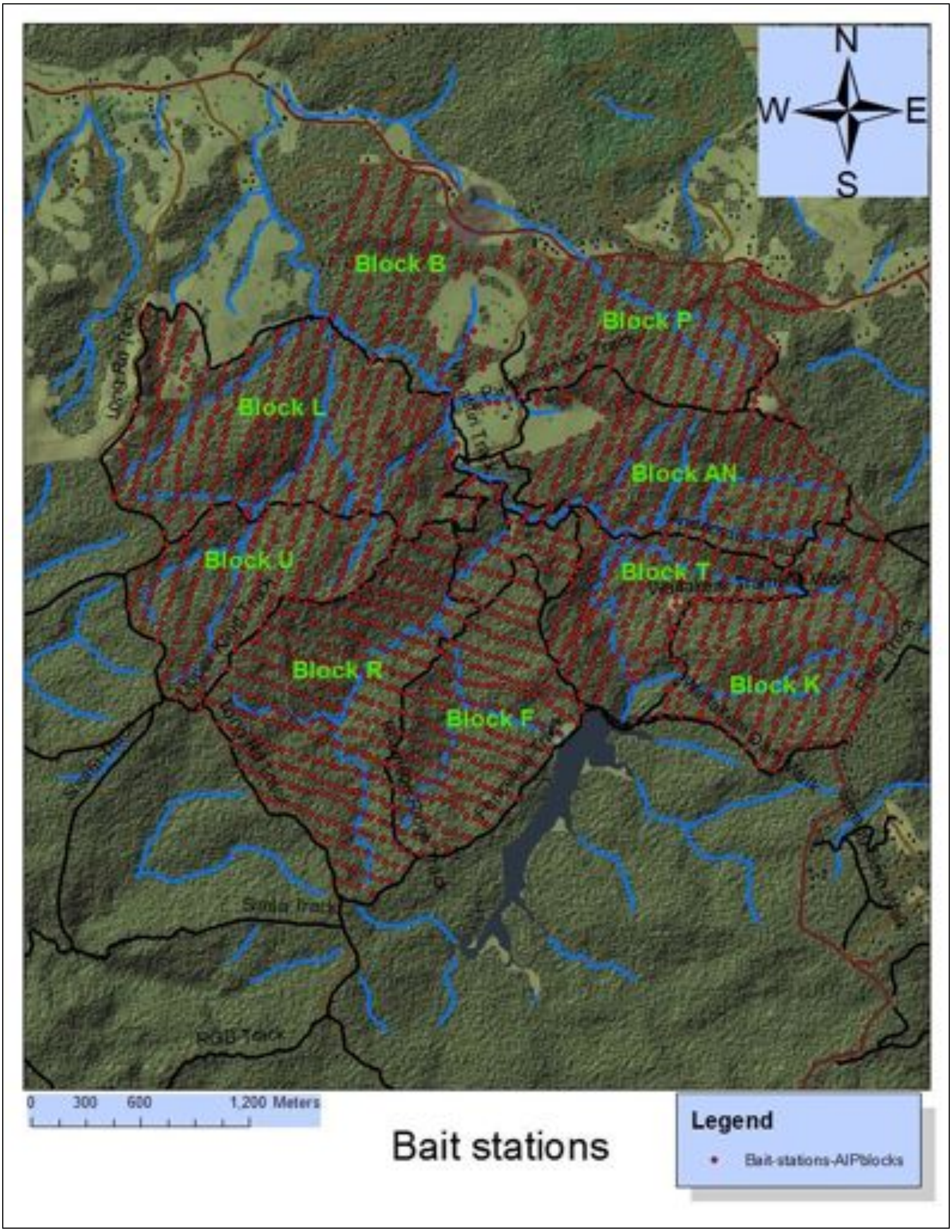
List of Plates:

List of appendices :

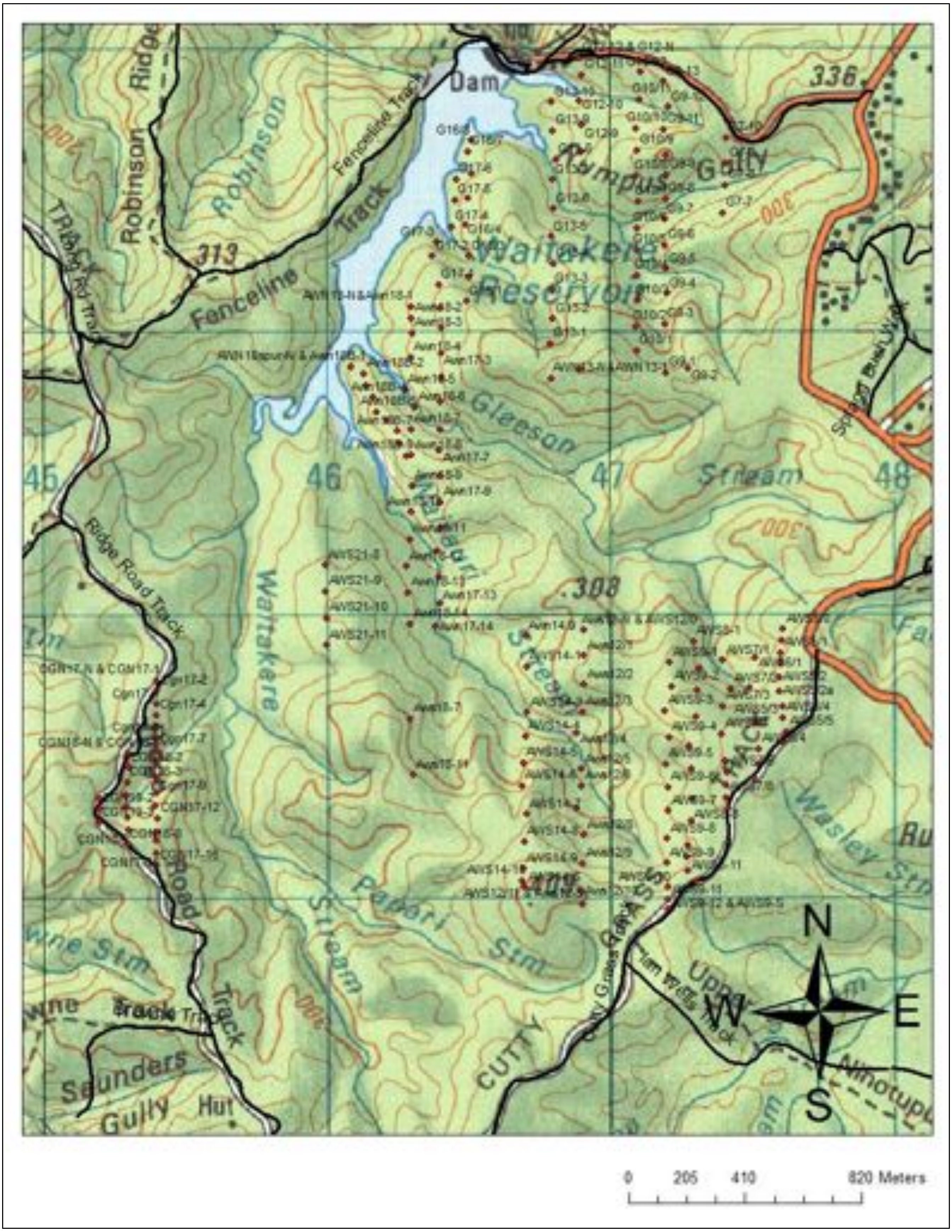
Appendix 1


Cascades Rat Monitoring lines February 2008
10 stations
5 stations
B Block
P Block
L Block
AN Block
U Block
T Block
R Block
F Block
golf course
Auckland City Walk
Lower Kauri Track
Cascade Track
Upper Kauri Track
Waitakere Tramline Track
Robinson Ridge Track
Rumpus Gully
Fence Line Track
Kelly Stream

Appendix 2

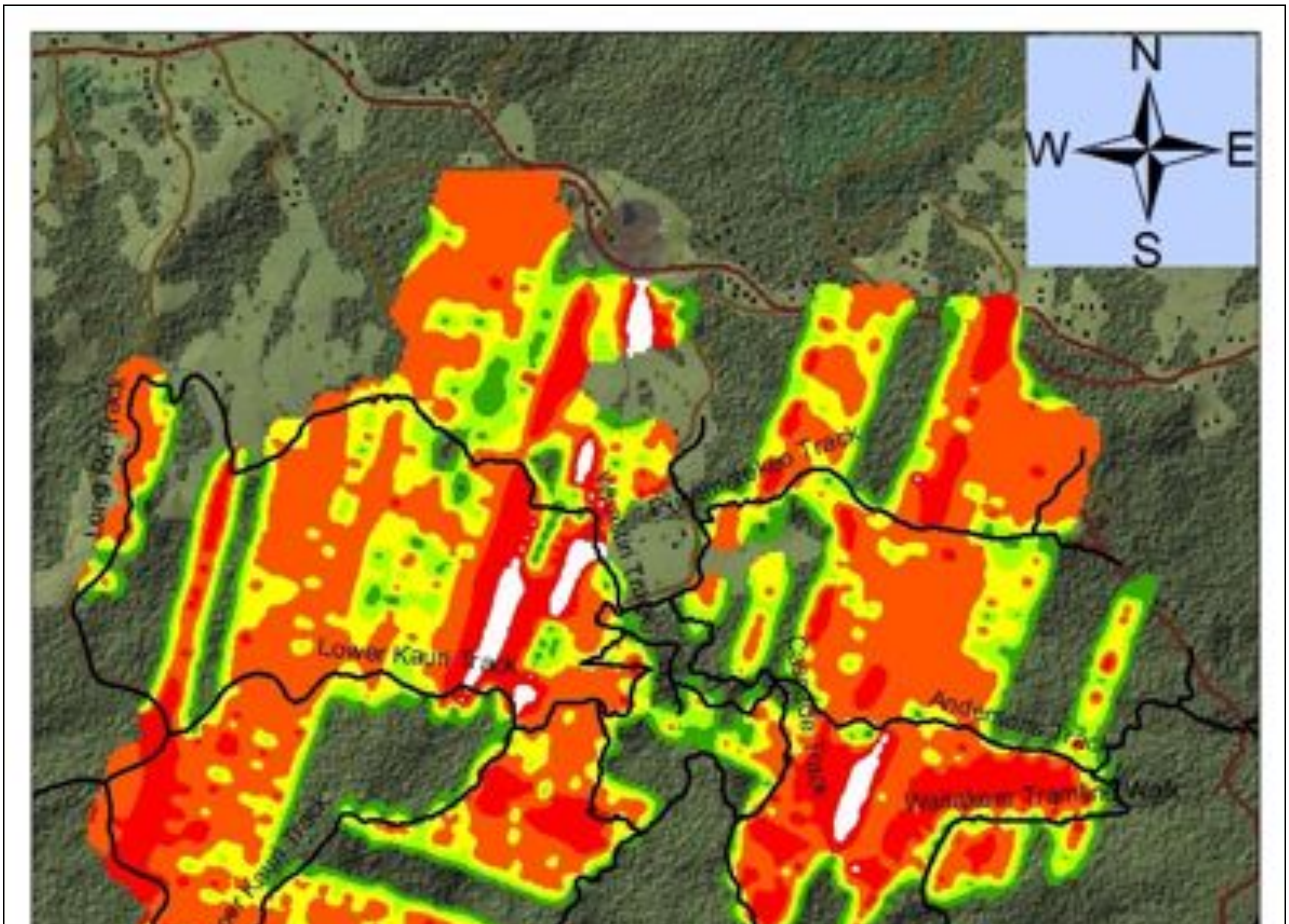

N
W
E
S
Block B
Block P
Block L
Block AN
Block U
Block T
Block R
Block K
Block F
Long Run Track
Sassa Track
RGB Track
0 300 600 1,200 Meters
Bait stations
Legend
Bait-stations-AIPblocks

Appendix 3



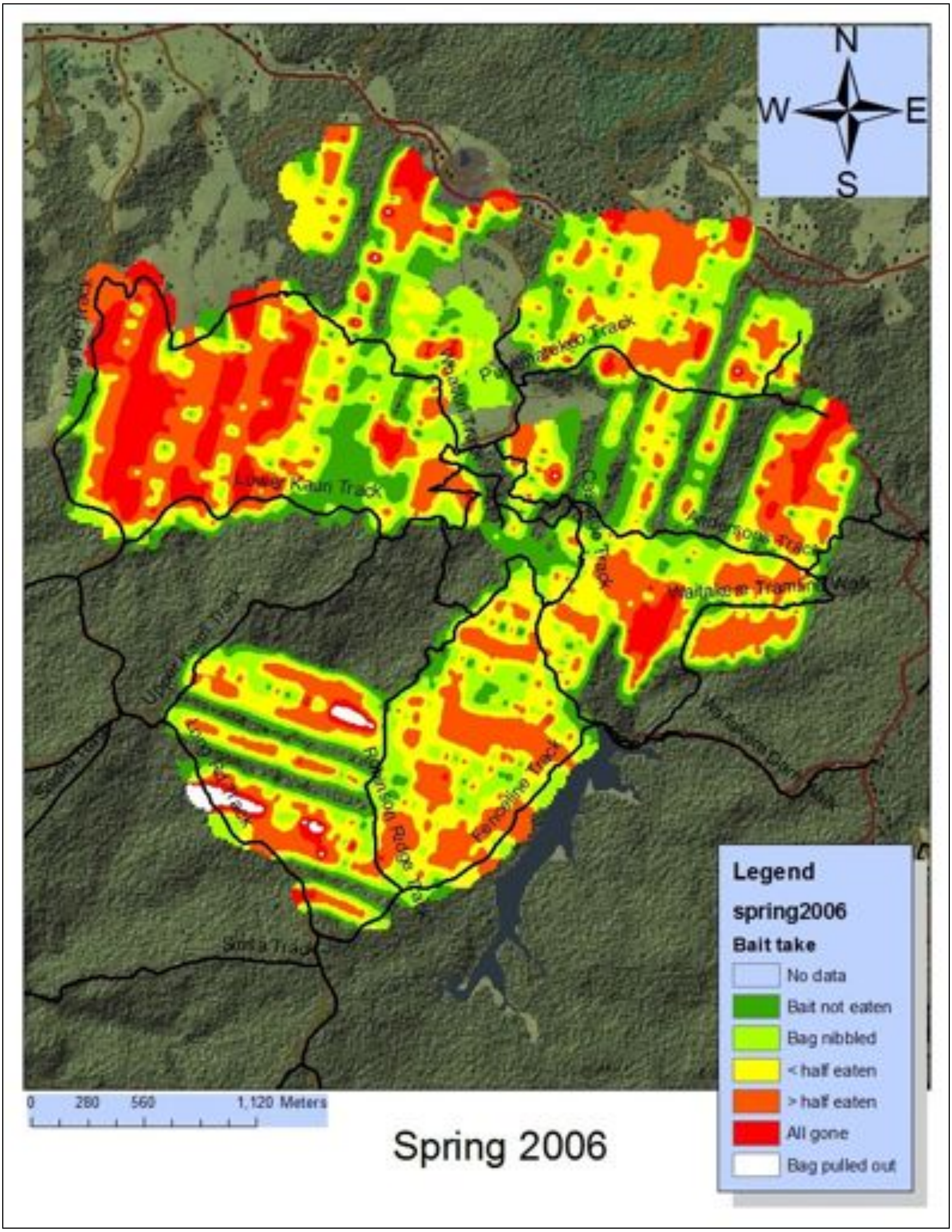
Dam
Robinson
Robinson
Fenceline Track
Track
313
Fenceline
336
Gully
Waitakere Reservoir
Gleeson
Stream
45
46
47
48
300
308
Ridge Road Track
Waitakere
Stream
Stm
Road
Track
Saunders
Gully
Hut
CUTTY
Wasley
N
E
W
S
0
205
410
820 Meters

Appendix 4

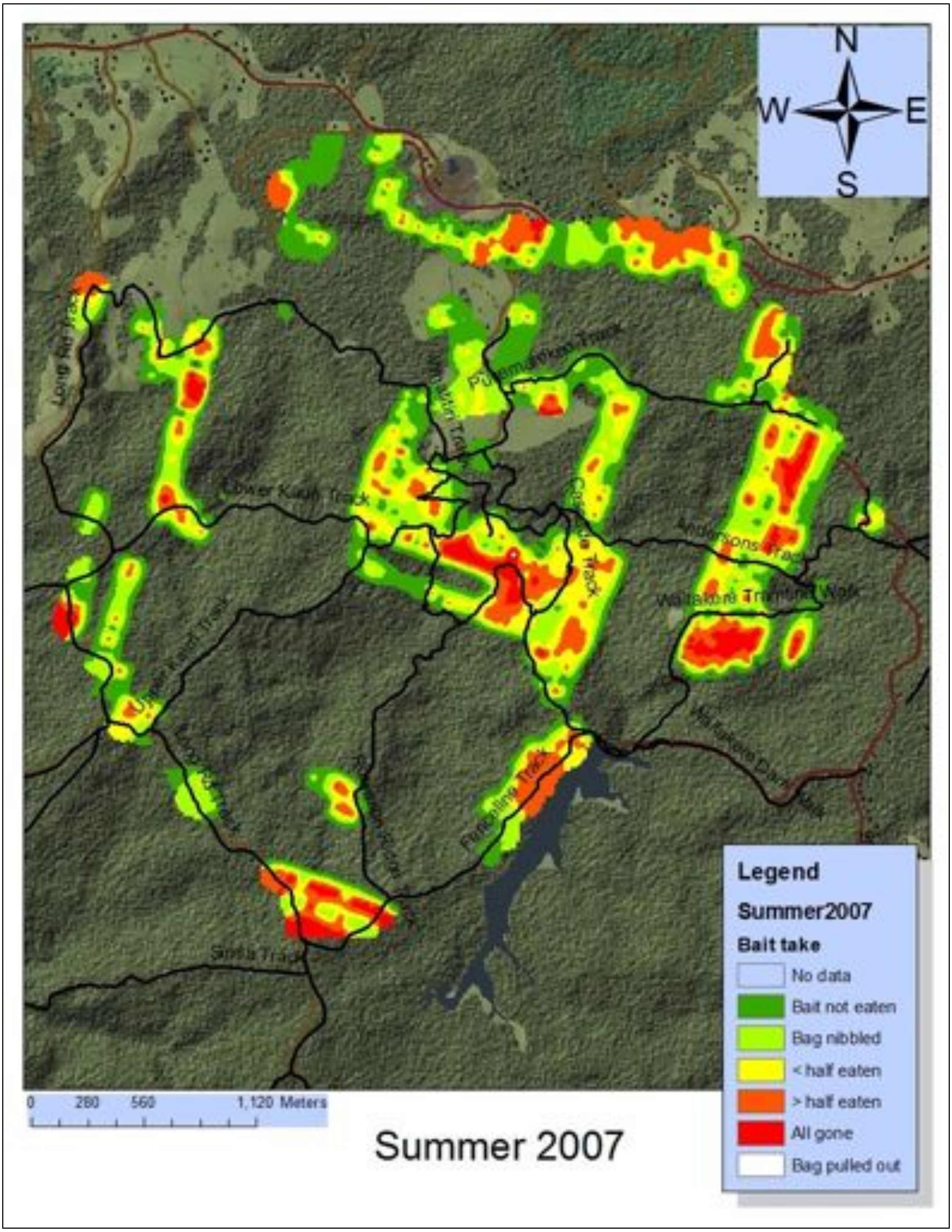


N
W
E
S
Long Rd Track
Lower Kaun Track
Upper Kaun Track
Long Rd Track
Robinson Ridge
Andersons Track
Walkabout Training Walk
Sofala Track
0 280 560 1,120 Meters
Winter 2006
Legend
winter2006
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out

Appendix 5

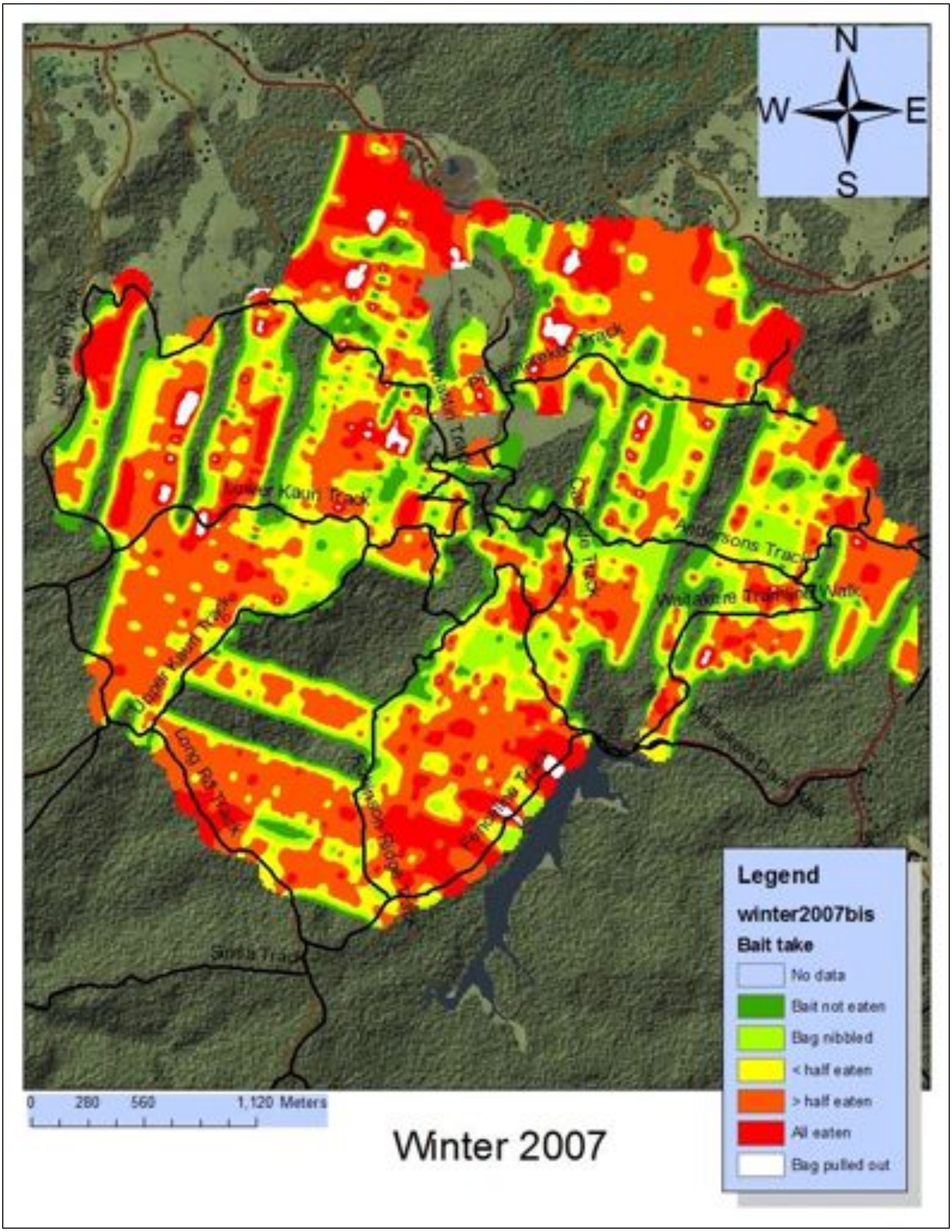

N
W
E
S
Lower Kauri Track
Fenceline Track
0 280 560 1,120 Meters
Spring 2006
Legend
spring2006
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out

Appendix 6

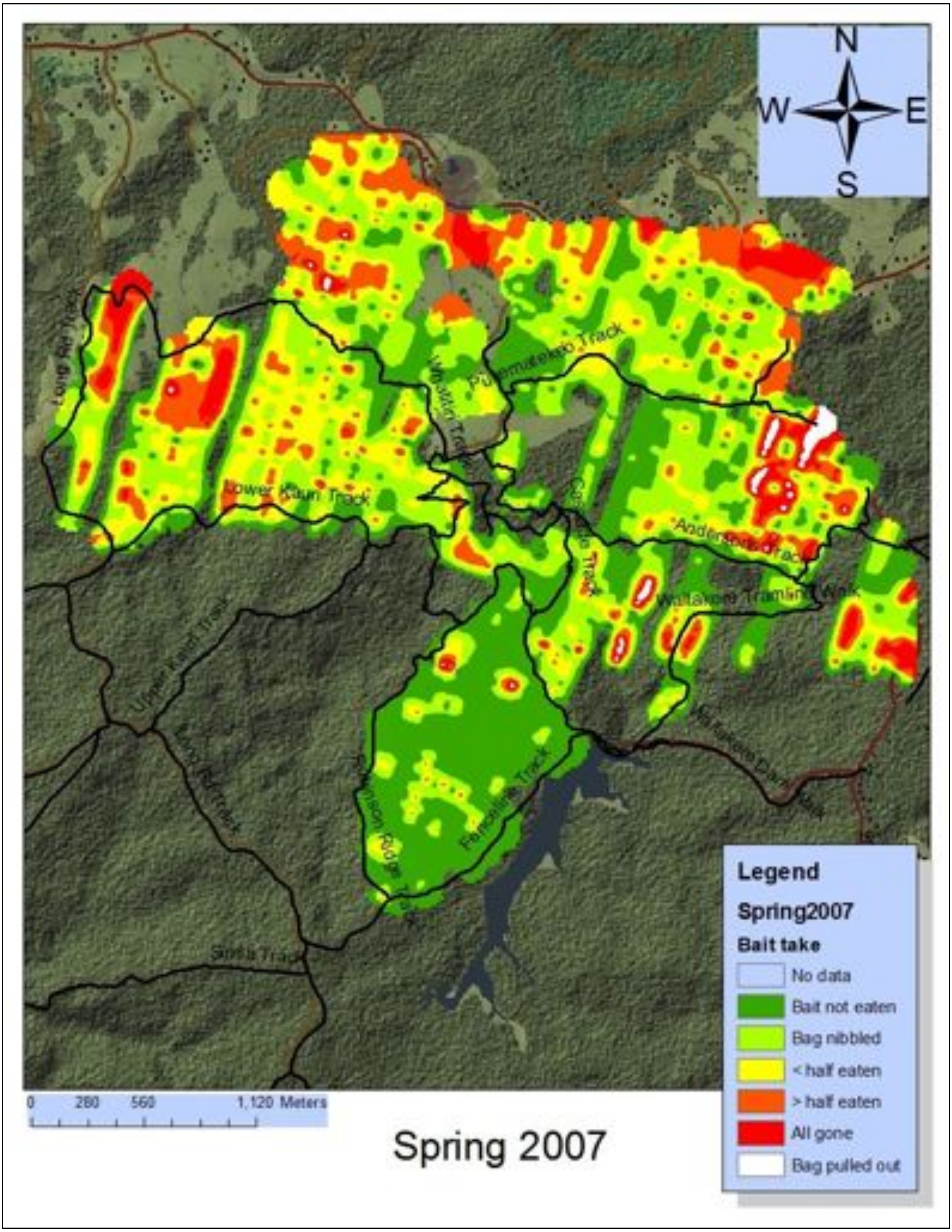


N
W
E
S
Long Ridge Track
Lower Kauri Track
Upper Kauri Track
Andersons Track
Waitakere Tramline Walk
Waitakere Dam Walk
Fence Line Track
Sinla Track
Legend
Summer2007
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out
0 280 560 1,120 Meters
Summer 2007

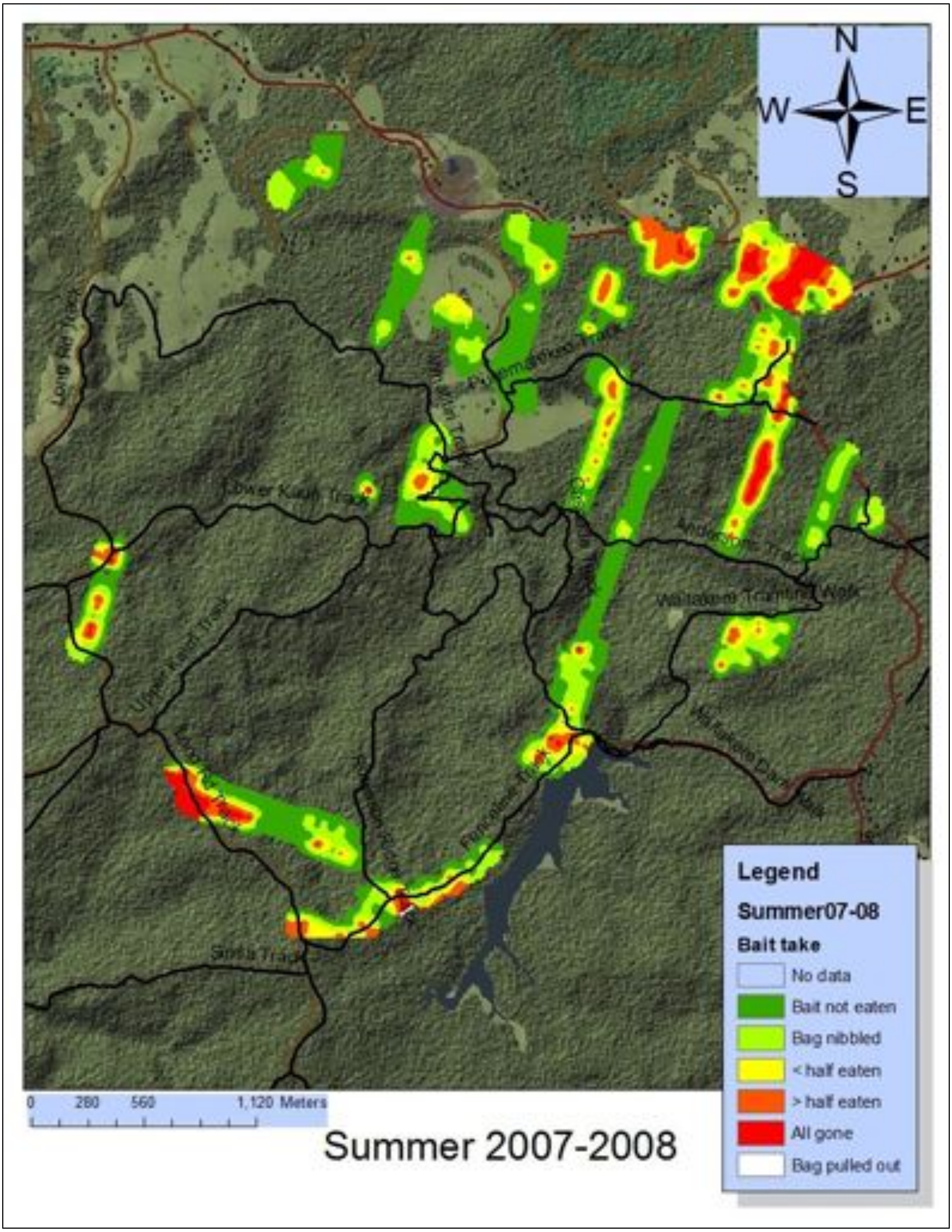
Appendix 7


N
W
E
S
Long Rat Track
Lower Kauri Track
Andersons Track
Upper Kauri Track
Long Rat Track
Simla Track
Legend
winter2007bis
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All eaten
Bag pulled out
0 280 560 1,120 Meters
Winter 2007

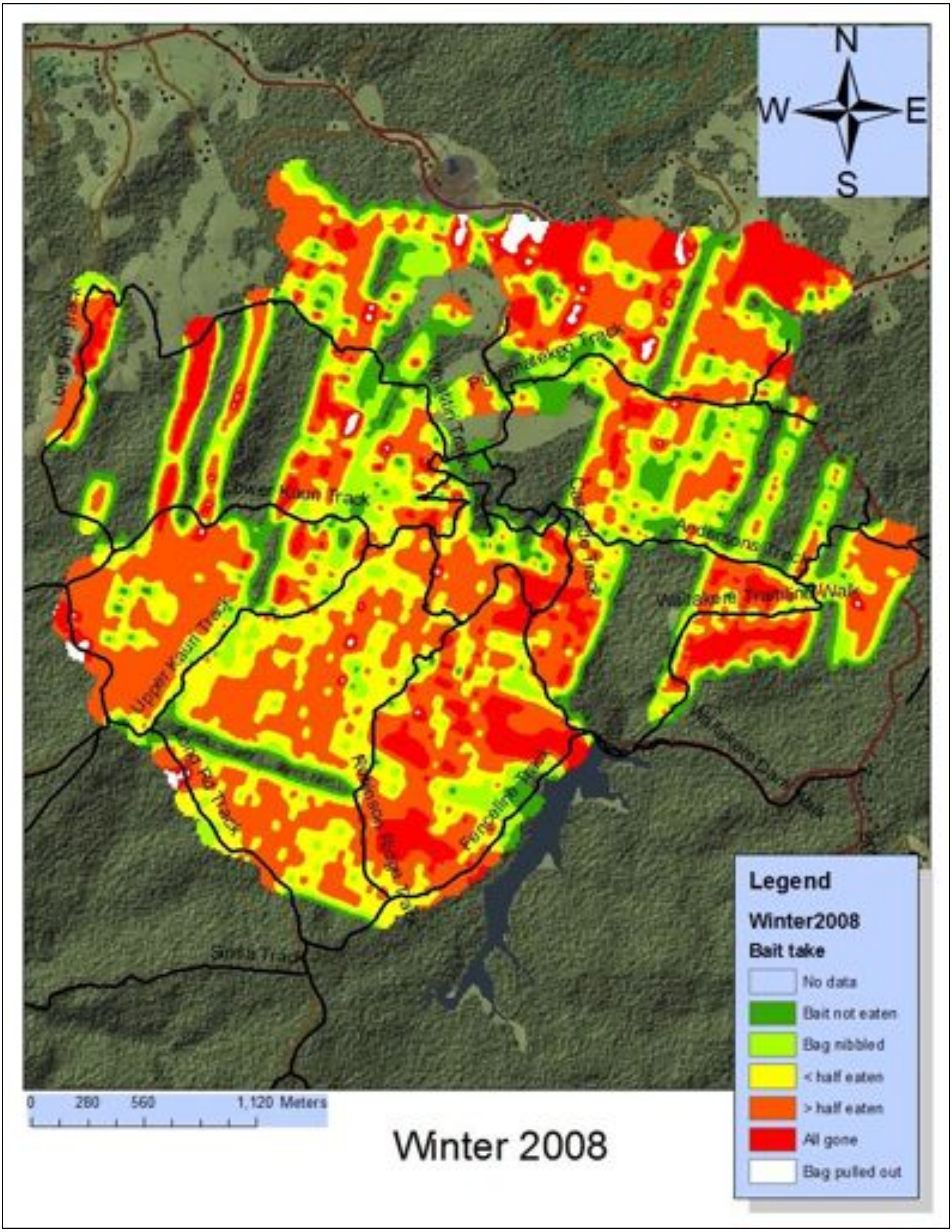
Appendix 8


N
W
E
S
Long Rd Track
Lower Kauri Track
Upper Kauri Track
Puriri Track
Fenceline Track
Andersons Track
Waitakere Tramline Walk
Slips Track
0 280 560 1,120 Meters
Spring 2007
Legend
Spring2007
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out

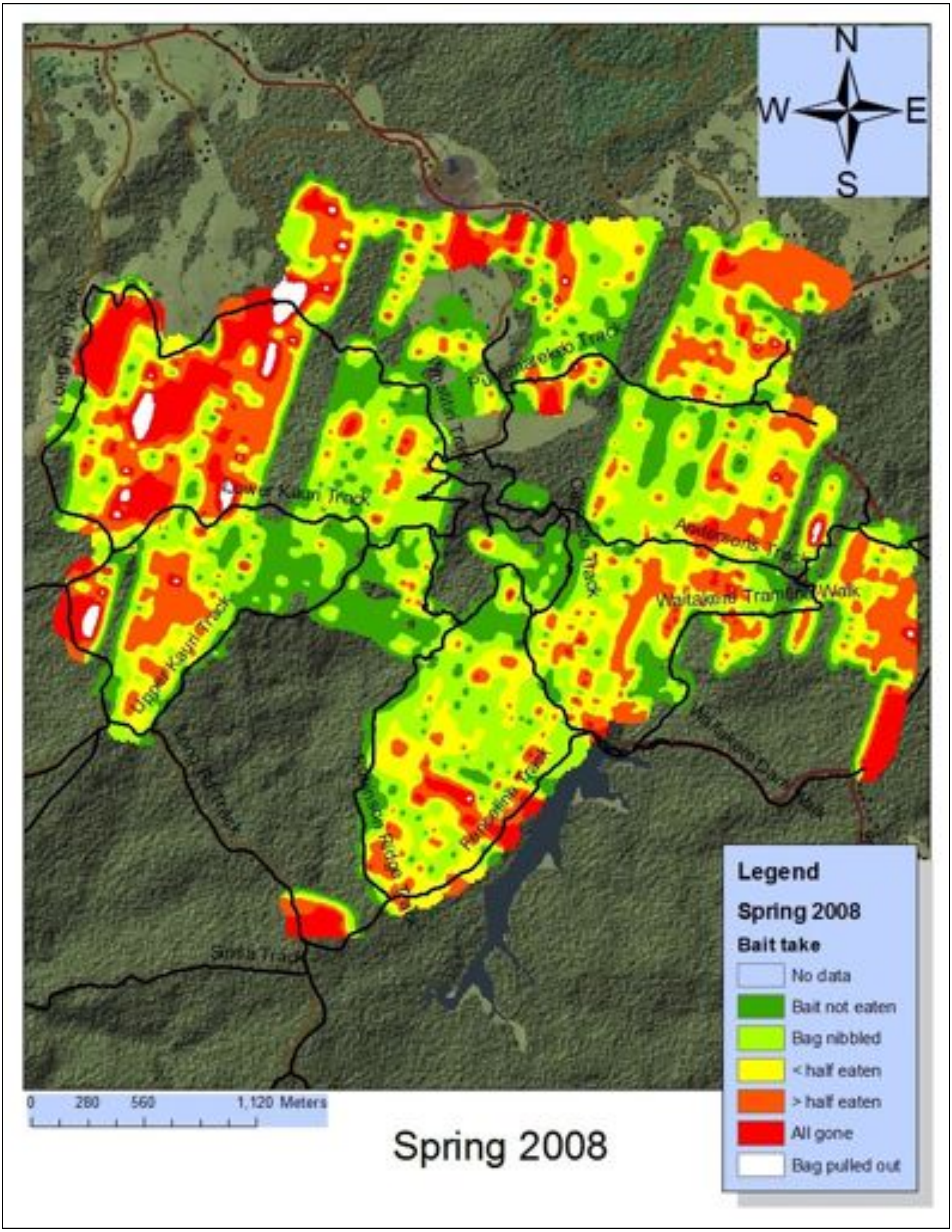
Appendix 9


N
W
E
S
Lower Kauri Track
Upper Kauri Track
Legend
Summer07-08
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out
0 280 560 1,120 Meters
Summer 2007-2008

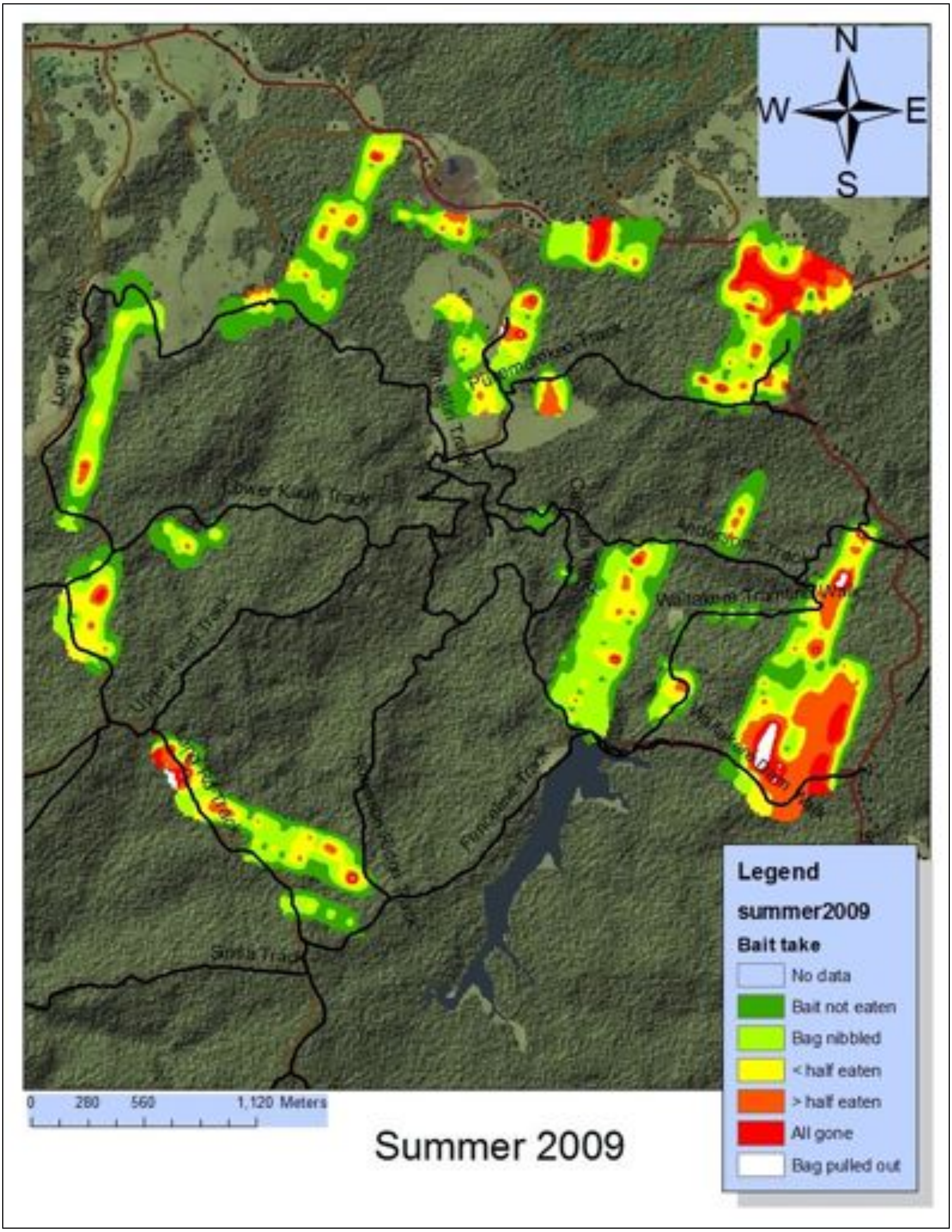
Appendix 10


N
W
E
S
Upper Kauri Track
Legend
Winter2008
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out
0 280 560 1,120 Meters
Winter 2008

Appendix 11

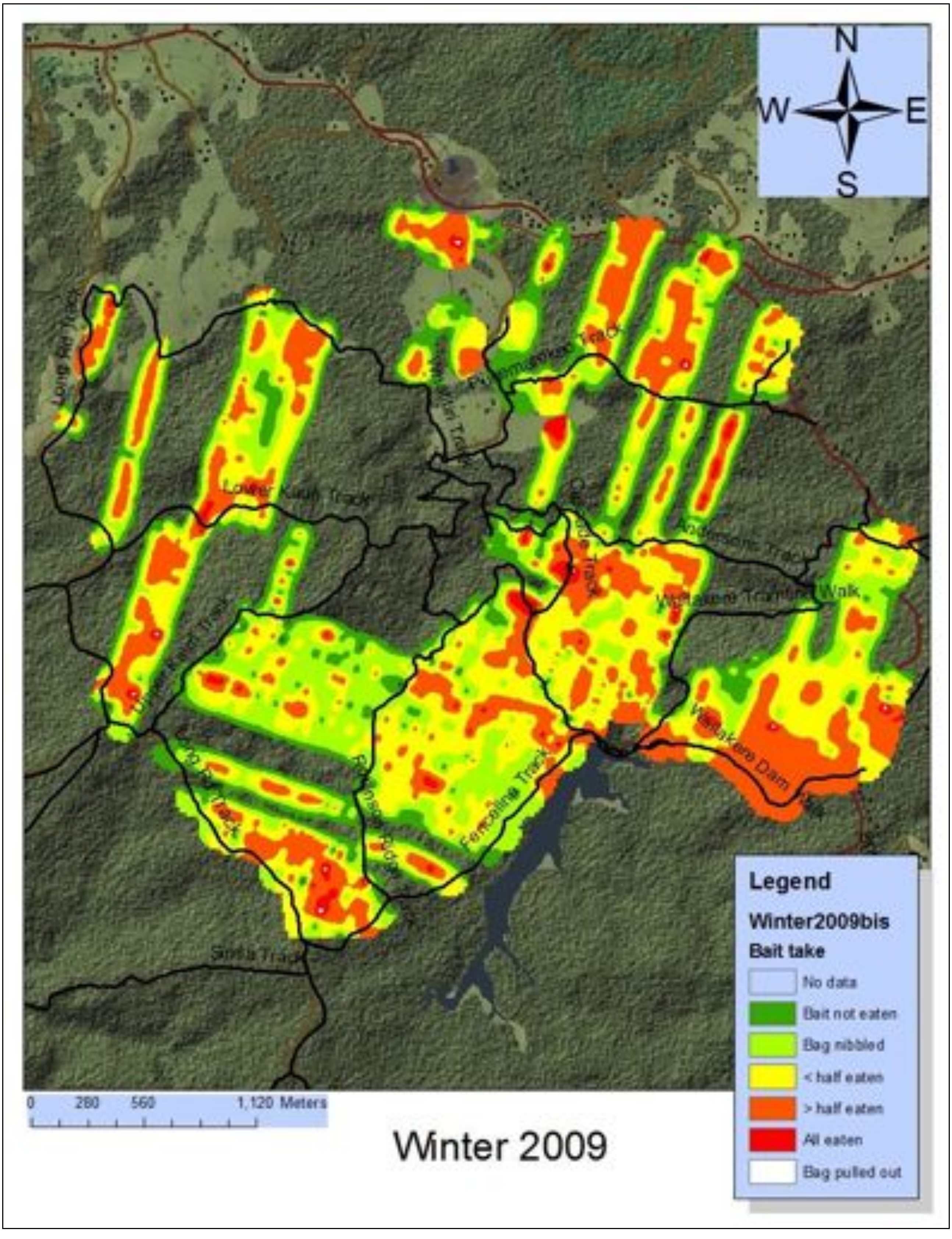

N
W
E
S
Long Rd Track
Lower Kauri Track
Upper Kauri Track
Anderson's Track
Waitakere Tramline Walk
Waitakere Dam Walk
Simla Track
Legend
Spring 2008
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out
0 280 560 1,120 Meters
Spring 2008

Appendix 12



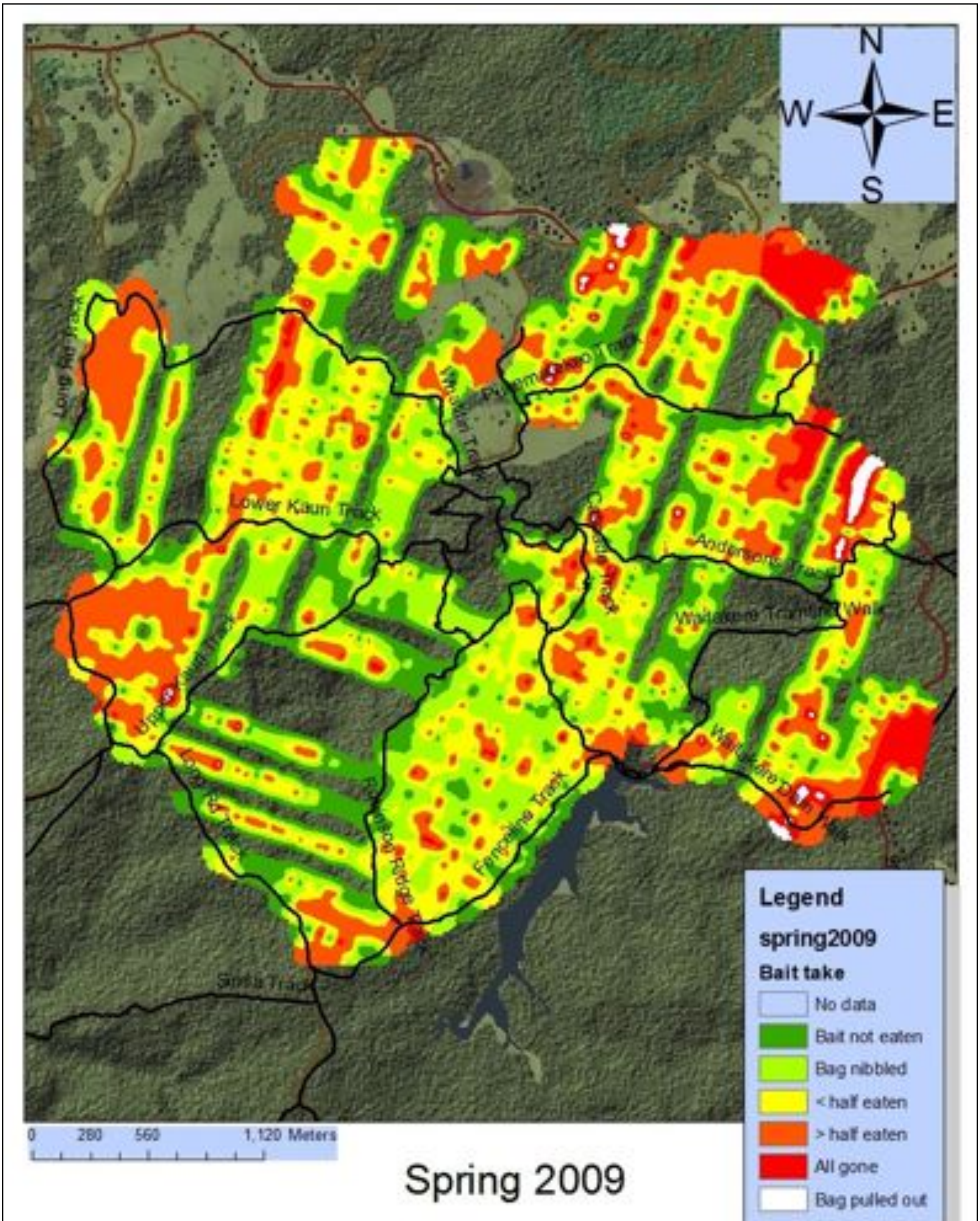
N
W
E
S
Long Rd Track
Lower Kauri Track
Upper Kauri Track
Fenceline Track
Anderson's Track
Sinha Track
Legend
summer2009
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out
0 280 560 1,120 Meters
Summer 2009

Appendix 13



N
W
E
S
Long Rd Track
Lower Kauri Track
Anderson's Track
Waitakere Tramline Walk
Fenceline Track
Waitakere Dam
Sinfia Track
0 280 560 1,120 Meters
Winter 2009
Legend
Winter2009bis
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All eaten
Bag pulled out

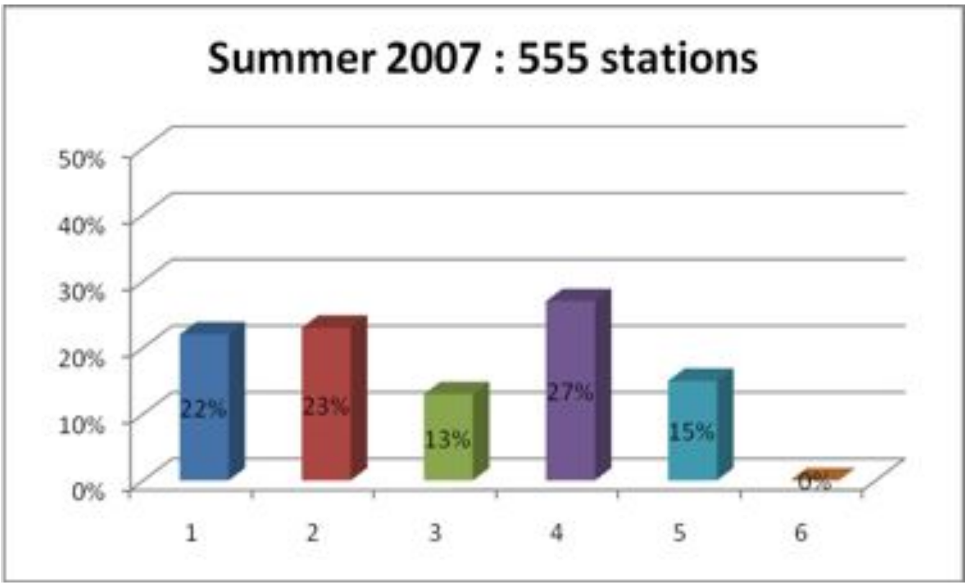
Appendix 14


N
W
E
S
Long Hill Track
Lower Kauri Track
Andersons Track
Fenceline Track
Sinha Track
Legend
spring2009
Bait take
No data
Bait not eaten
Bag nibbled
< half eaten
> half eaten
All gone
Bag pulled out
0 280 560 1,120 Meters
Spring 2009

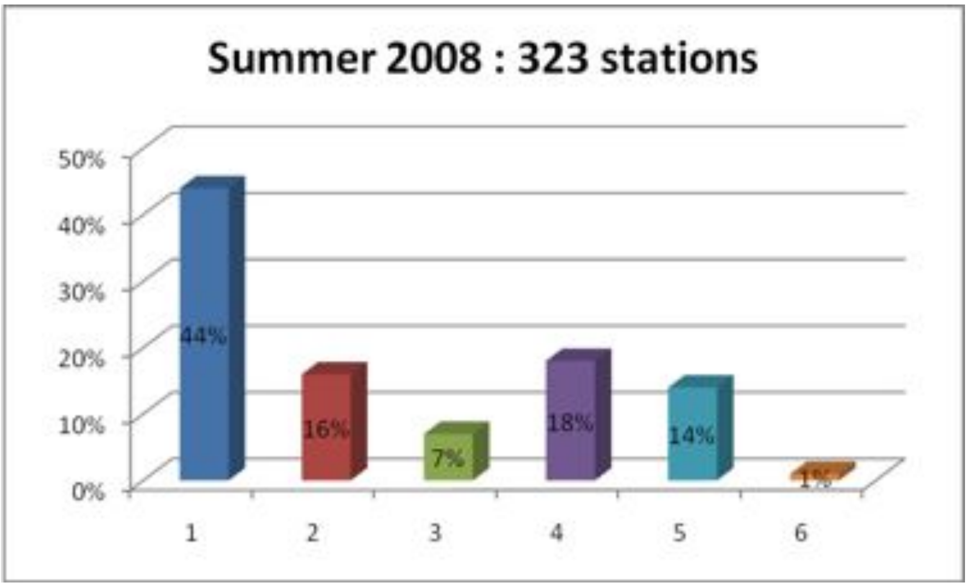
Appendix 15

	Category	Count	Percentage
Winter 2006	No data	869	40%
	1	59	3%
	2	102	5%
	3	134	6%
	4	668	30%
	5	313	14%
	6	48	2%
Spring 2006	No data	851	39%
	1	218	10%
	2	239	11%
	3	157	7%
	4	510	23%
	5	193	9%
	6	25	1%
Summer 2007	No data	1638	75%
	1	121	5%
	2	126	6%
	3	72	3%
	4	153	7%
	5	81	4%
	6	2	0%
Winter 2007	No data	730	33%
	1	120	6%
	2	210	10%
	3	177	8%
	4	555	25%
	5	315	14%
	6	86	4%
Spring 2007	No data	933	43%
	1	491	22%
	2	277	13%
	3	144	7%
	4	208	9%
	5	93	4%
	6	47	2%
Summer 2008	No data	1870	85%
	1	141	7%
	2	52	2%
	3	23	1%
	4	58	3%
	5	45	2%
	6	4	0%

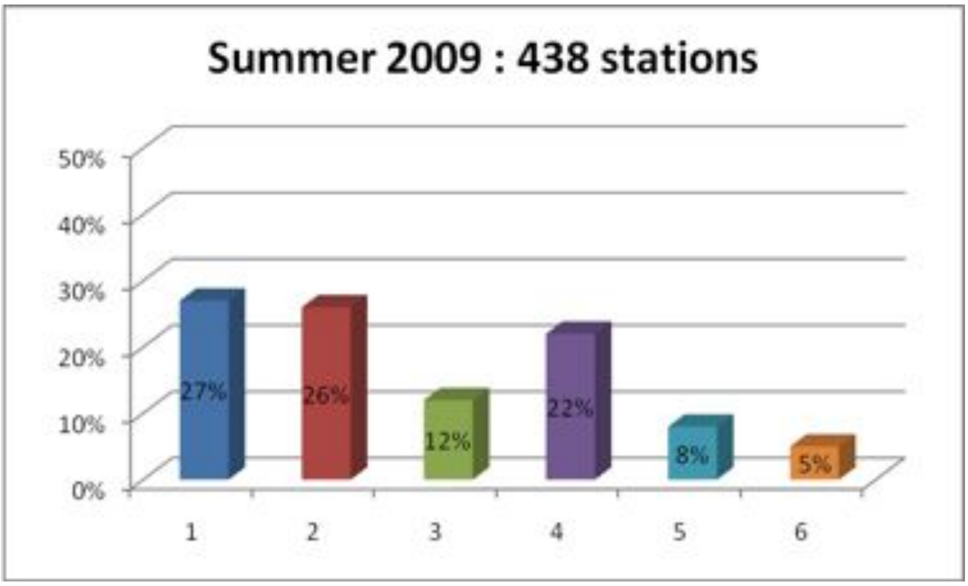
	Category	Count	Percentage
Winter 2008	No data	715	33%
	1	118	5%
	2	203	9%
	3	180	8%
	4	609	28%
	5	316	15%
	6	52	2%
Spring 2008	No data	743	34%
	1	350	16%
	2	338	16%
	3	161	7%
	4	358	16%
	5	182	8%
	6	61	3%
Summer 2009	No data	1755	80%
	1	118	5%
	2	112	5%
	3	54	2%
	4	98	5%
	5	33	2%
	6	23	1%
Winter 2009	No data	1151	52%
	1	104	5%
	2	189	9%
	3	238	11%
	4	440	20%
	5	54	2%
	6	17	1%
Spring 2009	No data	665	30%
	1	308	14%
	2	383	17%
	3	156	7%
	4	497	23%
	5	142	7%
	6	42	2%

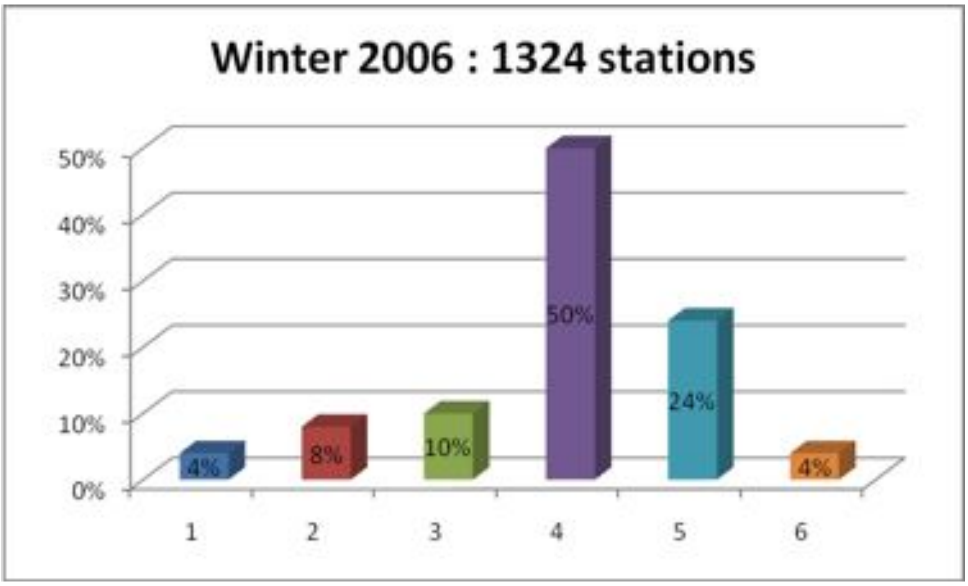


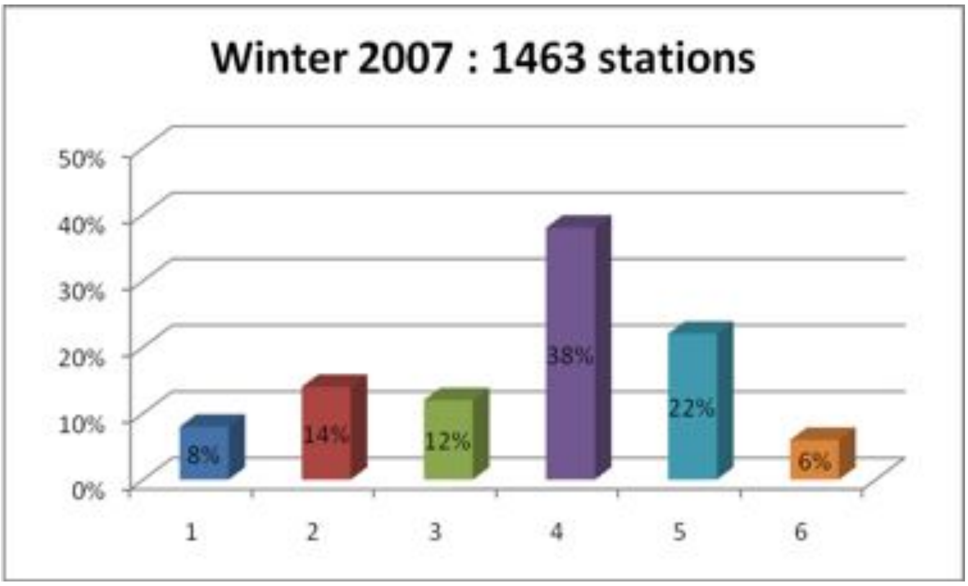
Summer 2007 : 555 stations
50%
40%
30%
20%
10%
0%
22%
23%
13%
27%
15%
0%
1
2
3
4
5
6

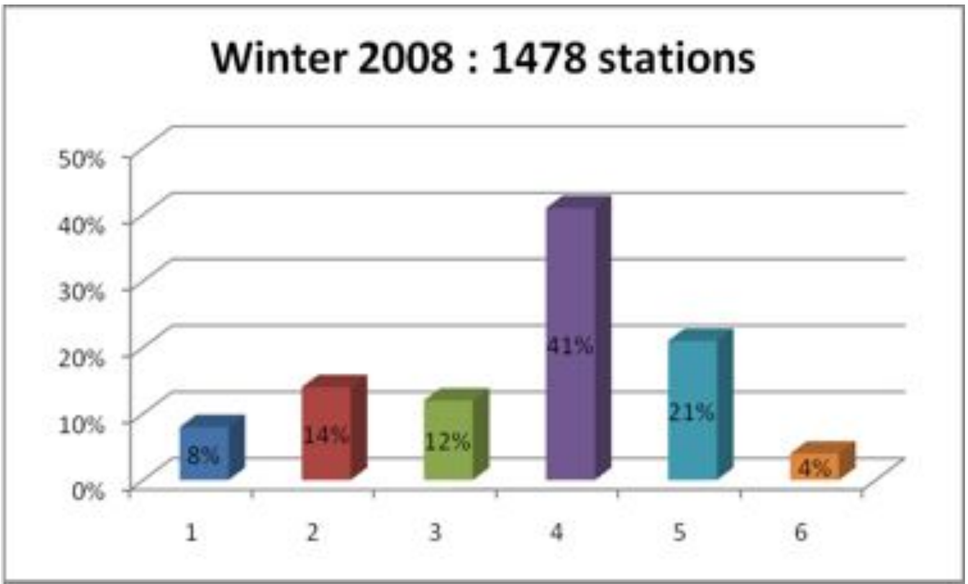


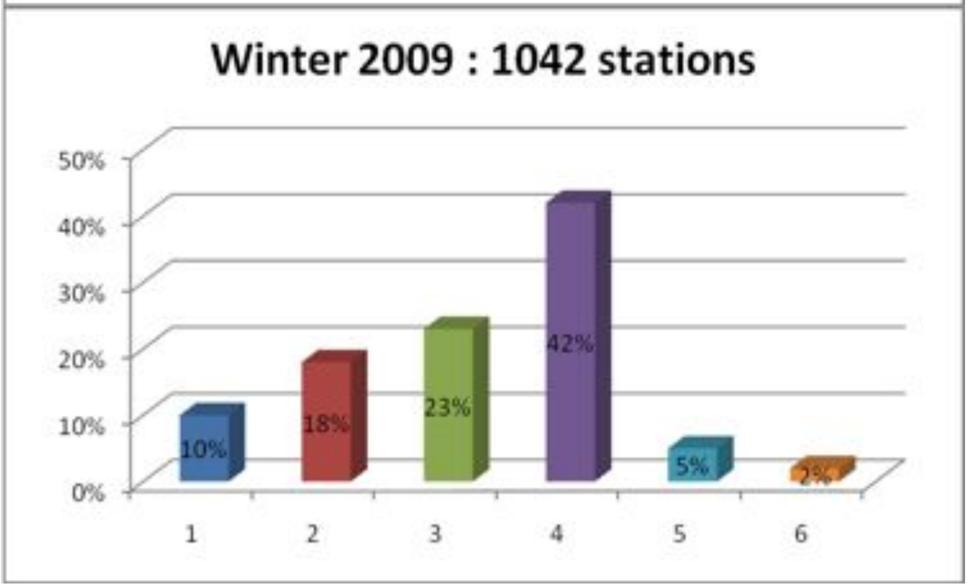
Summer 2008 : 323 stations
50%
40%
30%
20%
10%
0%
44%
16%
7%
18%
14%
1%
1
2
3
4
5
6

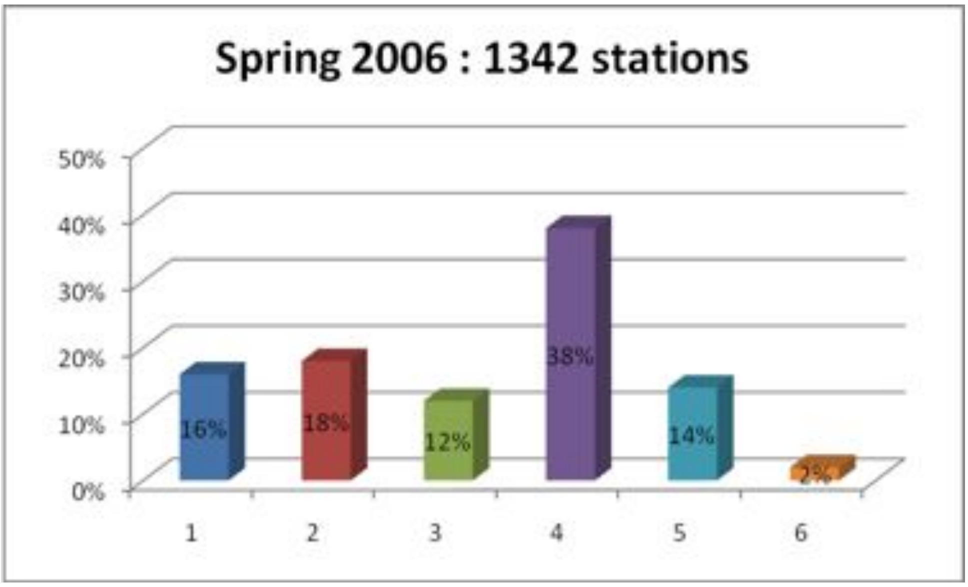

Summer 2009 : 438 stations
50%
40%
30%
20%
10%
0%
27%
26%
12%
22%
8%
5%
1
2
3
4
5
6

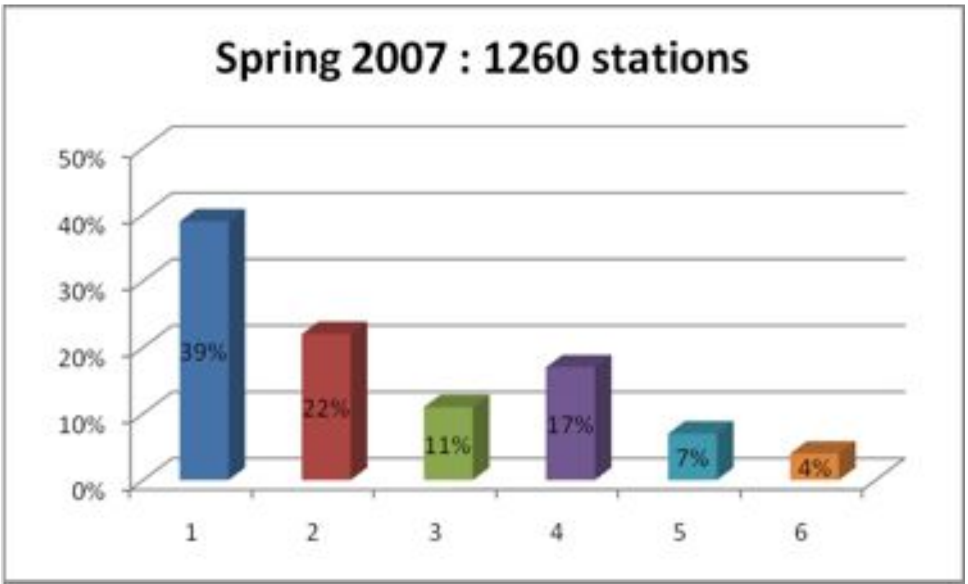

Winter 2006 : 1324 stations
50%
40%
30%
20%
10%
0%
4%
8%
10%
50%
24%
4%
1
2
3
4
5
6

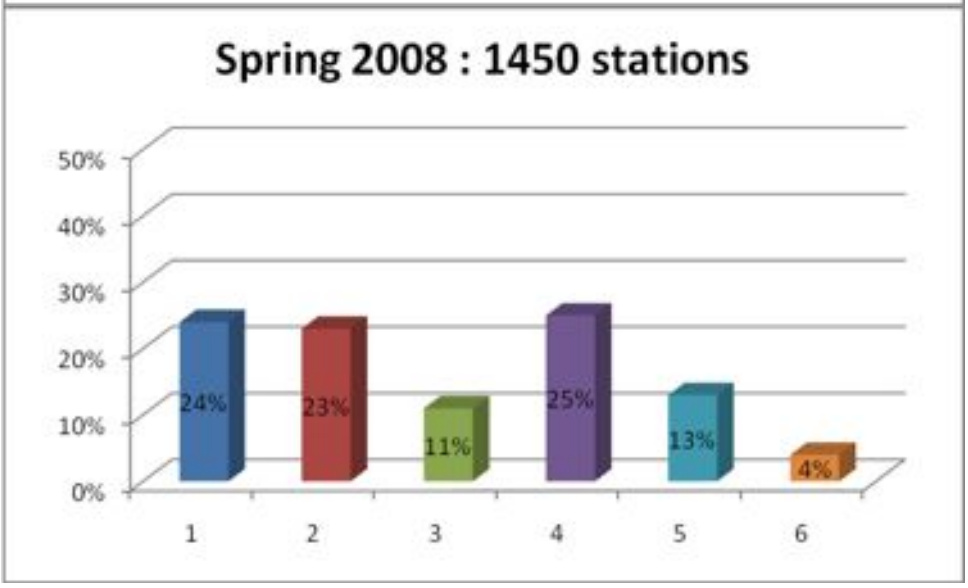

Winter 2007 : 1463 stations
50%
40%
30%
20%
10%
0%
8%
14%
12%
38%
22%
6%
1
2
3
4
5
6

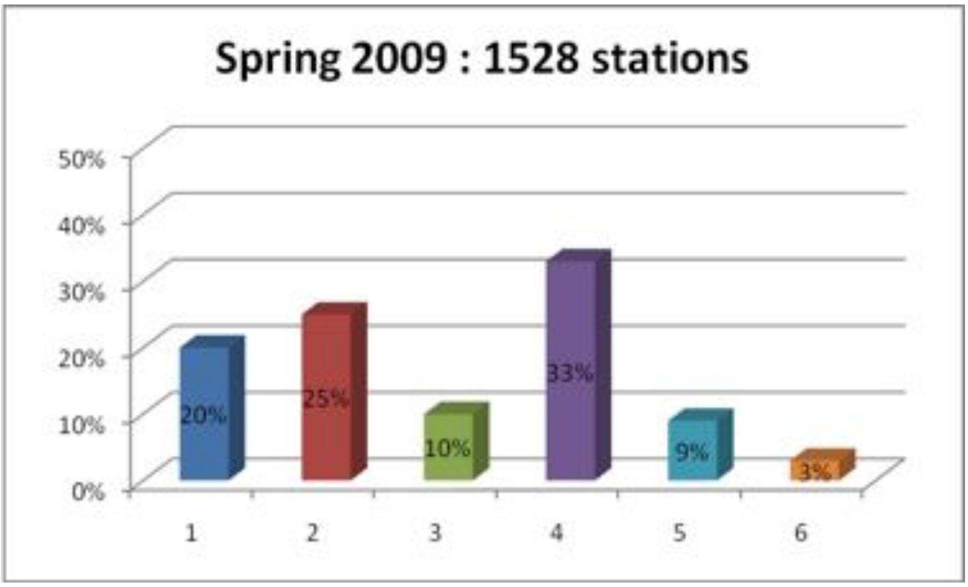

Winter 2008 : 1478 stations
50%
40%
30%
20%
10%
0%
8%
14%
12%
41%
21%
4%
1
2
3
4
5
6


Winter 2009 : 1042 stations
50%
40%
30%
20%
10%
0%
10%
18%
23%
42%
5%
2%
1
2
3
4
5
6

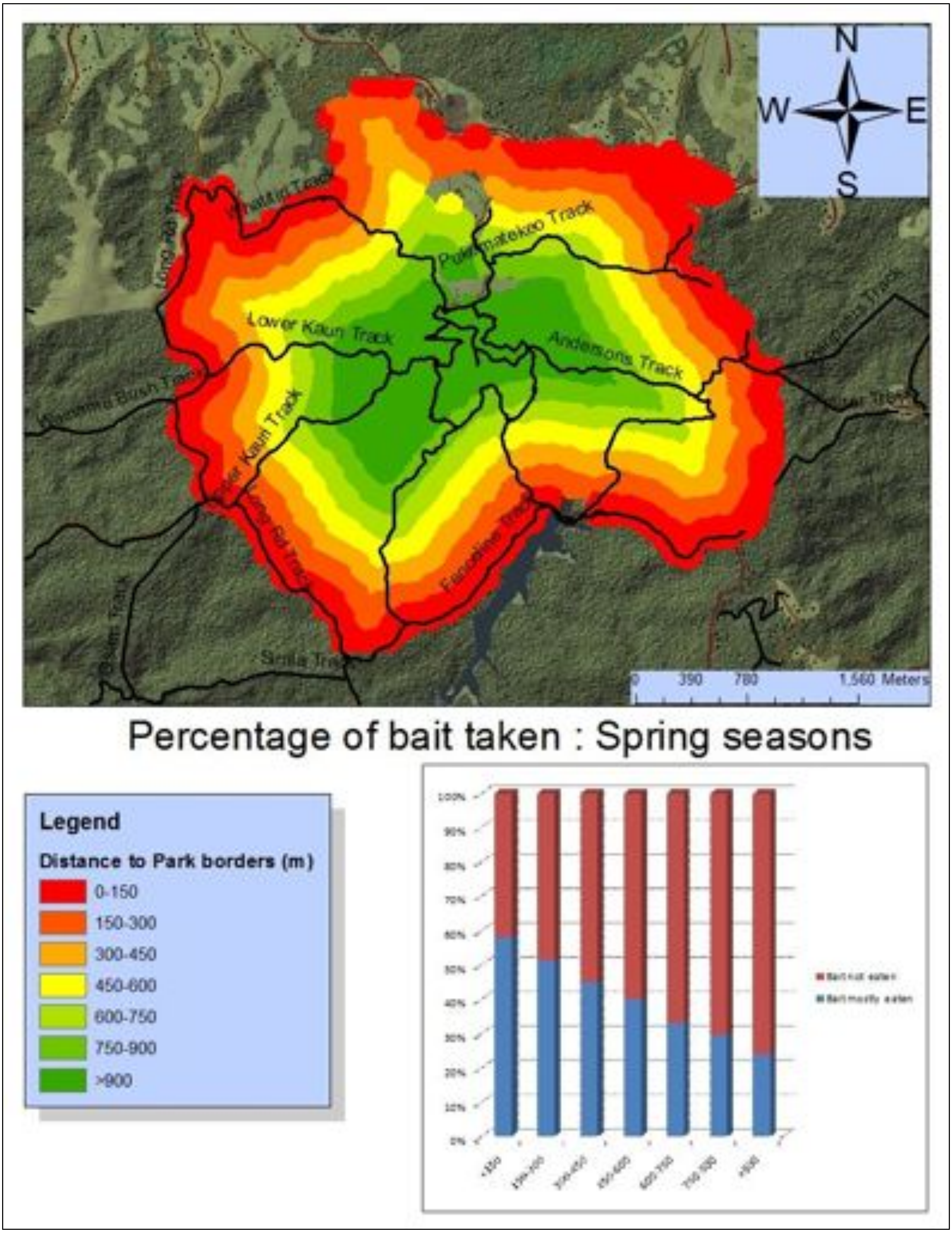

Spring 2006 : 1342 stations
50%
40%
30%
20%
10%
0%
16%
18%
12%
38%
14%
2%
1
2
3
4
5
6


Spring 2007 : 1260 stations
50%
40%
30%
20%
10%
0%
39%
22%
11%
17%
7%
4%
1
2
3
4
5
6

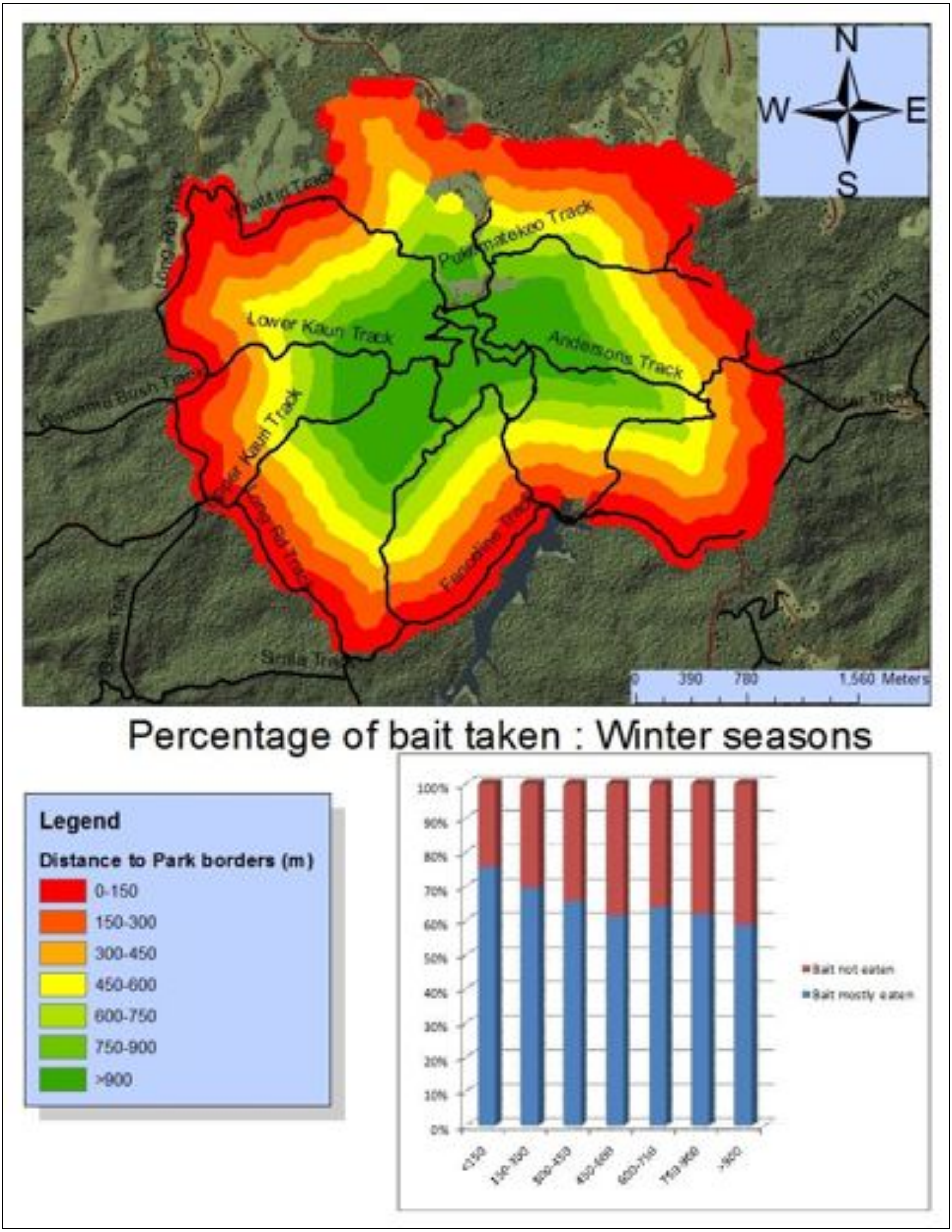

Spring 2008 : 1450 stations
50%
40%
30%
20%
10%
0%
24%
23%
11%
25%
13%
4%
1
2
3
4
5
6


Spring 2009 : 1528 stations
50%
40%
30%
20%
10%
0%
20%
25%
10%
33%
9%
3%
1
2
3
4
5
6

Appendix 16

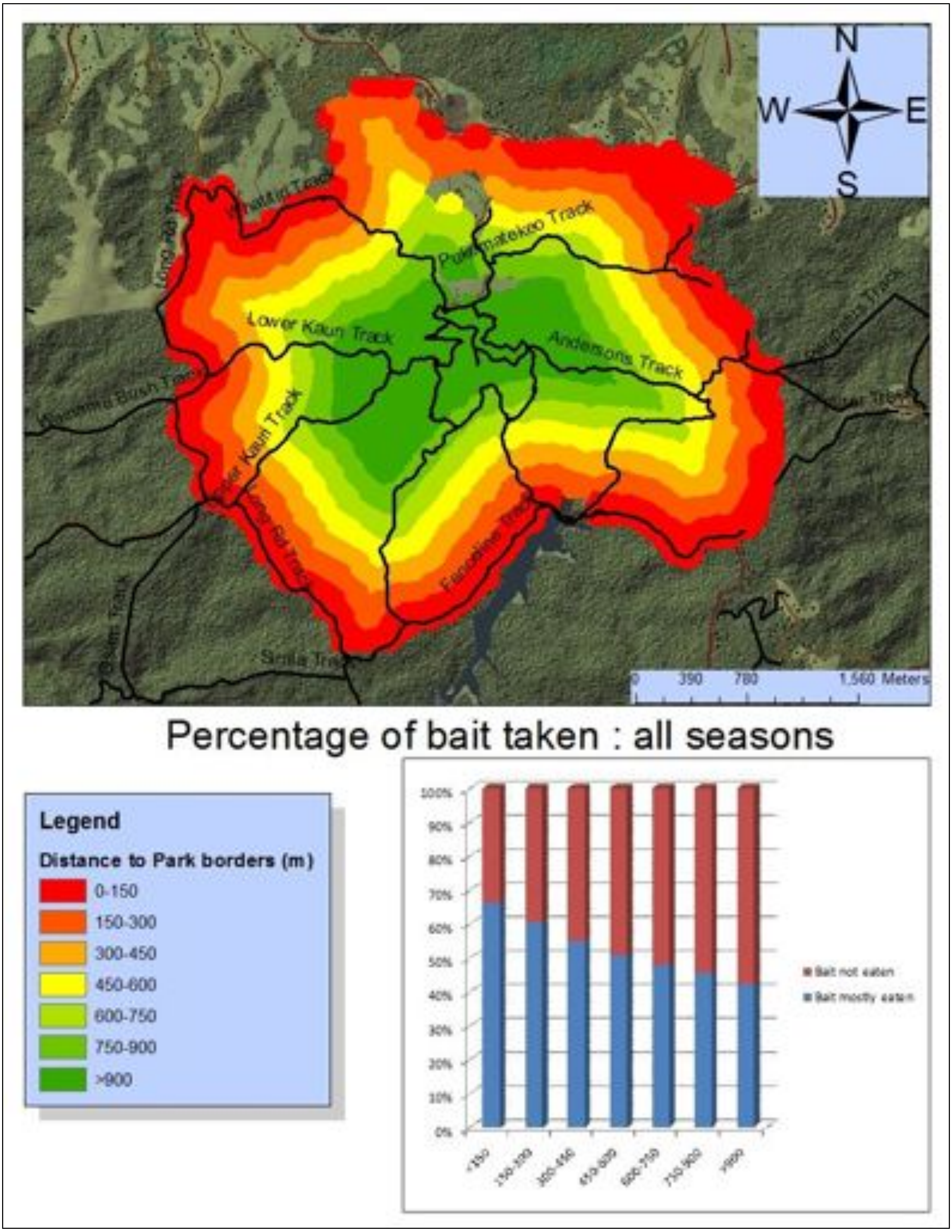

N
W
E
S
Pukematekeo Track
Lower Kauri Track
Andersons Track
Upper Kauri Track
Fence Line Track
Long Rd Track
Smiths Track
0 390 780 1,560 Meters
Percentage of bait taken : Spring seasons
Legend
Distance to Park borders (m)
0-150
150-300
300-450
450-600
600-750
750-900
>900
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

Appendix 17



N
W
E
S
Lower Kauri Track
Andersons Track
0 390 780 1,560 Meters
Percentage of bait taken : Winter seasons
Legend
Distance to Park borders (m)
0-150
150-300
300-450
450-600
600-750
750-900
>900
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Bait not eaten
Bait mostly eaten

Appendix 18


N
W
E
S
Lower Kauri Track
Andersons Track
0 390 780 1,560 Meters
Percentage of bait taken : all seasons
Legend
Distance to Park borders (m)
0-150
150-300
300-450
450-600
600-750
750-900
>900
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Bait not eaten
Bait mostly eaten