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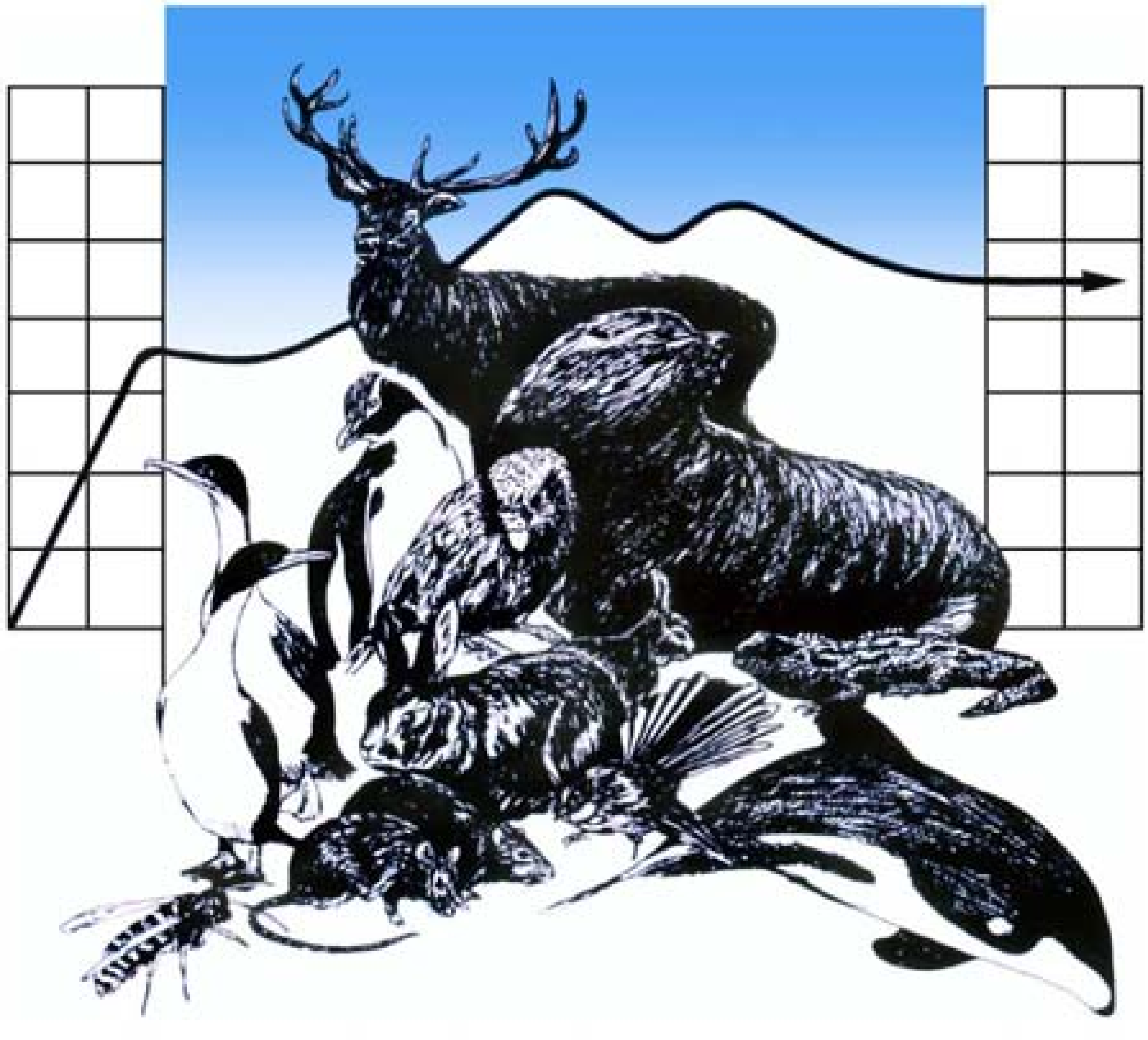

WILDLIFE MANAGEMENT

Determining the impact of the proposed manipulations at the NGL reserve on the abundance and distribution of jewelled geckos (*Naultinus gemmeus*) and introduced mammals

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A research report submitted in partial fulfilment of the requirements of the Diploma in Wildlife Management

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Code Names

Jewelled geckos (*Naultinus gemmeus*) are sought by international lizard poachers, with poaching being previously reported on the Otago Peninsula. It is likely that poaching has contributed to, or resulted in, the decline of some populations. Due to the potential threat of poachers identifying sites containing jewelled geckos, code names have been used in this report. These include the “NGL reserve” (or NGLR) and “hilltop site”. The names of all land owners around the reserve boundaries have also been excluded for the same reasons and will simply be known as Neighbours #1, #2 and #3. For further information on code names contact the author.

Executive Summary

The NGL reserve (NGLR) was established in 1993, in order to gain basic knowledge needed for the conservation of jewelled geckos (*Naultinus gemmeus*). At this time, jewelled geckos were abundant in the *Coprosma* bushes in the reserve but have since declined. Several manipulations are planned in an attempt to restore the habitat for any jewelled geckos left in the area or provide a suitable site for future translocation. The manipulations aim to restore the reserve to a similar state to when it was successfully supporting a large jewelled gecko population. The planned manipulations include the re-introduction of stock, removal of weeds and breaching of the fence.

This research provides baseline information to which future comparisons can be made. The research involved visual searches for jewelled geckos, a survey of lagomorph abundance, an assessment of rodent and mustelid activity and a vegetation survey.

Visual searches failed to detect the presence of any jewelled geckos in the reserve or around its boundaries, however two populations were discovered nearby and 22 individuals identified through photo-identification. The lagomorph survey involved pellet counting and detected a high estimate of lagomorph abundance before the manipulations. After the fence was breached, lagomorph abundance declined by ~37%.

Rodent and mustelid activity was assessed using tracking tunnels at three sites: inside the reserve, outside the reserve around its boundaries and at the hilltop site where a population of 18 jewelled geckos was found. Tracking tunnel data showed high rodent activity inside the reserve and around its boundaries, whereas rodent activity was significantly lower at the hilltop site. This was suspected to be due to the long absence of grazers at the NGLR and the resulting rank grass growth providing abundant food and shelter for rodents. In contrast, grazing stock had only been absent from the hilltop site for one year. No significant differences were found regarding mustelid activity between the three sites.

The vegetation survey outlined the vascular plant species present in the reserve and estimated the percentage cover of species which were important, either as jewelled gecko habitat or as weeds which threatened jewelled gecko habitat. This provided a baseline for future comparison and helped prioritise areas for weed control.

Likely factors which contributed to the decline of jewelled geckos at the NGLR are rodent predation, poaching and habitat fragmentation. Future monitoring at the site is highly recommended to test the long-term effectiveness of the manipulations and determine whether any re-colonisation of jewelled geckos occurs.

1.0 General Introduction

1.1 Taxonomy

Naultinus is one of two genera of geckos in New Zealand, the other being *Hoplodactylus*. *Naultinus* species are commonly known as "green geckos". All green geckos are arboreal and diurnal, in contrast to their predominantly nocturnal relatives in the *Hoplodactylus* genus. None of the *Naultinus* gecko populations are sympatric, presumably because each species is adapted to its local environment and also because their respective ecological niches are similar (Hitchmough, 2006).

All *Naultinus* geckos have an excellent sense of sight, smell and hearing. *Naultinus* species possess prehensile tails which enables them to climb effectively. They are more reluctant to shed their tail when disturbed by a predator than *Hoplodactylus*. New Zealand geckos are some of the world's most anatomically primitive geckos and were in the New Zealand region before its separation from Gondwanaland 80 million years ago.

Green geckos (genus *Naultinus*) were historically a significant component of natural ecosystems throughout much of New Zealand prior to human settlement 1800 ya (Hare *et al.* 2007). These lizards would have been important functional components of pre-settlement shrub-land and forest ecosystems, as fruit and nectar eating lizards can be significant pollinators and dispersers of seed for many trees and shrubs (Lord & Marshall, 2001). Since then, habitat modification and introduced mammalian predators have threatened many *Naultinus* populations, making their survival a conservation priority (Hare *et al.* 2007). There are nine known species in the genus, *Naultinus* as listed below.

- Jewelled gecko, *Naultinus gemmeus*
- Rough gecko, *Naultinus rudis*
- Marlborough green gecko, *Naultinus manukanus*
- Nelson green gecko, *Naultinus stellatus*
- Lewis Pass green gecko, *Naultinus poecilochlorus*
- West Coast green gecko, *Naultinus tuberculatus*
- Wellington green gecko, *Naultinus elegans punctatus*
- Auckland green gecko, *Naultinus elegans elegans*
- Northland green gecko, *Naultinus grayii*

1.2 The jewelled gecko

The jewelled gecko (*Naultinus gemmeus*) (McCann, 1955) is a diurnal, visually cryptic, long-lived, arboreal gecko that is only found on the southeast of the South Island, New Zealand (Hare *et al.* 2007; Jewell & McQueen, 2007). Jewelled geckos are normally bright emerald green above, but some males from Canterbury are coloured grey or brown (Jewell, 2006). Specimens usually have three rows of white, cream or yellow dorso-lateral patches (which are often diamond shaped) or stripes extending varying distances down either side of the back (*pers. obs.*). These patches or lines usually (but not always) have a darker coloured outline (*pers. obs.*). Interior mouth colour is deep blue or purplish-blue (Jewell, 2006; Whitaker *et al.* 2002). They are a moderate-sized gecko with a Snout-Vent Length (SVL) of up to 80 mm and a total length of 160 mm (Schneyer, 2001; Shaw, 1994; Whitaker *et al.* 2002).

Jewelled geckos often perch among twigs and foliage on sunny days, basking in the sun or stalking insects. Basking is believed to be a response to the relatively cold environment and necessity to maintain body heat (Heatwole & Taylor, 1987, cited in Duggan, 1991). Jewelled geckos are typically sit-and-wait rather than active pursuit predators. They use a perch or sometimes a position under cover from which they dash out to catch prey such as insects and moths (Heatwole & Taylor, 1987, cited in Duggan, 1991). They also eat the fruit and nectar from native plants such as *Coprosma propinqua*. Like all New Zealand geckos, jewelled geckos are viviparous and therefore give birth to live young. The life history of jewelled geckos is characterised by low annual reproductive output with a maximum of 2 offspring produced per year (Cree, 1994). Reproduction occurs annually and vitellogenesis occurs from autumn to spring, with pregnancy lasting about 7 months (Wilson & Cree, 2003). Birth occurs in mid to late autumn which is thought to be unique for lizards from cool-temperate zones (Wilson & Cree, 2003).

1.3 Habitat

Jewelled geckos inhabit forest (including both lowland broadleaf and montane beech, *Nothofagus*) and seral shrub-land including kanuka (*Kunzea ericoides*), manuka (*Leptospermum scoparium*), Hall's totara (*Podocaprus hallii*), matagouri (*Discaria toumatou*), *Muehlenbeckia, Coprosma* sp. and subalpine shrub-land and sub-shrub vegetation up to ~1,000 m (Whitaker *et al.* 2002). Jewelled geckos have also been reported occasionally from exotic woody vegetation, such as gorse (*Ulex europaeus*), pines (*Pinus sp.*) and

Macrocarpa. However, on the Otago Peninsula, jewelled geckos are mostly recorded from *Coprosma propinqua* (see *fig.* 1.) and kanuka (*Kunzea ericoides*). *Coprosma* is ideal for jewelled gecko as it is thick and twiggy, providing excellent protection from predation as well as providing fruit and a home to insect prey (see *fig.* 2.).

Fig. 1. *Coprosma propinqua* is commonly inhabited by jewelled gecko

Fig. 2. *Coprosma* is ideal for jewelled gecko as it is thick and twiggy, providing excellent protection from predation (note the partially buried jewelled gecko).

1.4 Threats, causes of decline and current distribution

Jewelled geckos have been given the threat status of 'gradual decline' by the Department of Conservation (DOC) (Hitchmough *et al.* 2007), however this conservation status is thought to be highly questionable (Jewell, 2006) and their actual status may be much worse. This status is questionable due to a lack of thorough surveys and the difficulties involved in finding individuals and estimating population size due to their cryptic nature, emergence behaviour (see Duggan, 1991) and the dense vegetation often inhabited. "The visually and behaviourally cryptic nature of *Naultinus* geckos and a lack of scientific attention pose challenges to their conservation management" (Hare *et al.* 2007).

Forest and shrub-land habitat was once widespread on the east coast of the South Island, however, periodic fires since the arrival of humans c. 750 years ago, and agricultural practices following the arrival of Europeans, has dramatically reduced the available habitat for jewelled geckos. Only isolated areas of shrub-land now remain and little of this is legally protected. As a result, jewelled geckos are now considered vulnerable because their range has become fragmented through loss of forest and shrub-land habitat (Jewell & McQueen, 2007). Furthermore, jewelled gecko have relatively small home-ranges (e.g. mean home range for males = $31.2m^2 \pm 0.08$ (n = 9), mean home range for females = $4.7m^2 \pm 0.8$ (n=12) (see Shaw, 1994)), which may limit their ability to travel between habitat fragments. In addition, jewelled gecko may be much more vulnerable to predation or other causes of mortality when travelling across open ground in highly fragmented habitat.

Today, jewelled geckos are most commonly found on Banks Peninsula and Otago Peninsula (Whitaker *et al.* 2002). Further populations or isolated sightings have been recorded from isolated sites, throughout Otago, Canterbury and Southland; however the persistence of these populations is largely unknown. Although well known on Otago Peninsula, elsewhere in Otago the Jewelled gecko appears to be rare and seldom encountered (Jewell, 2006). Distribution records, together with evidence that most of Otago was once covered in forest or woodland (Walker *et al.* 2003) suggest that in pre-settlement times jewelled geckos would have been widely dispersed across Otago and Canterbury.

As a result of historical and continuing loss of lowland forest and shrub-land habitats many jewelled gecko populations have become small, isolated and fragmented (Whitaker *et al.* 2002). Both habitat loss and consequent fragmentation of populations may threaten the survival of the species (Duggan & Cree, 1992; Shaw, 1994). Habitat loss is a continuing threat with large areas of low-altitude, seral shrub-land habitat being lost to exotic forestry, cleared or burned for agriculture or removed for urban development (Whitaker *et al.* 2002).

A further threat to jewelled geckos is predation. As a consequence of introduced predators many lizard species disappeared from the New Zealand mainland and are now mainly or entirely found on offshore islands (Towns & Daugherty, 1994). Predation on jewelled geckos has not been reported, however considering the effect of introduced predators on other lizard species in New Zealand, many species are a potential threat (Schneyer, 2001). These include a wide array of introduced mammalian predators including the house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), ship rat (*R. rattus*), weasel (*Mustela nivalis vulgaris*), stoat (*Mustela ermina*), ferret (*M. furo*), European hedgehog (*Erinaceus europaeus*), brush-tail possum (*Trichosurus vulpecula*) and feral cat (*Felix catus*).

In addition, native avian predators (kingfishers, *Halcyon sancta vagans*, Australasian Harrier, *Circus approximans*, morepork, *ninox novaeseelandiae,* New Zealand falcon, *Falco novaeseelandiae*) and introduced avian predators (e.g. Australian magpie, *Gymnorhina tibicen* and European starling, *Sturnus vulgaris*) may also have an impact. Slow population growth due to low annual reproductive output makes jewelled geckos more susceptible to decline or local extinction via predation.

Introduced herbivores such as European rabbits (*Oryctolagus cuniculus*), hares (*Lepus eurapoeus*) and the brush-tailed possum (*Trichosurus vulpecula*) may also have a detrimental impact on jewelled geckos via browsing which may prevent the establishment or spread of native shrubs (e.g. ring-barking of *Coprosma* sp. by European rabbits). This browsing may also inadvertently promote the spread of more grazing tolerant or faster growing exotic species such as gorse (*Ulex europeus*) which may out-compete native shrubs like *Coprosma* sp. for space, or shade emerging seedlings preventing growth and establishment. Jewelled geckos also appeal to the illegal pet trade and poaching has been reported or suspected from several locations (Lala Frazer & Rosi Muller *pers. comm.*).

1.5 The Otago Peninsula

The Otago Peninsula is nationally a significant area for the conservation of jewelled geckos (Whitaker *et al.* 2002). The future survival of jewelled geckos on the peninsula relies on the continued existence of their habitat and protection from threats. Although the species is widespread on the peninsula, the habitat at many sites is not protected (Whitaker *et al.* 2002) and most populations appear small and isolated from other such populations. In addition there are many threats to jewelled gecko populations on the Otago peninsula including habitat clearance or fragmentation, predation by introduced mammals, bird predation, urban development, illegal poaching and habitat modification by introduced browsers (see *fig.* 3.). This study involves one population on the Otago Peninsula which is subject to all (or most) of the above threats at the NGL reserve.

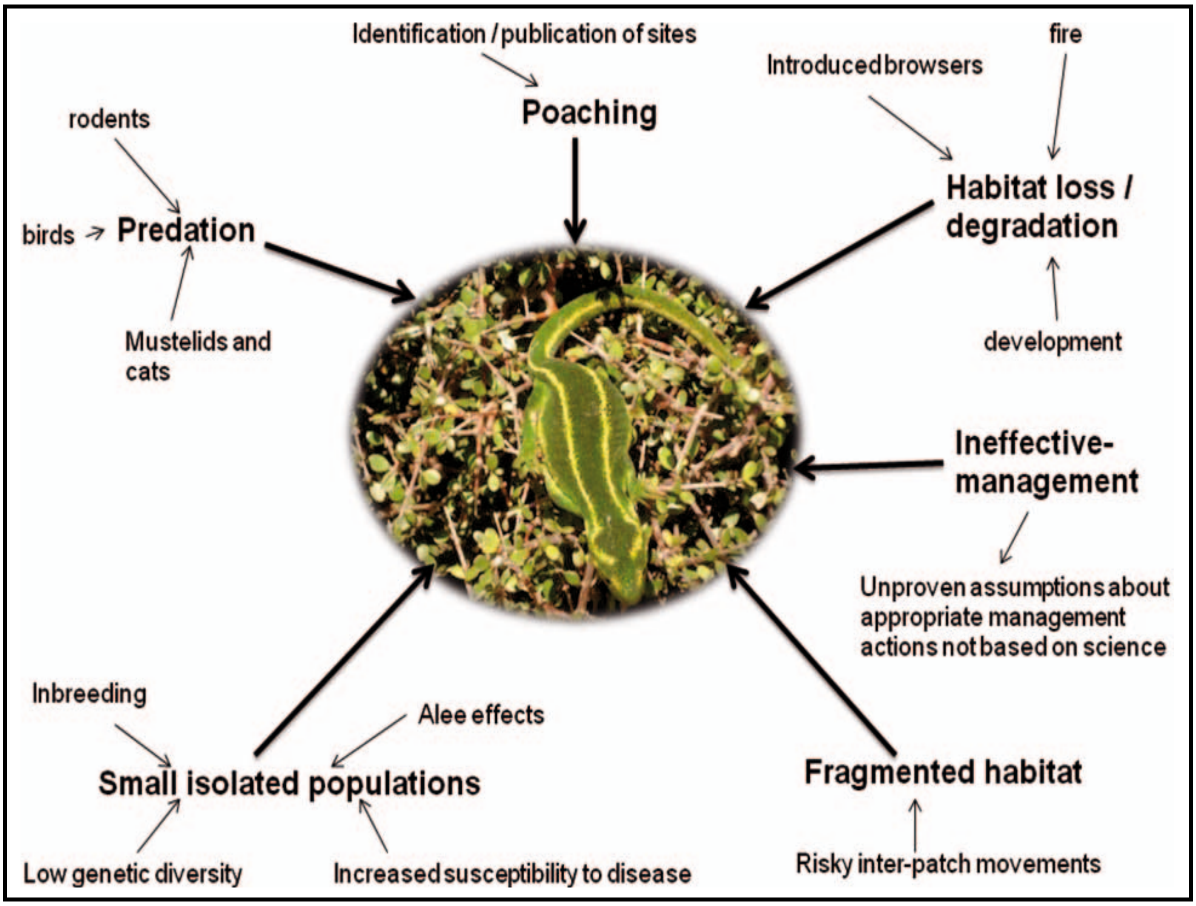

Fig. 3. The many potential threats effecting jewelled gecko populations on the Otago Peninsula and elsewhere.

2.0 The NGL reserve

2.1 Introduction

The NGL reserve (NGLR) was established in 1993, in order to gain basic knowledge needed for the conservation of jewelled geckos. An assumed, high population density compared to other sites, and the convenient access to the area was responsible for the decision to establish the reserve (Shaw, 1994). The reserve consists of 0.852 ha, moderately sloping, north-west orientated hillside (Schneyer, 2001). The reserve was gifted to the Department of Conservation (DoC) in 1994. It was home at the time to a large number of jewelled geckos which were to be found in the small bushes of *Coprosma propinqua*. *C. propinqua* shrubs in the reserve occur in clusters of varying size and height (1-3 m) separated by pasture.

A cat proof fence was erected around the reserve. The fence was funded jointly by the Dunedin Branch of Forest and Bird and Save The Otago Peninsula Inc Soc (STOP). This was a double height fence (~2m high) with an electric outrigger at the top to prevent mammals climbing over or birds perching on it and the netting on the fence also extends underground to prevent mammals from burrowing under. The gate into the reserve was locked in an attempt to restrict human access. There is also an aluminium strip around the fence which was designed to prevent geckos climbing to the electronic outrigger. Mustelids, cats and possums inside the reserve were non-systematically trapped and poisoned (Schneyer, 2001).

The mesh size (chicken netting) on the fence is thought to be small enough to exclude entry of all mammals except mice and rats, whilst allowing for passage of jewelled geckos through the mesh and therefore in and out of the reserve. There was never any intention that the fence should be rat or mice proof, although it is now known that these rodents do prey on reptiles (see Newman 1994; Towns 1994). It was thought that the fence would exclude several introduced mammals which predate on geckos such as mustelids and cats, thereby benefiting the jewelled gecko population. However, the population was never protected from rodent or bird predation.

Vegetation in the reserve consists of several native and introduced shrubs, small trees and exotic pasture grasses. Within the reserve jewelled geckos prefer *C. propinqua* habitat and within *C. propinqua* prefer sunny edge and low canopy areas (Shaw, 1994). However, jewelled geckos have also been seen in other vegetation inside and outside the reserve boundaries on rare occasions such as gorse and Macrocarpa. The entire shrub-land habitat is isolated from other areas of native vegetation on the peninsula by large tracts of pastoral land grazed by sheep and cattle (Schneyer, 2001).

In addition to predator exclusion, the fence was also designed to prevent introduced herbivores entering the reserve such as European rabbits, hares and the brush-tailed possum which are known to browse on *C. propinqua* and therefore may reduce the quality and quantity of jewelled gecko habitat and allow other unfavourable exotic species to dominate. STOP is now responsible for the management of the reserve under a memorandum of understanding with DoC. The establishment and recovery of *C. propinqua* has been promoted by planting of seedlings and removal of undesirable exotic vegetation (e.g. gorse, hawthorn and broom) which may out-compete *C. propinqua* for space and access to sunlight. *C. propinqua* and kanuka have both been planted recently, to increase the available habitat.

Shortly after establishment, Shaw (1994) estimated the size of the jewelled gecko population at 69±9 individuals by marking individuals with non-toxic ink and using mark-recapture methods. At this time there were also a number of individuals outside the reserve boundaries. However, unfortunately since this time the population in the NGLR has dramatically declined. Schneyer (2001) estimated a decline of 50% over a ~five year period from 1994–1999 and the population has declined further since.

Over the last few years Alf Webb has undertaken regular visual searches for jewelled geckos at the NGLR and has recorded the presence of 7 individual geckos between 9/9/2006 and 20/2/08. These 7 individuals comprised of 1 adult female, 2 adult males and 4 juveniles (at least one of which is female) (Alf Webb *pers. comm.*). However, before this study, it was not known how many (if any) of these individuals are still alive or present in the reserve. This year 2 juveniles were sighted on 12/1/08 and the last recorded jewelled gecko sighting at the NGLR was an adult male on 20/2/08 (Alf Webb *pers. comm.*). To my knowledge, no geckos have been sighted in the NGLR since February, 2008.

As can be seen by the work done by Alf Webb, there are likely to be very few individuals left in the reserve (if any). However there may still be a number of additional individuals in suitable habitat outside the fence but near the reserve. It is also possible that there are no jewelled geckos left in the area. Similar declines of other *Naultinus* populations on the mainland are common throughout New Zealand (Hitchmough, 2002).

2.2 Possible reasons for the decline

Protection against most mammalian predators (except rodents) and habitat modification should have caused the population in the NGLR to increase, however decreased sightings and evidence to date, suggest the opposite is more likely (Shaw, 1994; Schneyer, 2001; *pers. obs.*). Several reasons for this decline have been suggested and it is likely that several or all of the factors described below have contributed towards population decline.

Rodent predation

One suggestion involves an increase in mice and/or rat numbers. Rodents are known to predate on New Zealand geckos and skinks (see Newman 1994; Towns 1994) and numbers of rodents in the NGLR are thought to have increased in the reserve after the removal of grazing cattle and the resulting increase in rank grass growth providing an abundant source of food (grass seed) and shelter.

Reduction in available habitat / increased fragmentation

A further likely factor which contributed to the observed decline in jewelled geckos was a reduction in the quality and quantity of *C. propinqua* habitat, which occurred in the late 1990's. This occurred due to a combination of shading from the large Macrocarpa (which were removed in 2003), and grazing by introduced lagomorphs (European rabbits, *Oryctolagus cuniculus* and/or hares, *Lepus eurapoeus*). Prior to rabbit control undertaken in 2000, lagomorphs had reached exceptionally high numbers. This is thought to have occurred due to a small number of lagomorphs escaping eradication after the fence was built and subsequently breeding and multiplying. Thereafter, lagomorphs appear to have reached unnaturally high numbers due to being trapped within the fenced area.

By the late 1990's lagomorphs had reached such high numbers that they had effectively closely grazed the grass. After this, they began grazing heavily on *Coprosma* seedlings, ring-barking adult *Coprosma* and digging up their roots effectively killing most of the growth (Frazer, 2008). The presence of lagomorphs and the results of ring-barking (presumably from the late 1990's) are still visible in the reserve today (see *fig.* 4). Ring-barking, is the process of completely removing a strip of bark (consisting of secondary phloem tissue, cork cambium, and cork) around a tree's outer circumference, causing its death. This can occur through the feeding action of some herbivores such as rabbits who feed on bark at their height. Ring-barking can affect the health of *Coprosma* and even result in death. It is likely that lagomorph grazing and ring-barking, as well as shading from the Macrocarpa, heavily reduced the quality and quantity of jewelled gecko habitat in the NGLR during this period in the late nineties.

Research by Schneyer (2001) during this period, found that median home range sizes for jewelled geckos in the NGLR in 1998/1999 were significantly larger than median home range sizes in another population on the Otago Peninsula as well as those measured in the NGLR by Shaw in 1994 (Shaw, 1994). This was thought to be due to low resource supply in the NGLR as a result of increased habitat fragmentation (Schneyer, 2001). Schneyer (2001) suggested that this increase in home range size would result in more risky inter-patch movements, increasing mortality via predation and thereby resulting in population decline.

At the point when the halving of the gecko population was originally noted, the *Coprosma* had all but been killed by lagomorphs, although it has since recovered (Frazer, 2008). Rabbit control was undertaken in 2000 and the *Coprosma* bushes recovered surprisingly well although many branches had died (Frazer, 2008). The habitat now appears to be in much better condition than in the late 1990's, providing hope that re-colonisation can occur if there are sufficient jewelled geckos left in the area. However there is evidence that lagomorphs have re-invaded the reserve and numbers are building up again (Lala Frazer. *pers. comm.*). In addition to heavy grazing from lagomorphs, emerging *C. propinqua* seedlings may have failed to establish due to the spread of other vegetation and rank grass growth, shading the seedlings and preventing growth. The macrocarpas on the lower north side also shaded much of the reserve at one point but were removed in 2003 in order to increase the amount of sunlight available to geckos (Frazer, 2008).

Fig. 4. The presence of lagomorphs and results of ring-barking are visible in the reserve today. The figure shows:

a) Rabbit droppings in the reserve
b) Evidence of ring-barking on *C. propinqua* in the reserve
c) Death of *C. propinqua* due to ring-barking

Bird Predation

Predation by both introduced and native birds may have also had an impact. One likely suspect is the introduced Australian Magpie (*Gymnorhina tibicen*). Birds have been observed on other sites using high vantage points to identify the location of reptiles. It has been suggested that birds may be using the high fence posts surrounding the NGLR as vantage points to search for jewelled geckos and therefore predation by birds may be high. However, a research project carried out in the NGLR by Nadya Schneyer (Schneyer, 2001), involved netting and indicated that bird predation was not a problem. She also did some radio tracking which indicated that there was no evidence of geckos moving outside the reserve. It was therefore concluded that the reduced numbers were due to ground based predators such as rats and mice and a reduction in habitat quality (Schneyer, 2001).

Poaching

An additional likely reason for the decline in jewelled geckos is illegal poaching or removal of geckos from the reserve. All New Zealand lizards are protected by the Wildlife Act, which makes it illegal to take them from the wild, however poaching still occurs. Jewelled geckos are known to be a desirable species on the illegal pet market and may fetch high prices in Europe, America and Asia. The height and high visibility of the fence may make the reserve much more conspicuous to poachers, signalling to them the likely presence of jewelled geckos or at the least something of interest. Poaching of geckos from the Peninsula was reported in the late 1990’s. On occasion the fence at the NGLR has been cut particularly on the lower north facing side, indicating that poachers may have entered the reserve and taken jewelled geckos. However, it is impossible to estimate how many jewelled geckos may have been taken by poachers.

Predation by mustelids and feral cats

When the fence was cut, mustelids (ferrets, stoats and weasels) and/or cats may have entered the reserve and predated on jewelled geckos. These predators may still be present in the reserve as the fence is still damaged; suggesting that cats and mustelids can easily travel in and out of the reserve. Therefore it is possible that cats and/or mustelids have contributed to the decline in jewelled geckos via predation. Branches have also fallen over the fence which has allowed possums and cats to enter the reserve (Frazer, 2008). In addition, feral cats and mustelids may have been attracted to the reserve due to a high abundance of lagomorphs.

2.3 Proposed manipulations and rationale

In the previous section several plausible reasons for the decline in jewelled geckos at the NGLR were described. This section will outline the proposed manipulations aimed at reducing the impact of each of these causes of decline and thereby improving the suitability of the NGLR for jewelled geckos in the future. It is hoped that if the reserve is returned as far as possible to its previous state, this may encourage natural re-colonisation of jewelled geckos. “The crucial thing is that we are not looking at improving the habitat, because we don't know what we need to do to improve it, but rather at restoring it to the state when it was successfully supporting a large gecko population” (Lala Frazer *pers. comm.*).

To help achieve this, firstly, it is proposed that the fence should be reduced to the height of an ordinary farm fence (~1m) and the chicken netting removed in at-least some locations. The rationale behind this will be outlined below. The top level of the fence will be removed and the bottom level restored to a grazing fence without the chicken wire in order to allow containment of stock. Grazing stock (sheep) will be introduced to control the grass height.

Possible causes of decline:

1) Rabbit/hare browsing / reduction in available habitat

To prevent continuing damage and loss of jewelled gecko habitat (e.g. *C. propinqua*), lagomorph densities must be reduced in the NGLR to avert ring-barking and browsing of seedlings. STOP members have already fenced off with enclosures of low chicken wire, some groups of relatively newly planted *C. propinqua* seedlings that were being nibbled to the ground by lagomorphs. Poisoning of the rabbits is not desirable at this stage because the poison, Pindone has been found in the livers of green geckos. Therefore the aim is merely to return lagomorphs to the population density that would have been there prior to the fence being erected in order to avoid a build up of numbers such that they begin ring-barking and killing *C. propinqua*, again.

It is hoped that this reduction in lagomorph density will be achieved by removing the chicken wire in some locations and therefore breaching the fence and allowing the current animals inside the NGLR to disperse so that their density is reduced. In theory, lagomorphs will no longer be fenced in leading to unnaturally high population densities. Lagomorph densities in the NGLR will be estimated before and after the manipulations take place in order to confirm whether or not a reduction has been achieved.

2) Predation by mice and rats

In order to reduce predation by mice and rats the grass height will be reduced by grazing intermittently with the neighbour's sheep in order to control blackberry and gorse and lower the grass levels. It is hoped that this will limit the amount of food and shelter available to rodents. This in turn should reduce rodent abundance and rodent predation on jewelled geckos. Low grass levels are associated with successful jewelled gecko populations elsewhere on the Otago Peninsula, and lower grass height should limit the mice population. Rodent numbers will be estimated before and after the manipulations using tracking tunnels.

3) Vegetation

After removal of the chicken wire, grazing and ring-barking of *C. propinqua* should be reduced helping recovery. With the removal of the macrocarpa, natural re-vegetation of mahoe and ngaio has occurred, shading out *Coprosma* and kanuka. As well, without grazing, broom has become established and in some areas is threatening the survival of the kanuka planted. Through the use of volunteers, plants such as gorse, broom, blackberry, ngaio and mahoe will be removed from shading new *Coprosma* plantings and known gecko food plants. *C. propinqua* have been planted from at least 2001 and now cover much of the remaining paddock area and the macrocarpa cleared area. There is however room for more planting to take place. Since increased vegetation cover may increase resource availability and therefore habitat quality in the NGLR, planting of native vegetation should be of high priority (Schneyer, 2001). Vegetation types present in the reserve and their percentage cover will be identified via a vegetation survey.

4) Predation by birds

It is hoped that reducing the height of the fence may prevent birds from using the high fence posts as vantage points to identify the location of jewelled geckos, thereby reducing predation. Any birds seen during field work will be observed and recorded.

5) Poaching

This is likely to be an ongoing problem because the site is one that has been identified as holding jewelled geckos and therefore may always be a target (Frazer, 2008). It is hoped that lowering the fence height to normal farm fence height will make the reserve less obvious to poachers and poachers returning to this location will hopefully come to the conclusion that there are no longer any jewelled geckos left in the reserve. Neighbours and researchers visiting the reserve have been asked to record any sightings of people in the vicinity and report any suspicious activity. All visits to the reserve should be recorded in the log book on site in the plastic container near the plaque.

2.4 Revised plan of action

Due to several reasons not all of the manipulations were completed by the end of the available time for research in this study. The fence was not removed except for a small section where a farm gate and small section of fence (~2m) was installed. The gate was positioned in such a way that sheep could enter the reserve through the gate from either the access drive or from a paddock on Neighbour #2's property. Neighbour number #2 kindly offered to let their sheep graze the reserve, however by the time this report was completed grazing had not been re-instated. The reason for this was that the grass had reached such a height (up to ~1m) that it was not thought suitable for the sheep to graze. The revised plan is to cut the grass first to a height where it will be more palatable to the sheep, before introduction.

Since the rank grass had not been removed by the time the research for this report had been completed (the 4th of March), rodent densities were not expected to change a great deal. However, it was thought that a reduction in lagomorph densities would occur as after the fence was breached, lagomorphs could leave the reserve under the gate or through the small section of fence thereby preventing the build up of unnaturally high numbers. On the 18th and 25th of March, working bees were held and the majority of the rank grass was finally removed and some of the weeds which were shading jewelled gecko habitat (e.g. gorse, mahoe, ngaio and broom). It is hoped that sheep can soon be introduced to the reserve to keep the grass low and remove any rank grass which was missed during the working bees.

One of the original aims of this study was to see what effect the manipulations had on rodent, mustelid, lagomorph and jewelled gecko numbers at the NGLR. However, as the manipulations were not completed by the end of this study, this was not possible except for lagomorphs' as the fence was breached. Nonetheless, this study provides a baseline for the vegetation composition and abundance and distribution of jewelled geckos and introduced mammals to which future comparisons can be made to test the effects of the manipulations.

3.0 Jewelled gecko searches

3.1 Aim

Undertake a series of visual searches in the NGLR and on surrounding properties to estimate how many jewelled geckos are present and determine their distribution and occupied habitat. Identify individuals through digital photography.

3.2 Methods

Visual searches for jewelled geckos were undertaken from November through to March in order to record the distribution and abundance of any jewelled geckos present. Searches were undertaken at each site by visually searching all potential jewelled gecko habitat. Attention was focussed on species known to be used by jewelled geckos (e.g. *Coprosma sp.* kanuka, manuka, gorse, halls totara and Macrocarpa).

Before and after each survey, details were recorded on a survey sheet (similar to *fig.* 5.) concerning the date, start time, location to be surveyed, searchers present and weather conditions including cloud cover, temperature and wind speed. Cloud cover was allocated a value by the searcher on a scale from 1 to 8, with 1 being clear sky and 8 being complete cloud cover. Air temperature (°C) was measured in the shade using a digital thermometer and wind speed (m/s) was recorded using a hand-held anemometer. Aerial photographic maps were obtained from the Dunedin City Council website (www.cityofdunedin.com) to aid in identifying areas of suitable habitat to aid during searches. Jewelled geckos are most likely to be emergent (and therefore visible) on hot/warm sunny mornings with low Relative Humidity (RH) and cloud cover (see Duggan, 1991). Therefore surveys were undertaken, whenever possible, in these conditions in order to maximise the number of sightings.

Individuals were identified during visual searches using photo-identification. This method involves photographing individual animals when basking on an opportunistic basis. Photographs were taken from as many angles as possible to maximise the probability of correct identification. It has previously been suggested that variation in the appearance of jewelled geckos may be adequate to differentiate individuals (Shaw, 1994) (see *fig.* 6.). Therefore photography may potentially be used for individual recognition. Concerning jewelled geckos, identifiable marks may include dorso-lateral, ventro-lateral and head markings, fungal spots and scars (Shaw, 1994). In addition, size, life history stage and sex can aid identification.

If jewelled geckos were located during surveys, photographs of each individual were taken using a digital camera from as many different angles as possible. As much information as was possible to obtain about each individual was recorded on the survey sheet. This information included location (G.P.S), vegetation found on (e.g. *C. propinqua*), sex (male, female or gravid female), life history stage (adult, sub-adult or juvenile) and a description of the geckos appearance including patterns (e.g. white diamond shapes or yellow lines), colour (e.g. bright green, dull green, brown/green) and any other distinguishing features such as scars or the absence of a tail (see *fig.* 5.). The location (or exact bush) of any geckos found was also marked on an aerial photographic map.

Sex was determined by visual confirmation of the presence (male) or absence (female) of a hemipenal sac. Photographs along with information recorded on the survey sheets (sex, life history stage etc) were used to help identify individuals during searches. It is thought that the information recorded on the survey sheets along with the photographs would maximise the chances of correctly identifying individuals seen for the first time or re-sighted in subsequent surveys.

Due to the cryptic habits of jewelled geckos it is impossible to estimate their abundance using direct-count techniques (Schneyer, 2001). However, once collected, information concerning individuals sighted in an area during each survey can be used to estimate population size using mark-recapture techniques. In this study, if sightings occur frequently enough, the first several surveys could be used as the mark and the next several as the re-sight, allowing an estimate of population size to be calculated using the Lincoln-Petersen method.

Location/site:	Date:	Week day:	Number:			
Weather Before:			Start time:			
Cloud cover (/8)	Temp:	R.H. (%):	Finish Time:			
Weather After:			Searchers:			
Cloud cover (/8)	Temp:	R.H. (%):				
Gecko Number	Sex	Life History Stage	Vegetation	G.P.S.	Pattern/colour	I.D.
1						
2						
3						
4						
5						
6						
7						
8						
9						
Animals Seen:						
Further Notes						

Fig. 5. An example of a survey sheet which was used in this study during jewelled gecko surveys

a) Diamonds with black spots in middle

b) White lines, brown speckles

c) Yellow lines and T-shaped scar

d) Missing tail

e) Yellow lines with black spots down the middle

f) White diamonds with yellow flecks in between

Fig. 6. This figure shows six different individual jewelled geckos in order to illustrate individual variation in appearance. Note the vastly differing patterns between the individual geckos, the missing tail on d) and the T-shaped scar on c).

3.3 Results

NGLR

Twelve specific one hour thorough searches of the entire reserve were undertaken. Eight of these searches were undertaken in November and the remaining four in February and March. All searches were undertaken by the author with help from Alf Webb on a few occasions. In addition to the twelve specific searches, the reserve was also visited on an additional 17 occasions between October 26th and March 25th during the lagomorph survey, tracking tunnel surveys, vegetation survey and working bees. Although, the specific purpose of these visits was not to search for jewelled geckos, the *Coprosma* was often casually searched whilst travelling around the reserve. During all searches and visits to the reserve no jewelled geckos were sighted either in the reserve or around its boundaries by anyone present. Therefore I am reasonable confident that there are either none (or very few) jewelled geckos in the reserve or around its boundaries, even though there is still a lot of potential habitat (e.g. *C. propinqua*). During this time searches were also done at another site on the Otago Peninsula with a significant population of jewelled geckos to practice sighting and check if the gecko were out basking in the same conditions as when the reserve was searched. In contrast to the reserve, jewelled geckos were seen at this site on every visit.

Roadside

Attempted to survey this area on a few occasions from below the drive right across towards Dunedin along a steep hill/cliff face. There are several isolated patches of *Coprosma* here but most of it is growing on steep ground which is very difficult to access and therefore survey. There is also a lot of thick scrub which makes it difficult to reach the patches of *Coprosma* without making a lot of noise. There may potentially be jewelled geckos along the roadside, but I was unable to locate any.

Neighbour #1

I undertook five thorough searches on Neighbour #1's land close to the access drive. The land is overgrown with rank grass similar to that inside the reserve; however there is a reasonable amount of habitat (e.g. *C. propinqua*). There is also a large amount of gorse, in which jewelled geckos have been previously sighted (Alison Cree *pers. comm.*). No jewelled geckos were sighted here.

Neighbour #2

Little suitable habitat as most of the land is pasture, no jewelled geckos sighted.

Neighbour #3: The hilltop site

I found a jewelled gecko population in an area of small clumps of *Coprosma sp.* on Neighbour #3's land about 150m from the reserve boundary. A total of 28 searches where undertaken here between the 10th of November and the 4th of March. From these searches a total of 18 individual jewelled geckos were identified through photography. All jewelled gecko were observed on *Coprosma* sp. except a few individuals which were recorded on the semi parasitic native mistletoe, *Ileostylus micranthus*, which grows in association with *Coprosma*. To date, the population consists of 6 adults (3 females (all gravid) and 3 males), 4 sub-adults (3 males, 1 unknown) and 8 juveniles (sex unknown). The area where this population was found was being grazed by sheep until approximately one year ago. The results from all searches at the hilltop site are shown in figure 7.

Neighbour #3: Fence-line:

Along the fence-line between the reserve and the population on the hilltop there are a few small isolated clumps of *Coprosma* amongst other trees such as Ngaio and halls totara. This area was regularly searched on the way to the hilltop site. No jewelled geckos were ever seen along this fence line either in the totata, *Muehlenbeckia* or *Coprosma* sp. despite regular searches until the 2nd of March when a gravid adult female was discovered in the *Coprosma*. It was then re-sighted in the same location the following day. This gecko was sighted 110m from the reserve boundary and has never been observed at the hilltop site. As the fence-line area was routinely searched it is felt that this individual was not present here during the whole study. It is unknown where this gecko came from, but it provides hope that there may be more in this area, especially since she was gravid. This provides hope for future re-colonisation of the reserve, although the sighting was still a significant distance from the boundary.

Neighbour #3: Gully

This area was searched 3 times without seeing any geckos in November. However, it was decided to have one last look in this area before the completion of the study. This proved worthwhile as a further population may have been discovered in the process. Two gravid adult females and an adult male were sighted here on the 4th of March in a small group of

Coprosma sp. in the lower gully. There are likely to be more jewelled geckos here due to the presence of two gravid females and they may be present in the gorse which covers the majority of the gully. The area where this population was found was being grazed by sheep until approximately one year ago.

Summary

A total of 22 jewelled geckos were discovered in three separate areas. These consist of 18 on the hilltop, 3 in the gully and one along the fence-line on Neighbour #3's land. Every effort was made to identify as many individuals as possible. Details from photography and/or observation were recorded about each sighted individual in Table 1 below.

Table 1. This table shows in each column from left to right: the site each gecko was found in, identification number, life history stage (lhs), sex (male, female or gravid female e.g. F (G)), number of locations found in (loc), injuries (inj), number of times sighted out of 28 visits (X), and total percentage of times sighted (X%).

Site	#	lhs	Sex	loc	Pattern/colour	inj	X	X%
Hilltop	1	A	M	2	Diamond		5	0.18
Hilltop	2	SA	M	3	yellow lines	no tail	8	0.29
Hilltop	3	A	M	2	cream lines, brown speckles		9	0.32
Hilltop	4	A	F (G)	1	yellow lines, spots down middle		14	0.50
Hilltop	5	A	M	3	cream linked diamonds	reg. tail	8	0.29
Hilltop	6	A	F (G)	2	yellow lines, white head markings		19	0.68
Hilltop	7	J		2	yellow lines		14	0.50
Hilltop	8	SA	?	1	faint yellow lines, break in middle		6	0.21
Hilltop	9	J		1	brown diamonds		3	0.11
Hilltop	10	SA	M	3	cream diamonds with black dots	reg. tail	7	0.25
Hilltop	11	A	F (G)	1	yellow lines, black square patch		11	0.39
Hilltop	12	J		1	light brown diamonds		2	0.07
Hilltop	13	J		1	small light brown diamonds		6	0.21
Hilltop	14	J		1	light brown lines		2	0.07
Hilltop	15	J		1	light brown diamonds		4	0.14
Hilltop	16	J		1	dark brown diamonds		1	0.04
Hilltop	17	J		1	yellow lines, black head mark		4	0.14
Hilltop	18	SA	M	2	yellow lines, dark outline		7	0.25
Fence-line	1	A	F (G)	1	linked diamonds looks old		2	0.07
Gully	1	A	F (G)	1	yellow diamonds some linked		1	0.25
Gully	2	A	F (G)	1	thick yellow lines dark outline		1	0.25
Gully	3	A	M	1	linked diamonds brown speckles		1	0.25

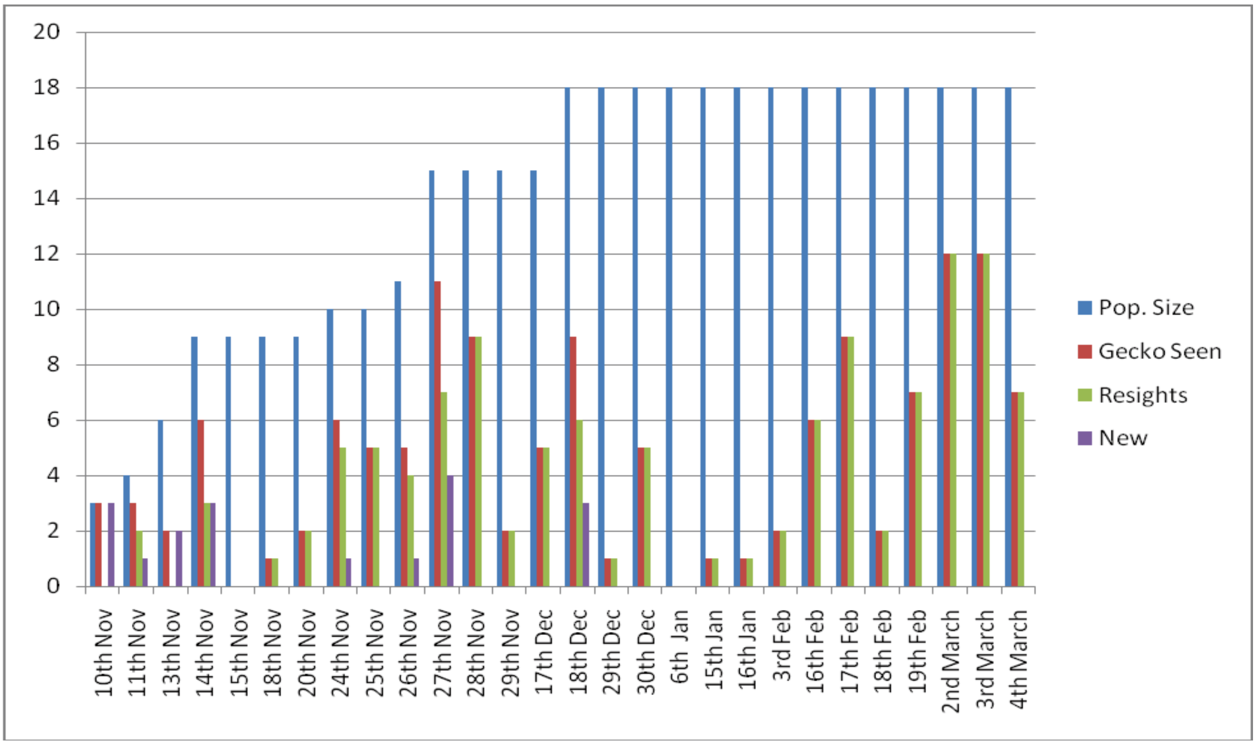

Fig. 7. This figure shows the results from the 28 searches undertaken at the hilltop site. The number of individual jewelled geckos is shown on the y-axis. The total known population size is shown by the blue bars and increases over time as more individuals are discovered. The red bar shows the number of jewelled geckos seen in each survey. The green bar shows the number of jewelled geckos seen in each survey which have already been sighted previously and the purple bar shows the number of new individuals which have not been previously sighted per survey.

3.4 Population size estimate for the hilltop site using the Lincoln Petersen method

Enough sightings occurred at the hilltop site to allow a population size estimate to be calculated using the Lincoln Petersen method (see below).

$$N = \frac{(M+1)(C+1)}{R+1} - 1,$$

where,

N = Estimate of total population size
M = Total number of animals captured and marked on the first visit
C = Total number of animals captured on the second visit
R = Number of animals captured on the first visit that were then recaptured on the second visit

An approximately unbiased variance of N, or var(N), can be estimated as:

$$\mathrm{var}(N) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)(R+1)(R+2)}.$$

During this study the first half of the 28 visits to the hilltop site can be used as the mark (M) and the second half the capture (C). During the first 14 visits, a total of 15 individuals were identified and photographed. Therefore the mark (M) =15. During the second 14 visits, 16 individual jewelled geckos were photographed. Therefore 16 were captured (C) = 16. The number of animals captured on the first 14 visits that were then recaptured on the second 14 visits was 13. Therefore R =13.

Population size estimate for the hilltop site using the Lincoln Petersen method

$$N = \frac{(M+1)(C+1)}{R+1} - 1,$$

where,

N = Estimate of total population size
M = 15
C = 16
R = 13

N = ((15+1) (16+1) / 13+1) - 1 = 18

The population estimate for the hilltop site = 18

An approximately unbiased variance of N, or var (N), can be estimated as:

$$\mathrm{var}(N) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)(R+1)(R+2)}.$$

var (N) = 0.56

It has been suggested that this estimate should be calculated separately for the different age groups and sexes (e.g. juveniles, sub-adults, adult males and adult females) and then the results combined (Shaw, 1994) as emergence behaviour and therefore probability of sighting is likely to differ with age and sex (see Duggan, 1991). This was done, but the estimate of population size still came to 18.

3.7 Discussion

All jewelled geckos observed during this study were found on *Coprosma* sp. or native mistletoe, *Ileostylus micranthus*. Jewelled geckos are known to use other species which were present in the study area including *Muehlenbeckia*, halls totara and occasionally gorse and Macrocarpa. Attempts were made to search these plants but no jewelled geckos were sighted. There may however, still be jewelled geckos occupying some or all of these species. Halls totara and Macrocarpa are difficult to search because of their height. A couple of attempts were made to survey the Macrocarpas below the reserve for the presence of jewelled geckos or silhouettes high above the ground, however nothing was seen. It is thought that if jewelled geckos are present in species other than *Coprosma* sp. in the area they are likely to be at low densities as none were seen during the study. Shaw (1994) also only sighted jewelled geckos in *Coprosma* sp. in the reserve and surrounding area. However jewelled geckos have been observed several years ago in the Macrocarpa on one occasion (Graeme Loh *pers. comm.*) and the gorse on Neighbour #1's property (Alison Cree *pers. comm.*).

The Lincoln Petersen estimate of population size at the hilltop, gave an estimate of 18 individuals (e.g. the exact same number as were identified from photography). If there are any individuals here who were not seen during this study, they are most likely to be juveniles. This is because of their lower probability of being emergent (e.g. basking) and higher conspicuousness. Due to the small area of habitat (~0.25ha), I believe all the adults were likely to have been identified. The fact that all adults identified were seen between 5 and 19 times (out of 28 visits) supports this (see Table 1). In contrast juveniles were sighted much more irregularly (between 1 and 14 times) (see Table 1).

Every effort was made to ensure as many individuals were identified as possible, however it is likely that there will be several individual geckos (in the areas in which jewelled geckos were found during this study and/or in other areas) that have not yet been discovered and photographed to date. This is likely to be the case, due to the erratic and unpredictable emergence behaviour shown by jewelled geckos as well as individual variation in preferred basking sites, vegetation and times. For example, some individuals may regularly bask in sites which are out of view or difficult for the searcher to scan (e.g. above head height). In addition some areas such as the road side were extremely steep and therefore difficult to survey.

Emergence Behaviour

Due to the erratic emergence behaviour of jewelled geckos, some individuals were sighted much more than others. Emergence behaviour was shown to differ markedly with sex and life history stage. The average probability of sighting an individual gravid female was 0.5 (n=3), compared to 0.26 for adult males (n=3), 0.22 for sub-adults (n=4) and 0.11 for juveniles (n=8). Despite the small sample sizes, these findings are consistent with those found by Duggan (1991) who studied the emergence behaviour of jewelled geckos at the NGLR. This study found that in spring, females were emerged significantly more frequently than males, and adults were seen with significantly greater frequency than juveniles (Duggan, 1991).

The individual who was sighted most often (19 out of 28 visits or 68% of visits) was a pregnant female (see #6 in table #1). Females appeared to bask in a much wider range of weather conditions. Females were often visible on cooler days with full or partial cloud cover as well as warm sunny days, whereas males and juveniles were usually only seen during warm sunny days (*pers. obs.*). The lower number of juveniles sighted may potentially be influenced by their small size which is likely to result in a lower probability of detection during surveys. However some juveniles were regularly sighted (e.g. No. 7, Table 1). This juvenile was sighted on 14 of 28 visits. Therefore it may be that emergence varies substantially between individuals as well as between life history stage and sex.

Emergence behaviour of *N. gemmeus* also appears to be related to season with much more individuals basking, and therefore visible, in spring and autumn as opposed to summer (Duggan, 1991, *pers. obs.*). It may be that it is not necessary for jewelled geckos to bask as often in the summer due to the abundance of solar radiation. In addition, it may not be necessary for jewelled geckos to bask right at the surface of the *Coprosma* because solar radiation from the sun may penetrate further into the *Coprosma* and therefore sufficient energy can be obtained by basking a short distance below the surface of the vegetation and therefore out of view.

Jewelled gecko movements

Jewelled geckos were found to occasionally move between bushes. This was especially prevalent in adult and sub-adult males and less prevalent for females and juveniles. Jewelled gecko movements were usually small and ranged from less than a metre to a maximum of 28m. This distance was recorded by an adult male, which was observed in one bush and then another 28 metres away a few days later. This is similar to the results found by others (e.g. Shaw, 1994) who found a maximum movement of 27m at the NGLR by an adult male from 194 fixes (61 individuals). In addition Schneyer (2001) documented a maximum movement of 44m. Recently, Webb and Rufaut (2008) recorded a maximum movement of 70m, which is the largest recorded movement for an individual jewelled gecko to date on the Otago Peninsula. Jewelled geckos were found to move across pasture or bare ground in order to move from one *Coprosma* bush to another, which has been commonly observed in other studies (e.g. Shaw, 1994; Schneyer, 2001; Webb and Rufaut 2008).

Advantages and limitations of visual searching and photo-identification

The method used during jewelled gecko searches in this study was visually searching the vegetation and identifying individuals via photo-identification. This method has several advantages. Firstly, the method is almost completely non-invasive and is undoubtedly far less invasive than other methods commonly used for identifying individual lizards in a population such as mark-recapture using artificial marks (see Shaw, 1994) or toe clipping (see Wilson *et al.* 2007). Photo-identification eliminates the need to handle jewelled geckos. If care is taken, good photographs can be taken from a distance whilst jewelled geckos are basking without disruption. A good digital camera which can take clear close up photos with an optical zoom of 10X or more is recommended. This study along with others (e.g. Webb & Rufaut, 2008) show that photo-identification is adequate to differentiate between individual jewelled geckos.

Photography of natural markings or features has been successfully used to estimate population size via individual recognition in many other species (e.g. fin shape in bottlenose dolphin in doubtful sound (Currey *et al.* 2007), the pineal spot on leatherback sea turtles (Buonantony, 2008) and dark pigmented patterns found on the skin of Hamilton's frog (*Leiopelma hamiltoni*) (Webster, 2004)).

Both the method of searching used and photo-identification also have several disadvantages or limitations. Firstly the method of searching favours *Coprosma* sp. and the majority of search effort involved this habitat. However, jewelled geckos were only seen in *Coprosma* sp. and an attempt was made to search other vegetation types. Another limitation is that visual searching and photo-identification is weather and season dependent. As a result, assessments of jewelled gecko populations using photo-identification are best undertaken on warm sunny mornings with low relative humidity in either spring or autumn when more jewelled geckos are likely to be emergent. Alternative methods such as the use of Artificial

Retreats (AR's) (see Muller, *in prep.*) may increase the range of weather conditions in which jewelled geckos can be detected.

Another disadvantage is that mistakes may still potentially occur (e.g. mistaken identity) which are much less likely when permanent markers are used. Mistakes are potentially eliminated altogether using methods such as toe-clipping or other forms of artificial marking. However, these methods involve catching and marking individual jewelled geckos which may potentially have detrimental consequences for individual survival. As most jewelled gecko populations on the Otago Peninsula are small (e.g. less than 100 individuals), less intrusive methods are encouraged. When using photo-identification any potential loss in accuracy is made up for by the lower intrusiveness of the method.

Photo-identification relies on high quality photographs and photographs are taken on an opportunistic basis. The quality of photographs which are able to be obtained is influenced by the position in the vegetation in which the individual is basking. Therefore, high quality photographs are sometimes unable to be obtained when an individual is sighted (for instance the individual may be partially buried in the vegetation, basking above head height or in a position which is difficult to view). Identification often depends on obtaining clear photographs from several different angles to maximise the probability of correct identification which can sometimes be difficult. The amount of time spent and difficulty involved in identifying individuals from a population is likely to increase with population size.

Recommendations for future monitoring

Future monitoring of jewelled geckos in the area is highly recommended using photo-identification. This can be used to monitor the jewelled geckos at the hilltop site to determine whether the population is increasing, decreasing or remaining stable. Even though, no jewelled geckos were sighted in the NGL reserve during this study, it is vital that the reserve continues to be monitored to see if any re-colonisation occurs. In theory, the manipulations that have taken place at the NGLR have made the reserve more suitable for the persistence of jewelled geckos. Therefore the manipulations may have significantly increased the chances of re-colonisation. If re-colonisation occurs, successful re-establishment of a population of jewelled geckos may depend on the continued control of rank grass and weeds which are out-competing or out-shading jewelled gecko habitat.

Use of AR's may be useful to determine if any jewelled geckos are still present in the NGLR or re-colonise the reserve in the future.

4.0 Lagomorph survey

4.1 Aim

Estimate the density and abundance of lagomorphs in the NGLR before and after the breach of the fence in order to access the effect of breaching the fence on lagomorph density and abundance.

4.2 Method

An estimate of the density and abundance of lagomorphs (European rabbits, *Oryctolagus cuniculus* and hares, *Lepus eurapoeus*) in the NGLR was determined before and after the fence was breached. To achieve this, pellet counts were used. Fecal pellet counting has been widely used to index or estimate the abundance of lagomorphs and ungulates. Pellet counting provides an economic and efficient estimate that is well suited to long-term population monitoring (Forys & Humphrey, 1997).

Rabbits and hares may both be present in the reserve and may differ in their abundance and distribution within the reserve; however only rabbits have been sighted in the reserve to date (*pers. obs.*). There was no attempt to distinguish between rabbit and hare pellets because rabbit and hare pellets are very similar in appearance. In fact, captive hares and rabbits on the same diet produce identical pellets (Flux, 1990). Furthermore, their effects on *Coprosma* are believed to be similar, therefore for the purposes of this study it was not vital to distinguish between the two species.

To estimate lagomorph density using pellet counting, the cleared plot method was used. In this method, pellet sampling grids of permanent markers are laid, the pellets around a set instance from each marker are removed, and then new pellets are counted after a specified amount of time (see Forys & Humphrey, 1997).

Firstly, a square grid was constructed around the reserve. Thereafter co-ordinates in metres (North and East) were randomly selected using a random number generator on a calculator to prevent bias. Any co-ordinates within the square grid, which lay outside the reserve boundaries, were ignored. To begin with, the co-ordinates of the centre of the first plot were calculated. If this co-ordinate landed in an area where lagomorph pellets were present within the reserve, then this co-ordinate was used for the survey. This procedure was repeated until twenty plots containing lagomorph pellets were selected.

An estimate of the proportion of the reserve containing lagomorph pellets was obtained by dividing the total number of co-ordinates calculated within the reserve boundaries by twenty (e.g. the number containing lagomorph pellets). This estimate was vital when calculating the estimated lagomorph density and abundance (see results). The centre of each of the twenty circular plots was marked using numbered pegs.

Once all plot locations were marked, all lagomorph pellets were removed from each circle within a 0.5 metre radius. After this, the circular plots were left alone for a two week period in order to allow lagomorphs to dispatch fresh pellets in each circle. In a study by Forys & Humphrey (1997) it was found that pellets of the endangered Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*) began to disappear off a metal grid 7 weeks after defecation, indicating that any sampling period less than 7 weeks should suffice for density estimation based on pellet counts. In this study, two weeks was considered to be enough time for a sufficient number of pellets to accumulate in the circular plots to allow density estimation. After two weeks, the number of new pellets was counted in each circle. This allowed an estimate of the density and abundance of lagomorphs in the reserve to be calculated. The calculations and steps required to do this will be outlined in the results section.

After the fence was breached on the 31st of January, the density of lagomorphs in the NGLR was re-examined using the same methods as was used before the manipulations. 17 days later, on the 17th of February, the plots were re-cleared and left for 2 weeks as was done before the fence was breached. This was thought to be enough time for the lagomorphs to discover that they could leave the reserve if they chose to do so. The effect of breaching the fence on the abundance and density of lagomorphs in the NGLR could then be determined by comparing the data collected before and after the fence was breached.

4.3 Results

Data were collected before and after the fence was breached using the cleared plot method on the number of pellets in each of twenty circular quadrats. After this, it was necessary to convert this data into an estimate of density and abundance.

To calculate density and abundance, it is necessary to obtain an estimate of the average number of pellets defecated per day. Due to their larger size and food intake hares excrete significantly more pellets per day than rabbits. Therefore in this study, the density and abundance values were calculated separately for both rabbits and hares. The average number of pellets defecated per hare per day was taken from a study on hare numbers and diet in an alpine basin in New Zealand and was 410 (see Flux, 1967). Whereas for rabbits, the study on the Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*) by Forys & Humphrey (1997) found an average of 137 pellets were defecated per day. No information was available on the average defecation rate of the European rabbit, *Oryctolagus cuniculus.*

It can be seen that rabbits and hares vary greatly in their defecation rate with rabbits releasing approximately 137 pellets per day and hares approximately 410 pellets per day. Below is an outline showing how the density and abundance estimates were calculated for both rabbits and hares separately. Table 2 shows a summary of the density and abundance estimates for both rabbits and hares before and after the fence was breached.

Before the fence was breached: lagomorph density and abundance

1 hectare = 10,000m²
0.852 hectare = 8520m² (size of reserve)
After 93 randomly selected plots in the reserve, 20 had lagomorph pellets.
Therefore 20/93 x 100 = 22%
22% of the reserve contains lagomorph pellets
8520m² x 22% = 1874.40m²
Area which pellets cover in reserve = 1874.40m²
Lagomorph survey found 955 pellets from 20 circular quadrats with 0.5m radius (r = 0.5)
Area of each quadrat = πr^2
$= \pi \times 0.5^2$
$= 0.785m^2$
20 quadrats x 0.785m² = 15.7m²
Total area surveyed = 15.7m²
Therefore 955 pellets per 15.7m²
1874.40m²/15.7m² = 119.39
Therefore 955 x 119.39 = 114,017
Therefore an estimated 114,017 pellets were dispatched over the reserve over 14 days.

Working for rabbits

Average rabbit dispatches 137 pellets per day
Survey went for 14 days
Therefore 137 x 14 = 1918
1918 pellets per rabbit over 14 days
114,017 / 1918 = 59

Abundance estimate = 59 rabbits

Density = 59 rabbits per 0.852 hectares
1 / 0.852 = 1.174
59 x 1.174 = 69

Density estimate = 69 rabbits / hectare

Working for hares

Average hare dispatches 410 pellets per day
Survey went for 14 days
Therefore 410 x 14 = 5740
5740 pellets per hare over 14 days
114,017 / 5740 = 20

Abundance estimate = 20 hares

Density = 20 hares per 0.852 hectares
1 / 0.852 = 1.174
20 x 1.174 = 23

Density estimate = 23 hares / hectare

After the fence was breached: lagomorph density and abundance

The same 20 circular plots were used as this was thought to provide a better comparison and lagomorph pellets were present in all of these plots prior to pellet removal

0.852 hectare = 8520m² (size of reserve)
22% of the reserve contains lagomorph pellets
8520m² x 22% = 1874.40m²
Area which pellets cover in reserve = 1874.40m²
Lagomorph survey found 558 pellets from 20 circular quadrats with 0.5m radius (r = 0.5)
Area of each quadrat = πr^2
$= \pi \times 0.5^2$
$= 0.785m^2$
20 quadrats x 0.785m² = 15.7m²
Total area surveyed = 15.7m²
Therefore 588 pellets per 15.7m²
1874.40m²/15.7m² = 119.39
Therefore 588 x 119.39 = 70,201

Therefore an estimated 70,201 pellets were dispatched in the reserve over 14 days

Working for rabbits

Average rabbit dispatches 137 pellets per day
Survey went for 14 days
Therefore 137 x 14 = 1918

1918 pellets per rabbit over 14 days
70,201 / 1,918 = 37

Abundance estimate = 37 rabbits

Density = 37 rabbits per 0.852 hectares
1 / 0.852 = 1.174
37 x 1.174 = 43

Density estimate = 43 rabbits / hectare

Working for hares

Average hare dispatches 410 pellets per day
Survey went for 14 days
Therefore 410 x 14 = 5,740
5,740 pellets per hare over 14 days
70,201 / 5,740 = 12

Abundance estimate = 12 hares

Density = 12 hares per 0.852 hectares
1 / 0.852 = 1.174
12 x 1.174 = 14

Density estimate = 14 hares / hectare

Table 2. This table shows the abundance and density estimates for both rabbits and hares before and after the fence was breached. This equates to a 37% reduction in lagomorph abundance/density after the fence was breached on January 31st.

Manipulation	Rabbit abundance est.	Rabbit density est.	Hare abundance est.	Hare density est.
Before	59	69/ha	20	23/ha
After	37	43/ha	12	14/ha

4.4 Discussion

Before: lagomorph density and abundance

This study resulted in an abundance estimate of 59 rabbits or 20 hares before the fence was breached. If rabbits and hares are both present in the reserve, the total estimated number of lagomorphs (e.g. rabbits and hares) will be somewhere between 20 and 59 depending on the proportion of each species. A density estimate of 69 rabbits per hectare or 23 hares per hectare was also calculated.

These density estimates appear high when compared to the density of lagomorphs found in other studies in the wild. For example, at a 1000-ha site in the Mackenzie Basin, Moller *et al.* (1997) reported the average density of rabbits as 19.4 per hectare and a maximum density of 52 per hectare (range 2-52, between 26 quadrats of 1 ha). Prior to rabbit control undertaken in 2000, lagomorphs were thought to have reached unnaturally high densities due to being trapped within the reserve fence (L. Frazer, *pers. comm.*). Before the fence was breached, this may have been beginning to occur again as the density of lagomorphs appears to be much higher than that commonly found in the wild.

After: lagomorph density and abundance

One of the aims of the manipulations was to breach the fence and thereby reduce lagomorph densities and prevent continuing damage and loss of *Coprosma* sp. habitat via ring-barking and browsing of seedlings.

After the fence was breached an abundance estimate of 37 rabbits or 12 hares was calculated. A density estimate of 43 rabbits per hectare or 14 hares per hectare was also calculated. This equates to a 37% reduction in lagomorph abundance and density after the fence was breached on January 31st. Therefore it appears that breaching the fence was successful in reducing lagomorph abundance. The after manipulation density estimates are in the range of those found in the Mackenzie Basin by Moller *et al.* (1997) (e.g. range 2-52, between 26 quadrats of 1 ha). However, they are still higher than the average density of rabbits found by Moller *et al.* (1997) (e.g. 19.4 per hectare). The reduction in lagomorph density may be enough to reduce the level of damage caused to the *Coprosma* sp. shrubs; however it may not prevent damage altogether. Damage to *Coprosma* sp. seedlings and ring-barking has been observed at other un-fenced sites where lagomorph density is thought to be high (*pers. obs.*).

Advantages and limitations of the cleared plot method

Advantages of the cleared plot method include that the method is quick, in-expensive, non-invasive and suitable for long-term population monitoring. Although live-trapping may have a higher correlation with actual population density, pellet counting provides an economic and efficient estimate that is well suited to long-term population monitoring (Forys & Humphrey, 1997). The study by Forys & Humphrey (1997) found significant correlations between pellet counting and radio-telemetry estimates ($r2 = 0.89$, $P < 0.0001$). In the study by Forys & Humphrey (1997), pellet-counting estimates took 80% less time to perform than live-trapping estimates.

There are also many limitations involved in using the cleared plot method. Firstly, it was not possible to distinguish between rabbits and hares as their pellets are often indistinguishable from each other (Flux, 1990). Only rabbits were seen in the reserve; however it is possible that hares were also present. During the survey it was often difficult to find and clear all the pellets from each plot during the set up because of the long grass. In addition, the same difficulty was encountered when all the pellets in the quadrats were counted two weeks later. This may have resulted in the number of pellets in each plot being overestimated (e.g. if all pellets were not cleared during the set up) or underestimated (if all pellets were not counted in the plot two weeks later). This may have resulted in either an over or under-estimate of abundance and density. However as care was taken, both when clearing the plots and when counting the pellets any errors are thought to be minor.

The estimates of lagomorph abundance and density are based on several extrapolations and the accuracy of these abundance and density estimates is difficult to determine. To achieve, a more accurate estimate of lagomorph density and abundance, more surveys could have been undertaken and then an average calculated with a measure of uncertainty (e.g. standard error). However, this was not possible in this study due to time constraints. As the same method was used before and after the manipulations, it is felt that the calculated reduction in density and abundance is likely to be comparable to what has occurred in reality. A noticeable reduction in the number of rabbits sighted in the reserve was also observed (*pers. obs.*). One potential problem with the observed reduction in lagomorph abundance is that it is not possible to isolate the effect of season from the effect of breaching the fence (e.g. the observed reduction in lagomorph abundance may be related to season).

Recommendations for future monitoring

Future monitoring of lagomorph abundance at the NGL reserve could be undertaken to test how the removal of rank grass / introduction of sheep, affects lagomorph density. It is possible that lagomorphs may now no longer pose a significant threat to jewelled gecko habitat (e.g. *Coprosma* sp.) now that the fence has been breached and density presumably reduced. However, it will be important to continually monitor the state of the *Coprosma* to determine whether damage from lagomorphs is still occurring, despite the fence being breached.

5.0 Assessment of rodent and mustelid activity

5.1 Aim

Determine the distribution and activity of mammalian predators (rodents and mustelids) in the NGLR and outside around its boundaries in order to provide a baseline for future comparisons.

5.2 Method

The distribution and activity of mammalian predators (rodents and mustelids) in and around the NGLR was assessed. Mammalian predators known to be present, or potentially present, in and around the NGLR included the house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), ship rat (*R. rattus*), weasel (*Mustela nivalis vulgaris*), stoat (*Mustela ermina*), ferret (*M. furo*), European hedgehog (*Erinaceus europaeus*), brush-tail possum (*Trichosurus vulpecula*) and feral cat (*Felix catus*). The presence of all these predators can potentially be recorded using tracking tunnels; however the tunnels are best suited for monitoring rodent or mustelid activity (Gillies & Williams, 2008a). To detect the presence or absence and to estimate the activity of these predators, tracking tunnels were used. The tracks of all these mammals are recognisable from each other; however it is not possible to distinguish between the two different species of rat.

Tracking tunnels are commonly used in New Zealand as a method of indexing rodent and mustelid abundance (Gillies & Williams, 2008a). The technique uses a “run through” tunnel (see *fig.* 8.) containing two pieces of paper either side of a sponge soaked with a tracking medium (food colouring). As an animal passes through the tunnel it picks up the tracking medium on its feet, then as it departs from the tunnel it leaves a set of footprints on the papers (Gillies & Williams, 2008a). In this study, the methods set out for surveying rodent and mustelid numbers using tracking tunnels as outlined by Gillies & Williams (2008a) were followed.

Before this study began, seven tracking tunnels were already present in the reserve and a further seven around its boundaries. These tracking tunnels were set out in a range of environments and all are at least 50 metres apart in accordance with the regulations set out by Gillies & Williams (2008a). The tunnels are spaced this distance apart in order to prevent single animals passing through multiple tunnels.

Surveys were completed only, over periods of fine weather lasting at least two days and one night. This was done in order to prevent the tracking tunnel papers becoming wet and the ink running as can happen during rain. At the commencement of each survey the papers were inserted into the tunnels and all tunnels were baited with a generous ~ 3 - 4 cm sized blob of peanut butter at both ends of the tunnel. The papers were then left overnight and collected the next day carefully recording the tunnel number from which they came. All left over bait was removed from the tunnels in order to prevent habituation (the animals habitually passing through the tunnels).

Once the papers were collected, all papers were analysed and all footprints identified using the footprint identification guide by Gillies & Williams (2008b). Following this, an activity index (or tracking rate) was calculated for each animal in each area after each tracking tunnel survey. This was done by dividing how many tunnels had that particular animals tracks on by the total number of tunnels in the area and multiplying by 100 (e.g. if mice tracks were present on 4 tunnels then: 4 / 7 x 100 = 57%). When appropriate the number of tunnels was adjusted for possum disturbance (see Gillies & Williams 2008a for more details).

Fig. 8.

One of the tracking tunnels used to examine the activity of rodents and mustelids. The tracking paper is inserted over the wooden base. The wire is used to hold the tracking tunnel in place and prevent animal disturbance.

Photo: Carey Knox

5.3 Results

After the discovery of the population at the hilltop site, it was decided to compare the activity of mammalian predators in this area with the other two sites. This was because it was thought useful to see if there was a correlation between the activity of mammalian predators and jewelled gecko numbers (e.g. the higher the activity of mammalian predators, the less jewelled geckos present). Therefore it was hypothesized that the activity of rodents and mustelids would be significantly lower at the hilltop site compared to the other two sites.

Initially the tracking tunnels from outside the reserve were moved to the hilltop site which was then compared to inside the reserve in surveys 2 and 3. However, after a request at the local Dunedin DoC office, another seven tracking tunnels became available for this study. This enabled all three areas to be compared simultaneously during tracking tunnel surveys 4 - 8. A total of 8 surveys were undertaken at the reserve (NGLR), 6 outside the boundaries of the reserve (outside) and 6 at the hilltop site (BO). In addition, the results of a tracking tunnel survey undertaken in June were also available. This resulted in nine tracking tunnel surveys available for analysis. Table 3 below shows which areas each of the surveys compared. All tracking tunnel surveys were spaced apart by at least one week in order to prevent or reduce habituation.

A summary of the average tracking rates with standard error for each animal present in each area is shown below in Table 4. This is also shown for the animals considered to be potential jewelled gecko predators in a bar graph with standard error bars (see *fig.* 9). The effect of season on rodent and mustelid activity can be seen in figure 10 which shows the activity index for mice, rats, ferrets and stoats from each survey at each site. Rodent activity increases over the summer at all three sites. There are no clear patterns regarding mustelid activity.

Table 3. This table shows which areas each of the tracking tunnel surveys compared, along with the date of each survey.

Survey Number	Date	NGLR	Outside	The hilltop site
June	June	+	+	
1	Nov-13	+	+	
2	Nov-20	+		+
3	Nov-27	+		+
4	Dec-19	+	+	+
5	Jan-06	+	+	+
6	Jan-15	+	+	+
7	Feb-16	+	+	+
8	Mar-03	+	+	+

Table 4. The average tracking rate or Mean Activity Index (M.I.A (%)) for each animal in each area during the tracking tunnel surveys.

Animal	Location		
	NGLR	Outside	The hilltop site
	M.A.I (%)	M.A.I (%)	M.A.I (%)
Mice	81 (±8)	59 (±10)	15 (±7)
Rats	54 (±11)	54 (±15)	8 (±5)
Ferrets	11 (±6)	8 (±6)	2 (±2)
Stoats	2 (±2)	5 (±3)	13 (±6)
Weasels	4 (±4)	0	0
Possums	27 (±9)	10 (±8)	21 (±7)
Hedgehogs	0	6 (±3)	13 (±6)
Skinks	3 (±2)	4 (±3)	6 (±4)
Insects	13 (±6)	19 (±8)	26 (±5)

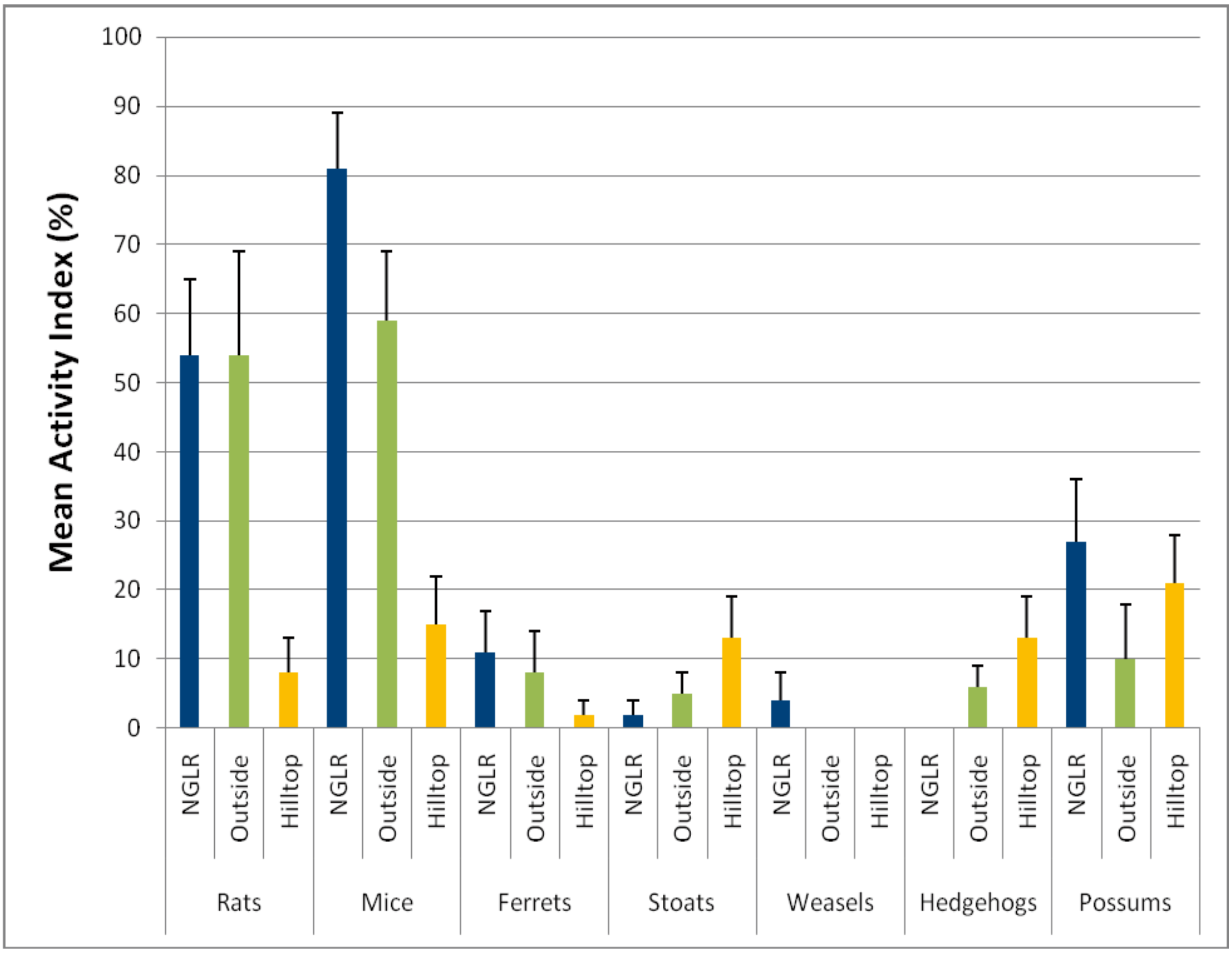

Fig. 9. This figure shows the mean activity index (%) with standard error for the animals considered to be potential jewelled gecko predators at each of the three sites.

(a) NGLR

(b) Outside

(c) The hilltop

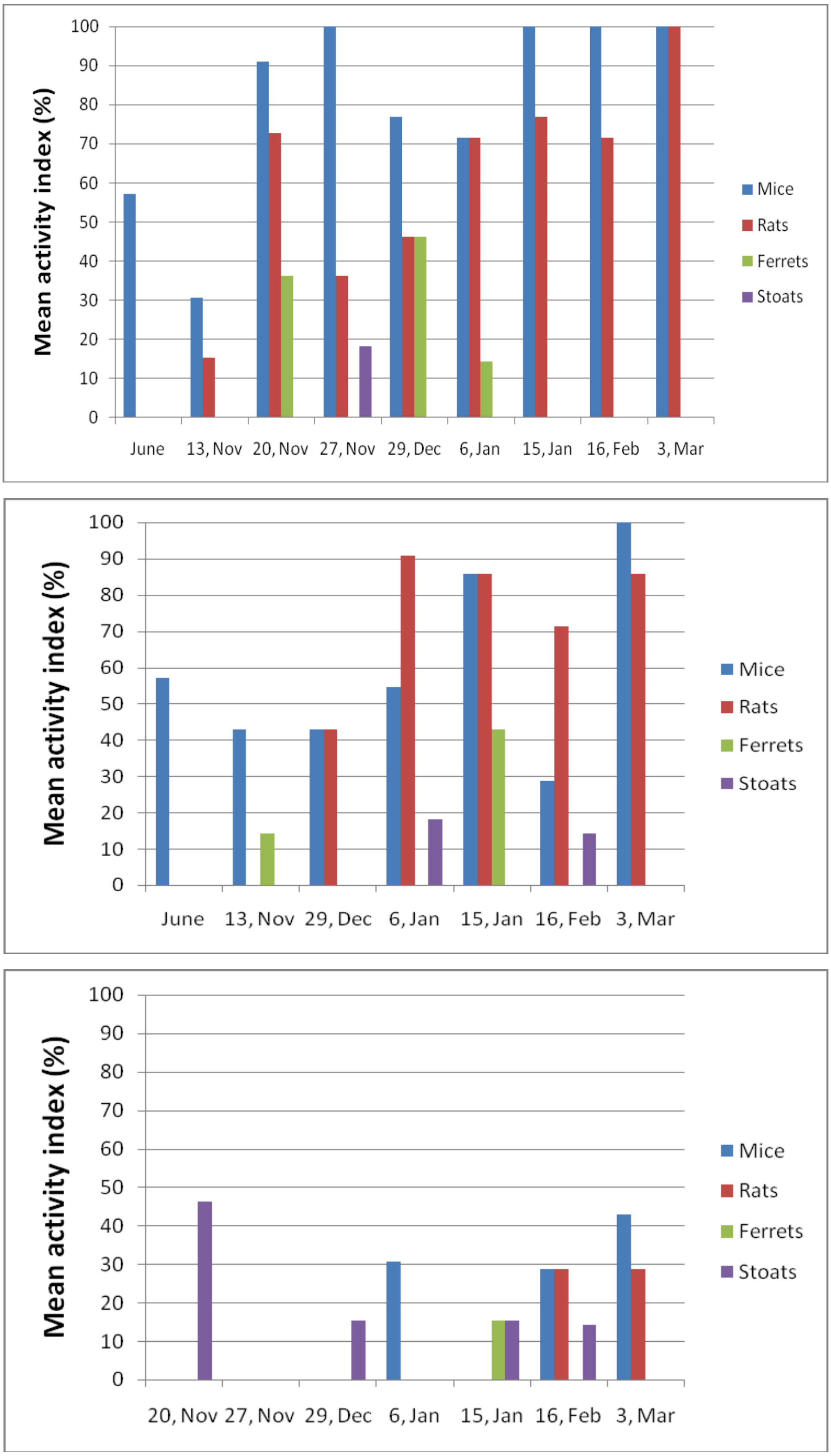

Fig. 10. The mean activity index (%) during each of the tracking tunnel surveys at each of the three sites: (a) NGLR, (b) Outside and (c) the hilltop.

Differences in rodent and mustelid activity

From table 4 and figure 9, it can be seen that the number of rodents (rats and mice) appears significantly higher in the NGLR and outside as opposed to the hilltop site as predicted. Differences in mustelid numbers between the three sites are less clear. To test whether differences in rodent and mustelid activity between the three sites were statistically significant, a series of t-tests were undertaken. This was done for each of the mammalian predators (mice, rats, ferrets and stoats) as well as for rodents (rats and mice) as a group and mustelids (ferrets and stoats) as a group. Weasels were excluded, as they were only recorded at one of the sites. The tests were two sided because there was no prior reason to be interested in a difference in a particular direction. The 5% (α=0.05) level of significance was used for all tests. Table 5 below shows the results of the t tests with significant differences highlighted.

Table 5. This table shows the results of the t tests with significant differences highlighted.

		Mice	Rats	Rodents	Ferrets	Stoats	Mustelids
NGLR VS Outside	T-Stat	1.750	0.037	1.003	0.302	-0.720	-0.003
	p-value	0.104	0.971	0.325	0.767	0.486	0.998
	Significance	NO	NO	NO	NO	NO	NO
NGLR VS Hilltop	T-Stat	6.145	3.859	6.638	1.334	-1.686	-0.256
	p-value	0.000	0.003	0.000	0.212	0.136	0.800
	Significance	YES	YES	YES	NO	NO	NO
Outside VS Hilltop	T-Stat	3.708	2.846	4.648	0.917	-1.215	-0.251
	p-value	0.003	0.025	0.000	0.386	0.255	0.803
	Significance	YES	YES	YES	NO	NO	NO

The table above shows that the activity of rodents was similar between the NGLR and outside and was statistically non-significant (at α=0.05). In contrast, both NGLR and outside are significantly different to the hilltop site (at α=0.05). This suggests that rodent activity is significantly higher in and outside the reserve compared to at the hilltop site. In contrast there were no significant differences found concerning the activity of mustelids. Therefore there is no statistical evidence of a difference in mustelid activity between the three areas.

5.4 Discussion

Rodent activity

As stated above, rodent activity was significantly higher in and outside the reserve compared to at the hilltop site. This difference between the NGLR and outside and the hilltop site may be related to the past grazing regime at each site. Introduced domestic stock have been absent from the NGLR and outside for 15 years, in contrast to the hilltop site where stock were present until one year ago. In the absence of stock, the grass at the NGLR and outside has become rank, providing an abundant source of food (grass seed) for rodents. Rank grass may also provide shelter for rodents from their predators (e.g. mustelids and feral cats).

Many studies have shown increases in rodent activity and/or density following the removal of domestic stock (e.g. Newman 1994; Alterio & Moller, 1997; Alterio *et al.* 1998; Hoare *et al.* 2007). In addition, other studies have simultaneously compared grazed and un-grazed areas and shown that rodents are much more abundant in areas of rank grass. For example, Ratz (2000) found that mice were recorded 5-17 times more often in un-grazed areas than in grazed areas on the Otago Peninsula.

An example of the effect that large numbers of rodents can have on lizard populations after the removal of grazing stock can be seen on Mana Island (Newman, 1994). The only introduced mammalian species to become established on the Island was the house mouse (*Mus musculus*) and the island holds significant habitat for the threatened goldstripe gecko (*Hoplodactyius chrysosireticus*), and McGregor's skink (*Cyclodina macgregori*). Between 1987/88 and 1988/89 the capture rate (pitfall traps) for McGregor's skink declined significantly and this decline was attributed to increased predation by mice following an increase in numbers after cattle (the only stock present) were removed from the island in 1986 (Newman, 1994). Following removal of cattle, pasture grasses became rank and the mouse population increased dramatically (Hutton, 1990, cited in Newman, 1994).

In response to this, a programme to eradicate mice from the island was planned and successfully executed using aerial and ground distributed anticoagulant baits (Newman, 1994). Since then, the capture rates have increased significantly for both *C. macgregori* and the gecko (*Hoplodactylus maculatus*) (Newman, 1994). In addition, even though individual C. *macgregori* show strong site fidelity and are potentially long-lived (10+ years), only three of 64 caught to April 1988 have been recaptured since the last mouse was trapped (Newman, 1994).

Another example of how retiring coastal grassland from grazing domestic stock has resulted in the decline of a population of endemic lizards can be seen in a study by Hoare *et al.* (2007). In this example, grazing stock was removed from an area containing the last mainland population of the Whitaker's skink (*Cyclodina whitakeri*). A low abundance of Whitaker's skink in the 1980s prompted management recommendations to remove grazing stock to provide protection against introduced mammalian predators. Removing grazing stock did not result in an increased abundance of Whitaker's skink or copper skink (*C. aenea*). Instead, reduced grazing allowed introduced seeding grasses to proliferate, which led to periodic rodent irruptions, supporting a guild of introduced mammalian predators and depleting populations of Whitaker's skink and copper skink (see Hoare *et al.* 2007). In this example, attempted protection may have driven a vulnerable population towards extinction.

These examples show that rodents can have a severe impact on lizard populations via predation when pasture grasses become rank due to a lack of grazing providing an abundant food supply. A similar situation may have also occurred in the NGLR and rodents may have begun to predate heavily on jewelled geckos on an opportunistic basis within the reserve as numbers increased over time. This increase in rodent activity after the removal of grazers is likely to have contributed significantly to the decline in jewelled gecko abundance at the NGLR and the surrounding habitat outside the fenced area. In addition to predation, rodents may also damage vegetation and compete with jewelled geckos for food e.g. fruit and/or insects. When the fence was first built the impact of rodents on jewelled gecko was largely unknown and is thought to have been underestimated.

In contrast to the NGLR and outside, domestic stock have only been absent from the hilltop site for one year. Currently there appears to be a high density of jewelled geckos in a very small area, compared to other sites on the peninsula (e.g. 18 in <0.2ha) (*pers. obs.*). As this area was previously grazed, this density of jewelled geckos may have persisted here due to low rodent numbers and therefore low rodent predation.

Mustelid activity

In contrast to rodent activity, no significant differences were found in mustelid activity between the three areas examined. Nonetheless, other studies have suggested that mustelid numbers are often higher in rank grass and this may be due to an increase in rodent prey (see Ratz, 2000; Alterio & Moller, 1997; Alterio *et al.* 1998; Hoare *et al.* 2007). A relevant example of this is the removal of grazing domestic stock from grassland around yellow-eyed penguin (hoiho) breeding areas to establish so called 'vegetation buffers'. These buffers were predicted to reduce predation of hoiho chicks because long grass was thought to reduce lagomorph abundance and thereafter reduce the abundance of their mammalian predators. However these vegetation buffers did not exclude or deter predators and were found to attract feral cats, stoats and ferrets (see Alterio *et al.* 1998; Moller *et al.* 1998).

A further foot-print tracking study by Ratz (2000) compared rodent and mustelid activity around penguin breeding areas. This paper found that mice (*Mus musculus*), were recorded 5-17 times more often in the un-grazed areas than in grazed areas. In addition, stoats and ferrets were recorded twice and ten times respectively more often in rank grass than in grazed pasture. These studies all concluded that the concentration of stoats, ferrets and mice in the penguin breeding areas surrounded by rank grass was thought to increase the number of encounters between penguin chicks and predators, and therefore increase the likelihood of predation upon yellow-eyed penguin chicks (see Alterio *et al.* 1998; Moller *et al.* 1998; Ratz, 2000).

In the NGLR, the high number of rodents present may have increased the amount of food available to mustelids and feral cats. In addition, the high number of lagomorphs trapped in the reserve would have provided further attractant for mustelids and feral cats. This is likely to have increased the likelihood of encounters between mustelids and/or feral cats and jewelled geckos in the reserve and therefore potentially predation of jewelled geckos.

The effect of season

Rodent activity was higher in all three sites during the summer as opposed to spring. This is thought to be either due to an increase in rank grass (grass seed) over the summer as the grass grew in the absence of grazers and/or a seasonal effect on rodent activity. In contrast to these results, Ratz (2000) found that mice activity in un-grazed sites on the Otago Peninsula was higher in spring than in summer.

Advantages and limitations of using tracking tunnels

Conservation managers and researchers at mainland sites throughout New Zealand now commonly use tracking tunnels as a method of indexing rodent and mustelid abundance (Gillies & Williams, 2008a). There are several reasons why tracking tunnels are now a commonly used way of indexing small mammals instead of kill-trapping. Information can be gained on a variety of animals from large insects to whatever can fit through the tunnels (Gillies & Williams, 2008a). It is a non-invasive sampling technique so it does not impact the target population or any non-target species (Gillies & Williams, 2008a). Tracking tunnels are perceived as being more sensitive than snap traps for detecting the presence of rodents (particularly rats) at low abundance (Gillies & Williams, 2008a). The method is also less labour intensive than trapping because the tunnels remain permanently in place between monitoring sessions (Gillies & Williams, 2008a).

The method also has several limitations. For monitoring rodents and mustelids, tracking tunnels only provide a coarse index of relative abundance (activity). Therefore, they are not a direct measure of population density, but a measure of activity. Activity is expected to be correlated with density (e.g. the higher the activity, the higher the density). However this may not always be the case. For instance, mouse tracking rates may not always accurately reflect mouse density (Brown *et al.* 1996; Ruscoe *et al.* 2001), because behavioural interactions between rats and mice may result in lower detection rates for mice when rats are present in high numbers (Brown *et al.* 1996).

The technique is best suited for providing simultaneous comparisons of the relative abundance of rodents (particularly rats) or mustelids between similar habitat areas (e.g. treatment and non-treatment) or gross changes in relative abundance over time at a single site (Gillies & Williams, 2008a).

Tracking tunnels are also vulnerable to disturbance from non-target species. For instance several tunnels were interfered with by possums in this study. Possums often pulled the papers out of the tunnels and/or knocked over the tracking tunnels (Note: this disturbance is accounted for in the methods). In an attempt to prevent or reduce possum disturbance (or other disturbance), the tunnels in this study were held to the ground using lengths of wire and blue tack was used to stick the tracking papers to the wooden base of the tunnel. This was partially (but not always) effective. A further limitation is that tracking tunnel surveys can only be undertaken during periods of fine weather. Therefore due to rain, the frequency with which surveys can be undertaken is often reduced.

One of the major limitations concerning the assessment of rodent and mustelid activity in this study was that it was not possible to distinguish whether any changes in activity were due to the season or the manipulations themselves. However, by the time the research had been completed the rank grass was still present; therefore rodent and mustelid activity was not expected to be affected to a large degree by the manipulations that had taken place (e.g. the breaching of the fence and installation of gate). It seems unlikely that rodents or mustelids were trapped in the reserve as the activity of these predators did not change substantially after the fence was breached.

Another potential limitation is habituation, which refers to the animals learning to associate the tunnels with food (e.g. peanut butter) and begin to habitually pass through the tunnels in search of food. This would result in artificially high indexes of activity for the species concerned. In this study tracking tunnel surveys were spaced apart by at least a week in order to reduce the chances of habituation to the tunnels occurring and any leftover peanut butter was removed from the tunnels when the papers were collected. However, it is not known whether a week is sufficient time to leave between surveys in order to prevent habituation.

Recommendations for future monitoring

After the completion of the field work, the rank grass was finally removed during working bees on the 18th and 25th of March, 2009. Although stock had not been re-introduced to the reserve by the completion of this report, the plan is to put some sheep in as soon as possible to keep the grass height low. To test the effect of the manipulations (e.g. re-introduction of stock and removal of rank grass), it is vital that rodent and mustelid activity continues to be monitored at the NGLR. If the habitat outside the reserve is left un-grazed, this will provide an interesting contrast to the reserve. Tracking tunnel surveys will help determine whether the manipulations have had the desired effect of decreasing the abundance of mammalian predators or not in the NGLR. It is also recommended that the activity of mammalian predators continues to be assessed at the hilltop site. If this area remains un-grazed, rodent numbers are likely to increase in the area. Therefore it will be crucial to continue monitoring the jewelled geckos present here to see how the predicted increase in rodent activity affects jewelled gecko abundance. Research using tracking tunnels at these three sites which lasts at least a year would be valuable so the effects of season on rodent and mustelid activity can also be assessed.

6.0 Vegetation survey

6.1 Aim

Undertake a vegetation survey before the manipulations take place to record the various plant species in the NGLR and their distribution and percentage cover.

6.2 Method

A vegetation survey was undertaken in the NGLR to identify all the plant species present and determine their distribution and percentage cover. Firstly a survey was done to identify all (or as many as could be found) of the plant species present in the reserve. Samples of each species were collected for reference. Secondly the entire reserve was divided into 21 ~20x20m plots. These plots covered an area of approximately 400m² each, however some were slightly smaller or larger due to the unusual shape of the reserve (the reserve is 8520m² so 8520m²/21 = 405.71m² on average).

The reserve was divided into 21 plots to make estimation of the vegetation cover in each plot more manageable. In each of the 21 plots, the species present were noted and the percentage cover of the most abundant species (plants which cover at least 5% of the plot) estimated and recorded. Once all 21 plots were surveyed and percentage cover recorded, an average percentage cover of each type of plant over the entire reserve was calculated (for example, *Coprosma* covers 22% of the reserve area).

If the same methods are used to undertake this survey on a regular basis (e.g. yearly) comparisons can be made over time as the percentage cover of various species changes. This will enable, for instance, the effect of the manipulations (e.g. grazing) on the percentage coverage of *Coprosma* sp. and other plants thought to be important for jewelled gecko to be determined. The survey will also provide valuable information on the distribution of different plant species in the reserve which can be compared over time. Areas where undesirable species (e.g. gorse and broom) are present may also be highlighted which will be useful during weed removal operations.

6.3 Results

The species of vascular plant which were found and were able to be identified are listed below in Table 6. The entire reserve was divided into 21 ~20x20m plots in order to assess percentage coverage. A summary of the overall percentage coverage of the major vascular plant species (or groups of similar species) are shown in Table 7. In the Tables below plants which are considered to be potential jewelled gecko habitat are followed by a "(*)" symbol, whereas weed plants (plants which may threaten jewelled gecko habitat) are followed by a "(x)" symbol.

Table 6. All the vascular plant species which were found in the NGL reserve during the vegetation survey

Plant #	Plant Species	Total /21
1	*Coprosma propinqua* (*)	20
2	*Coprosma crassifolia* (*)	7
3	*Coprosma taylorae* (*)	2
4	Native mistletoe (*Ileostylus micranthus*) (*)	19
5	*Muehlenbeckia australis* (*)	21
6	Kanuka (*Kunzea ericoides*) (*)	6
7	Manuka (*Leptospermum scoparium*) (*)	3
8	Halls totara (*Podocaprus hallii*) (*)	7
9	Gorse (*Ulex europaeus*) (x)	9
10	Broom (*Cytisus scoparius*) (x)	13
11	Mahoe (*Melicytus ramiflorus*) (x)	21
12	Ngaio (*Myoporum laetum*) (x)	15
13	Pine tree (*Pinus radiata*) (x)	1
14	Macrocarpa (*Cupressus macrocarpa*) (x)	2
15	Yorkshire fog (*Holcus lanatus*)	20
16	Brown top (*Agrostis capillaris*)	20
17	Cocksfoot (*Dactylis glomerate*)	21
18	Sweet vernal (*Anthoxanthum odoratum*)	19
19	Chewings fescue (*festuca rubra*)	20
20	Crested dogstail (*Cynosurus cristatus*)	7
21	Timothy (*Phleum prateuse*)	3
22	Matipo (*Myrsine australis*)	2
23	Kohuhu (*Pittosporum tenuifolium*)	7
24	Poroporo (*Solanum laciniatum*)	7
25	Lawyer (*Rubus schmideliodes*)	7
26	A native rush (*Juncus gregiflorus*)	2
27	Jointed rush (*Juncus articulatus*)	2
28	*Fushia colensali*	1
29	Native jasmine (*Parsonia heterophylla*)	10
30	*Clematis foetida*	2
31	Native spinach (*Tetragonia implexa*)	4
32	Kowhai (*Sophora microphylla*)	1
33	Male fern (*Dropteris filix-mas*)	12
34	Fern (*Hypolepsis ambigua*)	7
35	Fern (*Polystichum neo-zelandicum*)	7
36	Water fern (*Histiopteris incisia*)	2

37	Hounds tounge (*Microsorum pustulatus*)	1
38	Hen and chicken fern (*Asplenium bulbiferum*)	8
39	Kiwikiwi (*Blechnum fluviatile*)	2
40	Silver tree fern (*Cyathea dealbata*)	2
41	Blackberry (*Rubus fruticosis*)	14
42	White clover (*Trifolium repens*)	5
43	Red Clover (*Trifolium pratense*)	1
44	Californian thistle (*Cirsium arvense*)	18
45	Scotch thistle (*Cirsium vulgare*)	17
46	Creeping buttercup (*Ranunculus repens*)	16
47	Giant buttercup (*Ranunculus acris*)	15
48	Ragwort (*Senecio jacobaea*)	15
49	Fireweed (*Senecio minimus*)	19
50	Bidibid (*Acaena anserinifolia*)	19
51	Catsear (*Hypochaeris radicata*)	13
52	Narrow-leaved plantium (*Plantago lanceolata*)	7
53	Mouse-eared chickweed (*Cerastium fontanum*)	3
54	Chickweed (*Stellaria media*)	4
55	*Microtis unifolius*	4
56	*Nemesia floribunda*	4
57	Cleavers (*Galium aparine*)	2
58	Hawthorn (*Crataegus monogyna*)	4
59	Hemlock (*Conium maculatum*)	5
60	Self heal (*Prunella vulgaris*)	6
61	Hawksbeard (*Crepis capillaris*)	7
62	*Hebe salicifolia*	3
63	Sweet briar rose (*Rosa rubiginosa*)	2
64	Bittersweet (*Solanum dulcamara*)	11
65	Nightshade (Solanum americanum)	6
66	Velvety nightshade (*Solanum chenopodioides*)	5

Table 7. The total percentage coverage of the major vascular plant species (or groups of similar species) found during the vegetation survey at the NGL reserve. Species known to be regularly used by jewelled gecko are followed be an asterisk (*), whereas species considered to be weeds which may outcompete or out-shade jewelled gecko habitat are followed by an (x).

% COVER OF IMPORTANT SPECIES	**Total % Cover**
Coprosma sp. **(*)**	16.3
Kanuka / Manuka **(*)**	0.9
Muehlenbeckia **(*)**	5.0
Halls totara **(*)**	0.4
Broom **(x)**	5.0
Gorse **(x)**	1.0
Mahoe **(x)**	16.5
Ngaio **(x)**	12.8
Macrocarpa **(x)**	1.0
Other	4.9
Pasture grasses and weeds	36.2
TOTAL	100.0

6.4 Discussion

The distribution and percentage cover of each of the vascular plant species considered to be important, either as jewelled gecko habitat or as a weed (a plant which threatens jewelled gecko habitat) in the NGLR are described below. Below each description is a figure corresponding to the relevant species showing its distribution and percentage cover.

(a) *Coprosma* sp. (*Coprosma propinqua, C. taylorae and C. crassifolia*)

Coprosma sp. is most abundant in the northern half of the reserve (see *fig.* 11), whereas the southern half is dominated by mahoe and ngaio. *Coprosma* sp. is thought to provide important habitat for jewelled geckos and is the vegetation which jewelled geckos have most often been seen in, at the reserve (see Shaw, 1994; Schneyer, 2001). In the NGLR, *Coprosma* sp. provides the majority of habitat necessary for jewelled gecko as coverage of other species known to commonly be inhabited by jewelled geckos is limited e.g. kanuka/manuka (see *fig.* 12). It is therefore apparent that the more *Coprosma* sp. available, the more habitat available for jewelled geckos, therefore the higher the percentage coverage of *Coprosma* sp. in the reserve the better. This study found that *Coprosma* sp. covered 16.3% of the entire reserve area (see Table 7). The percentage coverage is highest in the centre north area and north western corner of the reserve suggesting that these areas are the most likely to be suitable for jewelled geckos. Shaw (1994) estimated that *Coprosma* covered 33% of the reserve from the use of aerial photographs just after the fence was built in 1994. Ring-barking and shading from other species has clearly hampered the spread of *Coprosma* sp. in the reserve and this loss of habitat and increased fragmentation may have contributed to the decline in jewelled gecko abundance.

Encouragingly, *Coprosma* sp. was present in 20 of the 21 plots in the reserve (see Table 6). Many parts of the reserve (especially in the lower half) have an abundance of small establishing *Coprosma* shrubs. Therefore as long as these shrubs are protected and not-out shaded by other species, the percentage cover of *Coprosma* sp. may increase further in the future. Once stock is introduced, the effect of the stock on the *Coprosma* shrubs should be monitored closely and if deemed necessary vulnerable seedlings may need to be fenced off with chicken wire.

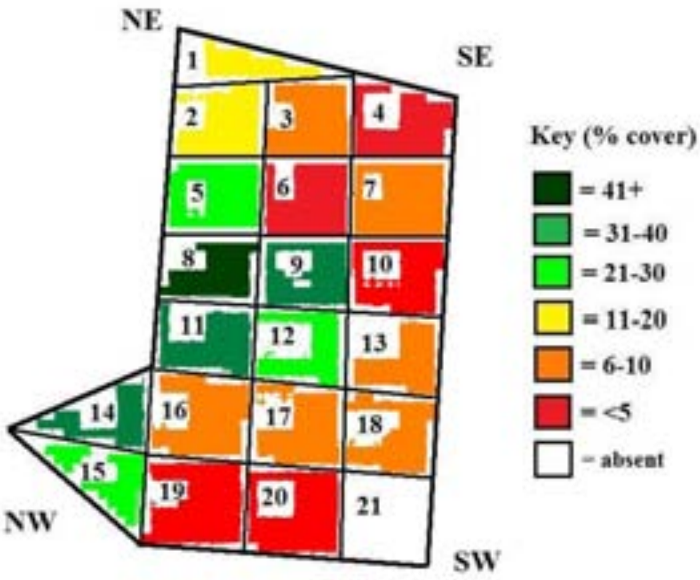

Fig. 11. The distribution and percentage coverage of *Coprosma* sp. amongst the 21 plots in the reserve.

(b) Kanuka/manuka (kanuka, *Kunzea ericoides* and manuka, *Leptospermum scoparium*)

Some kanuka and manuka have been planted in the lower half of the reserve as these plants are known to be used by jewelled geckos elsewhere. Currently kanuka and manuka cover less than 1% of the reserve (Table 7); however this may substantially increase as the young plants become established. These are most common in plots 17, 19 and 20 (see *fig.* 12). In all the areas where kanuka and manuka is present, it is competing for space and sunlight with other species; predominantly broom, mahoe and ngaio. In order to aid the establishment of kanuka and manuka and thereby provide more habitat for jewelled geckos, it is recommended that the broom, mahoe and ngaio be removed from these plots.

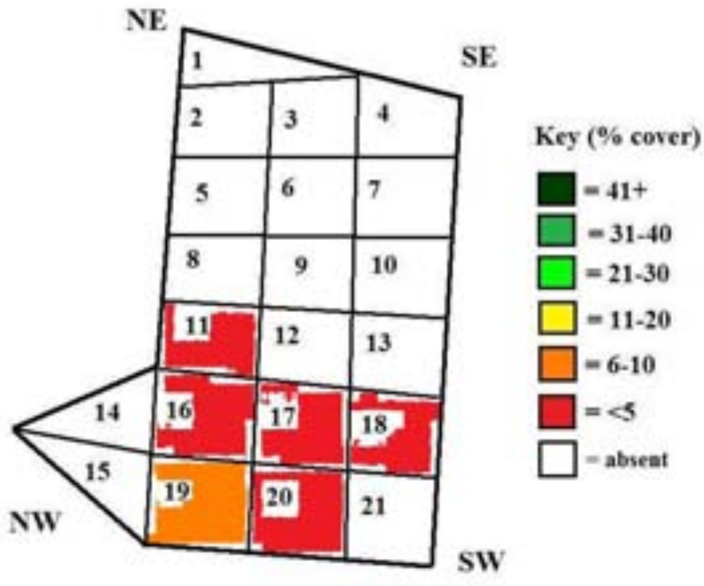

Fig. 12. The distribution and percentage coverage of kanuka and manuka amongst the 21 plots in the reserve.

(c) Mahoe (*Melicytus ramiflorus*)

Mahoe currently covers an estimated 16.5% of the reserve (Table 7). Mahoe is widespread in the reserve (*fig.* 13) and is present in all 21 plots (Table 6). In many areas Mahoe is out-shading *Coprosma* sp. and thereby preventing its spread and out-shading important jewelled gecko habitat. Due to this, it is recommended that mahoe be removed from the reserve from areas where it is out shading *Coprosma* sp. and/or kanuka/manuka. The plots were this is occurring most frequently are mostly in the southern half of the reserve (e.g. 3 and 15-19). Mahoe should be removed from these plots as soon as possible. The bush remnant on the southern side of the reserve can be left intact as there is little jewelled gecko habitat present.

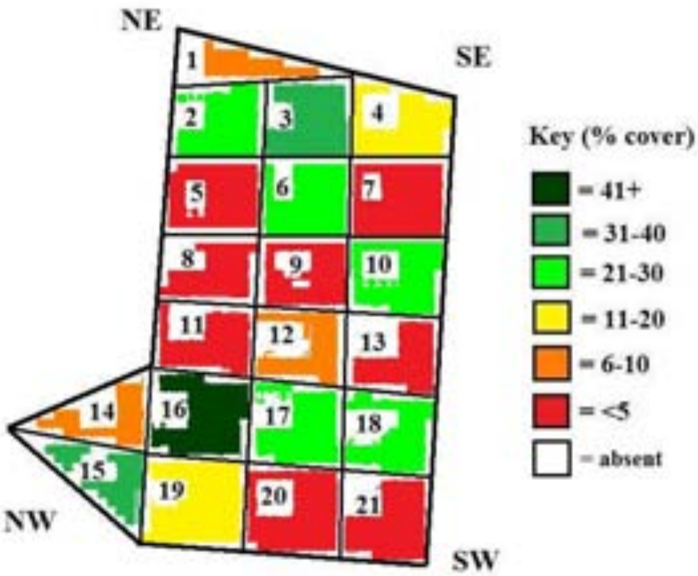

Fig. 13. The distribution and percentage coverage of mahoe amongst the 21 plots in the reserve.

(d) Ngaio (*Myoporum laetum*)

Ngaio covers 12.8% of the reserve (Table 7). Ngaio is most common in the southern half of the reserve (the bush remnant) and in the north-western corner (see *fig.* 14). Ngaio is present in 15 plots (Table 6). Like mahoe, in many areas ngaio is out-shading *Coprosma* sp. and kanuka/manuka and should therefore be removed. The plots were this is occurring most frequently are mostly in the southern half of the reserve (e.g. 6 and 16-20). Mahoe should be removed from these plots as soon as possible.

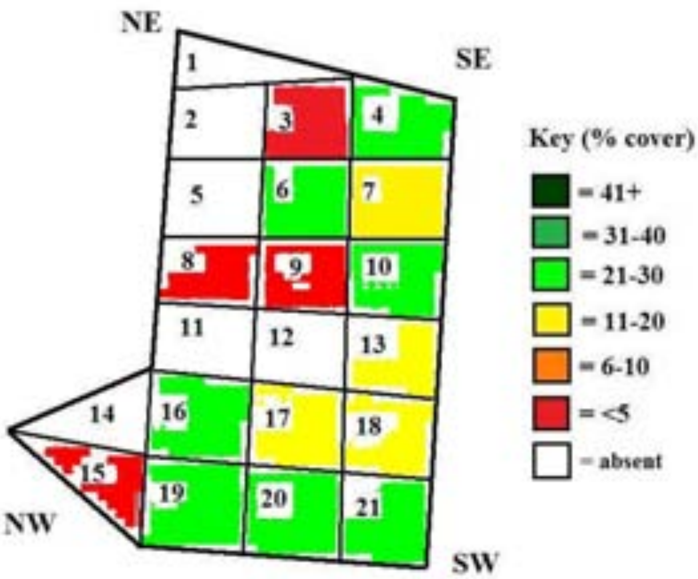

Fig. 14. The distribution and percentage coverage of ngaio amongst the 21 plots in the reserve.

(e) Broom (*Cytisus scoparius*)

Broom covers around 5% of the reserve (Table 7). In some areas this is out-shading jewelled gecko habitat and therefore should be removed, especially in the lower reserve. Broom is reasonably widespread and is present in 13 plots (Table 6), however in most plots (except 4 and 7) its coverage is low (e.g. <5%, see *fig.* 15).

Fig. 15. The distribution and percentage coverage of broom amongst the 21 plots in the reserve.

(f) Gorse (*Ulex europaeus*)

At present, gorse covers a small percentage of the reserve area (e.g. 1%). It is present in 9 plots (see *fig.* 16). Outside the reserve boundaries, gorse covers substantial areas and is known to be a very invasive and fast spreading weed which out-competes most other species. Due to this, it is recommended that all gorse is removed in order to prevent its further spread.

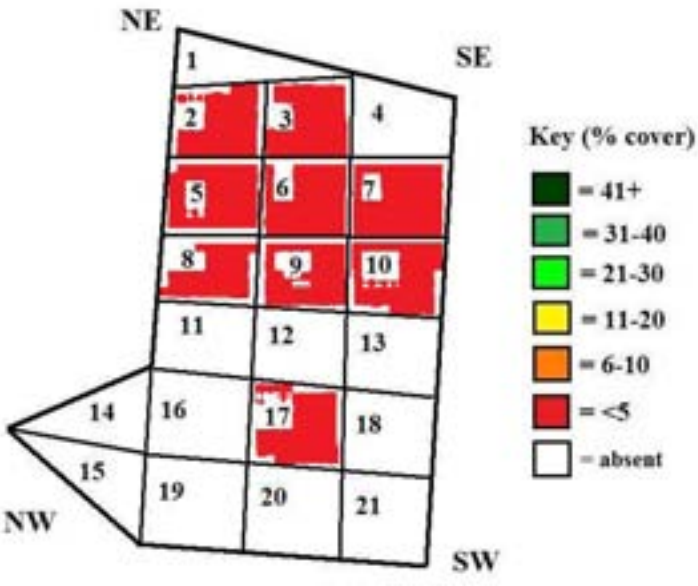

Fig. 16. The distribution and percentage coverage of gorse amongst the 21 plots in the reserve.

(g) Pasture/weeds

Pasture grasses and associated weeds (e.g. thistles, ragwort etc) cover 36.2% of the reserve area (see Table 7; *fig.* 17). Before the working bees on the 18th and 25th of March, 2009, the pasture grasses were rank and were over a metre high in some areas. In some areas the rank grass had grown above the height of *Coprosma* seedlings and may have inhibited their growth and establishment. It is recommended that sheep be introduced to the reserve to control grass growth and thereby reduce rodent abundance.

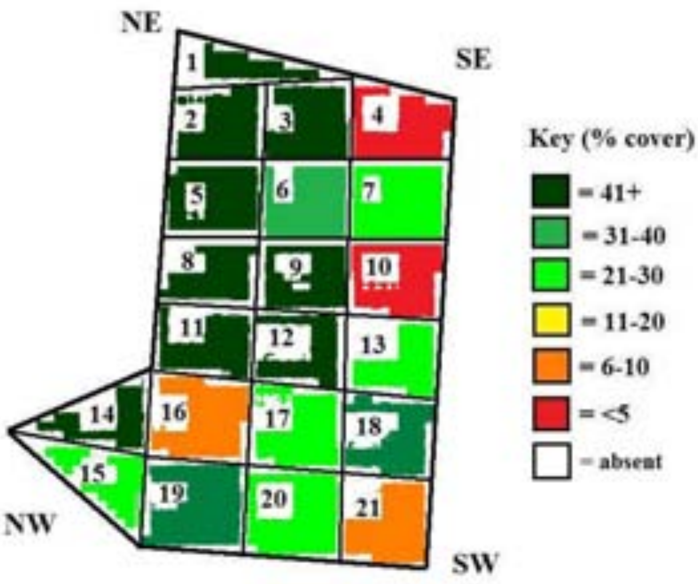

Fig. 17. The distribution and percentage coverage of pasture grasses amongst the 21 plots in the reserve.

Advantages and limitations of the vegetation survey

The vegetation survey provided valuable information for the future management of the NGLR. Information on the percentage coverage of both species important for jewelled geckos (e.g. *Coprosma* sp. and kanuka/manuka) and weed species which may threaten jewelled gecko habitat (e.g. mahoe, ngaio, gorse and broom) was gained. This information can be used as a baseline from which future comparisons can be made. Thereby the short-term and long-term effects of the manipulations (e.g. the re-introduction of grazers and/or weed removal) can be evaluated in order to determine their effect on the coverage of jewelled gecko habitat. The vegetation survey also highlighted the need for the removal of some of the mahoe, ngaio, gorse and broom and prioritised areas where removal is recommended in order to preserve jewelled gecko habitat.

There were also several limitations involved in the method used during the vegetation survey. Firstly, the estimation of the percentage cover of each of the 20m x 20m plots was done visually by the researcher and therefore may be subject to perception bias. However, every effort was made to be as accurate as possible. Secondly, the estimate of the percentage cover does not take into account the height of the vegetation which may significantly affect the amount of habitat available to jewelled geckos in each of the plots and the reserve as a whole. The accuracy of the percentage cover estimations during the vegetation survey could have been increased by dividing the reserve up into more, smaller plots. For example, the reserve could have been divided up into 10m x 10m plots. However this would have involved dividing the reserve up into 84 individual plots which would have been very time consuming. In addition, transects could have been undertaken to examine the vertical distribution of the vascular plant species present.

Recommendations for future monitoring

It is recommended that this survey be completed once a year in order to determine the short-term and long-term effects of the manipulations (e.g. the re-introduction of grazers and/or weed removal) on the coverage of jewelled gecko habitat over time. These surveys will also help prioritise areas where weeds (or plants threatening jewelled gecko habitat) need to be removed on a yearly basis.

7.0 General Discussion

7.1 Probable reasons for the decline

I will know discuss what I believe are the most likely causes of the decline (or extinction) of jewelled geckos at the NGL reserve. These causes will be presented in order of the most likely to the least likely contributing cause of decline and are summarised in figure 18.

1) Increased mammalian predation following the removal of grazers

As described on pages 44 and 45, rodent and mustelid activity is consistently higher in un-grazed habitats as opposed to grazed. Therefore, the removal of stock in 1994 may have condemned the jewelled gecko population at the NGLR to an inevitable decline. Since this time, in the absence of grazers, the number of predators in the reserve is likely to have increased despite the cat and mustelid proof fence. Although the fence may have originally been cat and mustelid proof, by the late nineties, branches had fallen over the fence and the fence had been cut in several places (presumably by poachers) allowing these predators to enter the reserve.

The growth and seeding of rank grass in the reserve and surrounding area is likely to have resulted in an increase in rodent numbers by providing abundant food and shelter. Thereafter, the number of mustelids and/or feral cats frequenting the reserve may have increased due to presence of large numbers of rodents and lagomorphs trapped inside. In summary, the exclusion of grazing from the reserve may have modified the environment in a way which favoured both rodent and mustelid abundance and this is thought to have resulted in increased predation of jewelled gecko (see *fig.* 19). However these predators are likely to have differed in their likely impact. The potential impact of each predator is further discussed below.

In my opinion mice and ship rats are the predators which are likely to have predated on jewelled geckos the most at the NGLR followed by mustelids. The impact of rodents on native species is often underestimated possibly due to their small size and conspicuousness. However, both rats and mice have been shown to have severe impacts on populations of native species in New Zealand including birds, reptiles and invertebrates.

The ship rat (*R. rattus*) is the most likely rat species to be present in the reserve. Unfortunately it is not possible to distinguish between the two species from the tracking tunnels used in this study; however the species which is most likely to be present in the reserve is the ship rat. In New Zealand, Norway rats are now common only in wet habitats such as rivers, streams, lakes, lagoons, swamps and estuaries, urban areas and on some offshore islands (Cunningham & Moors, 1996). In contrast, ship rats are found in most habitats and are now the most abundant and widespread rat on the New Zealand mainland (Cunningham & Moors, 1996). They are also commonly abundant in forest and scrubland habitat (see Brown *et al.* 1996; Innes, 2001). Although both species are potentially present, ship rats are the more likely of the two species to occupy this habitat.

Ship rats are nocturnal, are expert climbers and are known to be highly arboreal (unlike Norway Rats). Ship rats radio-tracked at Rotoehu Forest were mostly arboreal, with 73% of fixes above 2 m, but were nevertheless frequently recorded on the ground (Hooker & Innes, 1995). In New Zealand, ship rats are probably the most frequent predator of eggs, chicks and sitting adults of forest birds on the mainland (Innes, 2001). For example, Brown (1997) (cited in Innes, 2001) found that ship rats were responsible for at least 72% of predations at nests of North Island robins (*Petroica australis longipes*) and tomtits (*P. macrocephala toitoi*). In addition, Ship rats are the most frequently recorded predators of eggs and chicks of NI kokako and kereru (Clout *et al.* 1995; Innes *et al.* 1996; cited in Innes, 2001).

Arboreal species (such as jewelled geckos) are thought to relatively safe from predation by predominantly ground-feeding predators such as Norway rats and feral cats, however they have no refuge from arboreal ship rats, mice and mustelids which are capable of reaching both terrestrial and arboreal species (Towns & Daugherty, 1994). Due to their arboreal nature and small size, ship rats and mice are likely to be adept at moving through dense vegetation and climbing several metres above the ground. Although mice are primarily nocturnal, and therefore rarely seen during the day, a few years after the exclusion of grazing from the NGLR, mice were seen moving through the *Coprosma* bushes during the day (Alison Cree *pers. comm.*). Therefore, they are clearly capable of moving through this habitat which is likely to increase the probability of encounters with jewelled geckos.

Ship rats and mice could easily locate jewelled geckos in the *Coprosma* bushes at night via smell. Therefore ship rats and mice may be able to access jewelled geckos when they are buried deep within *Coprosma* at night or high in the canopy of trees such as kanuka. At night, jewelled gecko are likely to be out of the reach of ground based predators such as feral cats and ferrets because they are likely to be buried deep within vegetation and/or several metres off the ground.

Due to the thick scrubby nature of vegetation such as *Coprosma* it would be extremely difficult or impossible for larger predators (e.g. feral cats and ferrets) to move through the *Coprosma* in order to gain access to jewelled geckos below the vegetation surface (for example: try clenching your fist and pushing it through *C. propinqua*). In addition, if these predators can make it through the thick vegetation, they are likely to cause a lot of disturbance in the process which may alert jewelled geckos to the presence of a predator and invoke an escape response.

Feral cats and mustelids are predominantly ground based and nocturnal. A study by Alterio & Moller (1997) examined the daily activity of feral cats, stoats and ferrets. Out of these three predators, all three were more active at night than day. Stoats were the most active during daylight hours followed by feral cats then ferrets (Alterio & Moller, 1997). As a result of their emergence behaviour, jewelled geckos are likely to spend only a small proportion of their time at the vegetation surface and are only likely to be emergent during the day. Therefore jewelled geckos are only likely to be available to these larger predators (and birds) for a much smaller proportion of time as opposed to rodents (e.g. only when emergent or on the ground and only when these predators are active). These observations suggest that predation by a ferret or feral cat is unlikely but possible nonetheless. Jewelled gecko may be especially vulnerable to predation from feral cats or ferrets when basking low to the ground (<1m) or on the ground moving between habitat patches in fragmented habitat.

Rodents are also capable of reaching much higher densities in jewelled gecko habitat than other predators, which is likely to increase the probability of encounters with jewelled geckos. Estimates for the density of mice per hectare in New Zealand range from 6.2-13.8/ha in *Nothofagus* forest (Fitzgerald *et al.* 2004), 12-24/ha in sand dune areas (Miller, 1999; cited in Ruscoe, 2001) and 27-50/ha after beech mast seeding (Ruscoe, 2001). Mouse population densities are known to fluctuate widely between different habitats; however, in general, mice reach higher population densities in areas with dense ground cover (Ruscoe, 2001). For example, Ratz (2000) recorded mice 5-17 times more often in ungrazed areas than in grazed areas. Most studies on ship rats on the mainland show densities between 2 and 7/ha (see Wilson *et al.* 2007; Brown *et al.* 1996).

In contrast to rodents, a much lesser number of larger predators (e.g. stoats, ferrets and feral cats) are likely to be present in the reserve at any one time. For example estimates of the number of ferrets per kilometer squared on farmland at Palmerston (~60km north of the Otago Peninsula) range from 2.9-8.2 per km² (or 0.029-0.082/ha). Therefore there is likely to be a much higher number of rodents present in the reserve at any one time as opposed to mustelids and cats.

In summary, in my opinion, due to their arboreal nature, nocturnal activity, ability to move through dense vegetation, high potential density in un-grazed pasture and proven impact on other native species including skinks and geckos, ship rats and mice are the predators most likely to have had a substantial impact on the decline of jewelled geckos at the NGLR. In addition, stoats and weasels may also have predated on jewelled geckos within the *Coprosma* as their small size may allow them to move through this habitat. Feral cats and ferrets are likely to have had less of an impact, due to their inability to access jewelled geckos except when emergent close to the ground, or on the ground. However, habitat fragmentation may have increased the vulnerability of jewelled geckos to these ground-based predators.

2) Poaching

This possible cause of decline is the most difficult to assess. At least 6 jewelled geckos are known to have been taken by poachers, as they were later found in Hamburg, Germany and identified as being from the NGLR due to their unique toe clips. It is possible that poachers have taken a significant number of jewelled geckos from the area and this may be the primary reason for the decline. On the other hand, it is possible that only a small number were taken. Poaching of geckos from the Peninsula was reported in the late 1990's and is likely to be an ongoing threat. Jewelled geckos are known to be a desirable species on the illegal pet market and may fetch high prices in Europe, America and Asia. Poaching is suspected to have occurred at the reserve due to the identification of the site in a published book, tourists asking for directions to the reserve and the fence being cut, indicating that poachers are likely to have entered the reserve and taken geckos (Lala Frazer *pers. comm.*).

In my opinion, due to the erratic emergence behaviour of jewelled geckos, it is unlikely that all the jewelled geckos were taken by poachers as this would have required substantial skill and consistent and ongoing search effort. However, poachers may have taken a significant number of gravid females from the reserve. This is likely because gravid females are emergent significantly more often than other members of the population (see Duggan, 1991). For instance, in this study, the average probability of sighting an individual gravid female was 0.5 (n=3). In addition, gravid females may be desirable for breeding purposes. If a large number of gravid females were taken, this would have significantly reduced population growth.

In contrast, the average probability of sighting an individual juvenile in this study was 0.11 (n=8). This suggests that juveniles would have been the least likely to have been poached. As well as being emergent less often, juveniles are the hardest to spot when emergent due to their small size and conspicuousness. In my opinion, it is likely that poaching removed a significant proportion of the adult jewelled geckos and the rodents may have eliminated the majority of the remaining juveniles.

Since the NGL reserve, has been identified as holding jewelled geckos it may always be a target for poachers (if any are left or re-colonise in the future). The neighbours are vigilant at observing and reporting suspicious activity, however none of the neighbouring houses actually looks directly onto the reserve.

In addition to the reserve, no jewelled geckos were located in suitable habitat within 110m of the reserve fence during this study. However, jewelled geckos were previously, commonly seen around the perimeter of the reserve (see Shaw, 1994). In contrast, jewelled geckos were commonly seen at the hilltop site and at other populations on the peninsula. This may indicate that the jewelled geckos present in the land outside the reserve have also been poached and / or that they have declined due to the removal of grazers and suspected increase in rodents. Due to the distance of the hilltop site from the reserve, these geckos may not have been discovered by poachers. These geckos may have persisted here due to the site not being poached and / or the area being grazed (until a year ago) and the associated lower number of rodents (see tracking tunnel data).

3) Increased habitat fragmentation

Divaricating shrubs (such as *C. propinqua*) are likely to provide protective cover for jewelled geckos (Towns & Daugherty, 1994), making them less vulnerable to predation than when present on the ground or in other vegetation types. However, if their habitat is fragmented, jewelled geckos may have to travel at ground level between patches, and the composition and structure of vegetation between patches could influence their vulnerability to predation (Towns & Daugherty, 1994).

When moving on the ground jewelled geckos are thought to be extremely vulnerable to predation from a wide range of mammalian predators (e.g. rats, mice, mustelids, hedgehogs and feral cats). Exasperating this is the observation that jewelled geckos are slow moving and clumsy on the ground in comparison to ground living geckos and skinks (Alf Webb *pers. comm.*). Jewelled gecko are not known to spend much time on the ground, however they may be forced to travel between bushes along the ground in fragmented habitat when in search of mates, food or territories. No jewelled geckos were seen on the ground during this study, although jewelled geckos at the hilltop site occasionally moved between individual bushes requiring them to move along the ground through pasture. These were normally reasonably small distances (e.g. less than ten metres, max = 28m).

As previously stated, increased habitat fragmentation due to shadowing of *Coprosma* by weeds (e.g. mahoe, ngaio, broom and macrocarpa - prior to 2003) and ring-barking may have increased risky inter-patch movements and therefore the risk of predation on the ground at the NGLR (see Schneyer, 2001). In addition to having to move further between habitat fragments, the thick ground cover of rank grasses and weeds may have made it significantly more difficult for jewelled geckos to move between bushes. Scrambling through rank grass may considerably increase the amount of time spent moving between shrubs, and therefore increase the risk of an encounter with a predator on the ground. The combination of the rank grass cover, high mammalian predator abundance and increased distances needed to travel between habitat fragments may have dramatically increased their vulnerability to predation to predators on the ground such as rodents, mustelids and feral cats.

As stated earlier, introduced predators are suspected to have been present in high densities due to the rank grass. Furthermore, even if only the occasional introduced mammal predates on a jewelled gecko, the impact on the jewelled gecko population may be severe due to the slow population growth of the jewelled gecko (e.g. maximum of 2 offspring per mature female per year). Therefore, in conclusion, habitat fragmentation is thought to have contributed significantly to the decline of the jewelled gecko in the NGLR by increasing their risk of predation by mammalian predators.

4) Bird Predation

Another of the suggested reasons for the decline was an increase in bird predation due to the high fence providing a vantage point for birds to observe and then predate geckos. Based on previous research (see Schneyer, 2001) and my own observations I consider bird predation unlikely to be significant. When ~30 jewelled geckos were still known to be present in the reserve, a research project was carried out in the reserve by Nadya Schneyer, involving netting and indicated that bird predation was not a problem. She also did some radio tracking which indicated that there was no evidence of jewelled geckos moving outside the reserve. She therefore concluded that the reduced numbers were due to mice (Schneyer, 2001).

Although the effect of bird predation was not examined in any great detail during this study, casual observations were made. During this study, no birds were observed perching on the fence and no birds appeared to be surveying the *Coprosma*. Birds suspected to predate on jewelled gecko and other New Zealand lizards include the introduced Australian Magpie (*Gymnorhina tibicen*), European starling (*Sturnus vulgaris*), kingfisher (*Halcyon sancta*), New Zealand falcon (*Falco novaeseelandiae*) and Australasian Harrier (*Circus approximans*). Out of these birds, only the European starling and Australasian harrier were observed in the vicinity of the reserve.

The impacts of birds on jewelled gecko populations is difficult to assess, and is probably site specific and related to the availability of cover provided by the vegetation (Towns and Daugherty, 1994). Therefore although bird predation is not thought to have contributed a great deal to the decline at the NGLR, it may be significant at other sites.

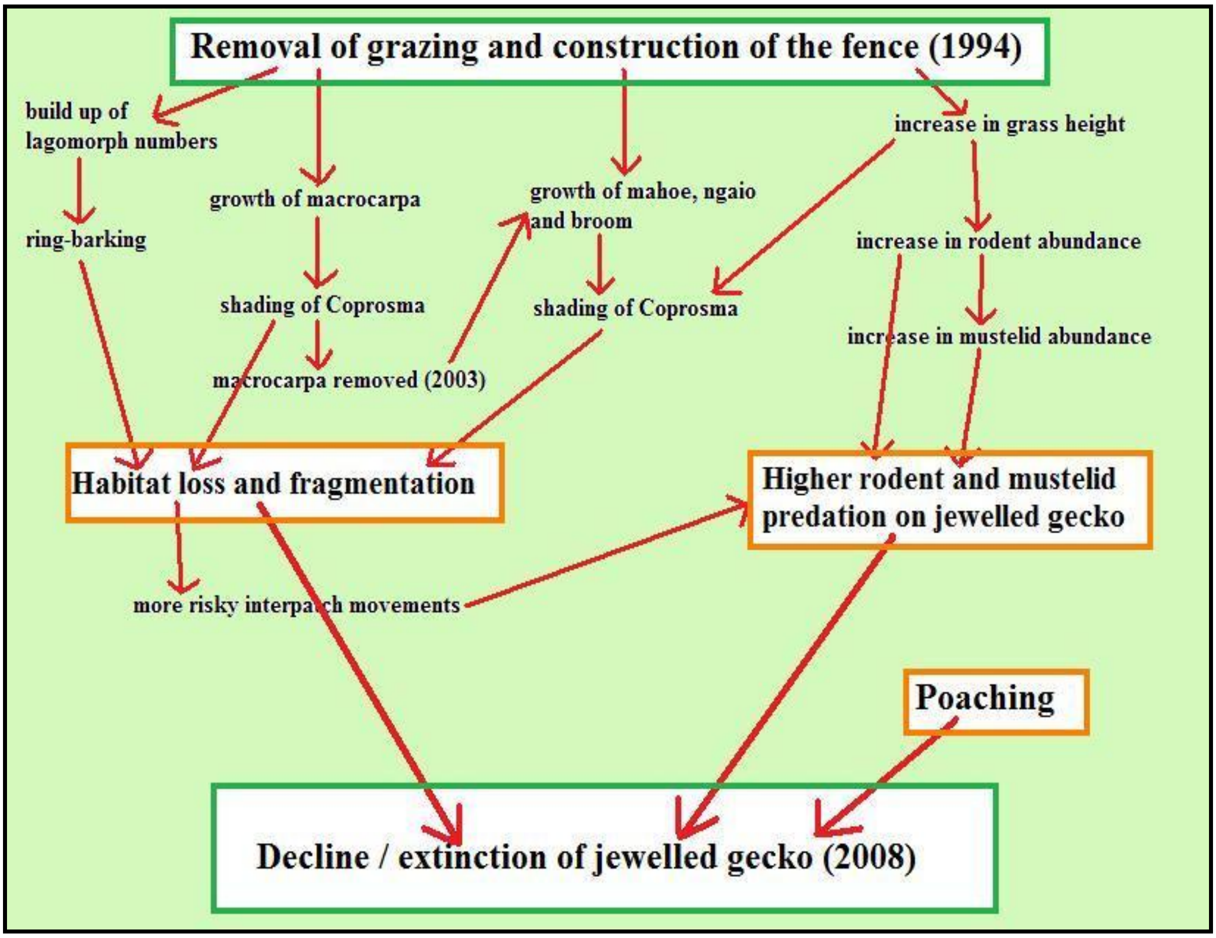

Fig. 18. This figure shows a flow chart of the likely factors which contributed to the decline of jewelled gecko in the NGLR. The three most likely factors which are thought to have contributed to the decline are highlighted in the orange boxes.

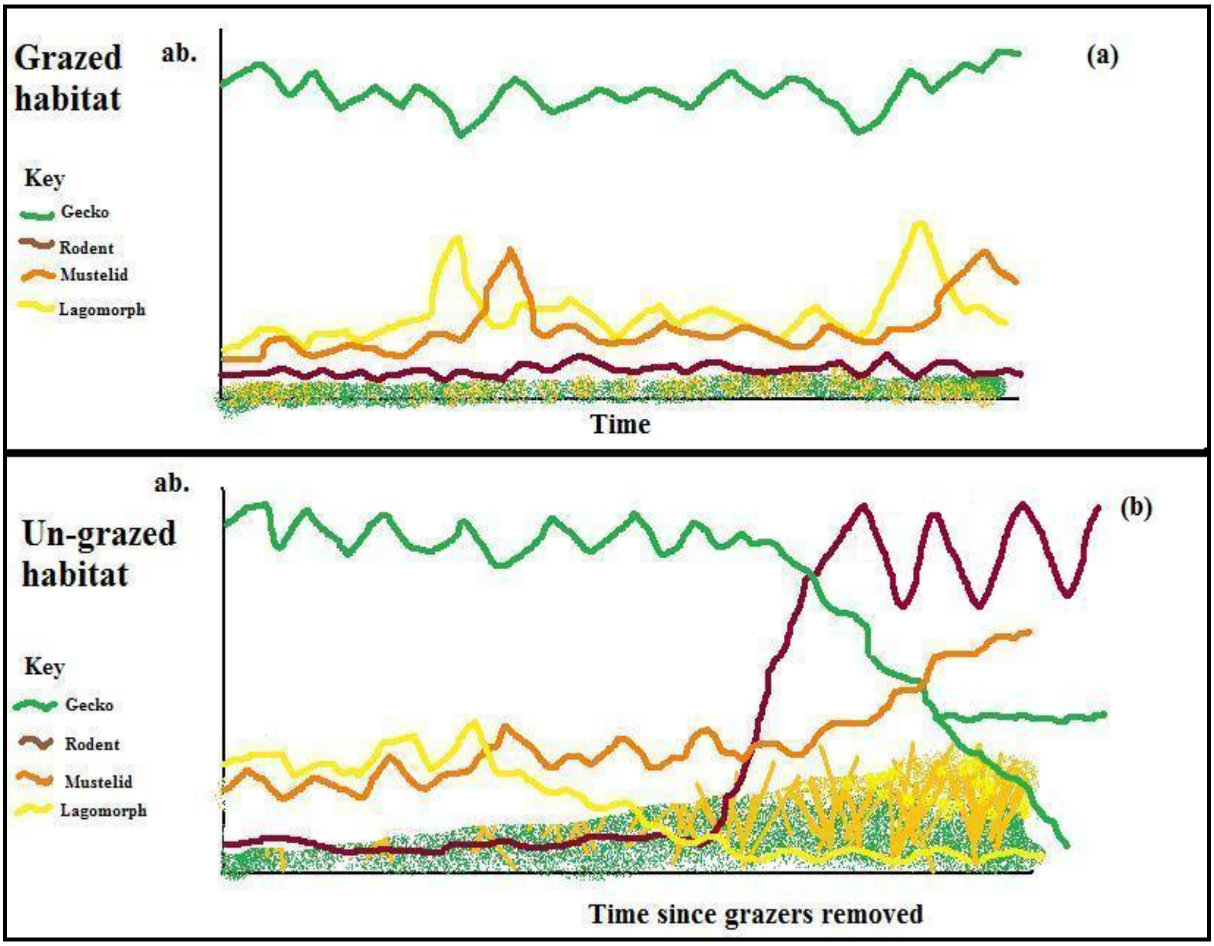

Fig. 19. This figure shows the potential relationship between grass height, gecko abundance and the abundance of introduced mammals (e.g. rodents, lagomorphs and mustelids). Time is shown on the X-axis and abundance on the Y-axis. In grazed habitat, rodent numbers are low and mustelid numbers are largely controlled by the number of lagomorphs present; therefore predation by mammalian predators on jewelled geckos is thought to be low. In contrast, when grazers are removed, introduced grasses proliferate and seed leading to an eruption in rodent numbers, mustelid numbers may also increase. This increase in the number of mammalian predators in un-grazed shrub-land habitats may lead to increased predation and thereby a decline in jewelled gecko abundance.

7.2 Implications of findings for the NGL reserve

The fact that no jewelled geckos were found in the reserve or around its boundaries was disappointing but was thought to be a definite possibility before the research was carried out. It was also thought to be possible that no jewelled geckos would be present on any of the surrounding properties. Therefore, the discovery of two populations within 500m of the reserve is definitely positive. This provides hope that the reserve may one day be re-colonised, now that the habitat has been restored to a state which is presumably more suitable for jewelled geckos (e.g. rank grass and weeds removed). There is still plenty of habitat left in the reserve (about four times as much as is present on the hilltop site). Now that the habitat has been restored, it will be interesting to see whether any natural re-colonisation occurs in the next few years. In addition, the site may now be deemed suitable for translocations in the future.

7.3 Areas in need of further research

On the Otago Peninsula, most jewelled gecko populations in grazed shrub-land habitats appear to be able to obtain high densities, whereas populations on land where grazing animals have been excluded appear to have either disappeared altogether or exist at lower densities (*pers. obs.*). In my opinion, it is likely that this difference in the density of jewelled geckos is due to the higher level of mammalian predation in un-grazed habitats (especially by rodents). Further research could compare the density of jewelled geckos between grazed and un-grazed shrub-land and compare this to the activity of rodents to see whether any patterns can be found. This research would provide valuable information for land owners interested in the conservation of jewelled gecko on their properties. These land-owners can then be advised as to whether grazing is advisable or not, and in which areas on their property, in order to effectively conserve populations or increase jewelled gecko abundance.

Juveniles are likely to be the most vulnerable life history stage to predation from rodents (especially mice) because of their small size and likely inability to defend themselves. Juveniles may be particularly vulnerable in un-grazed habitat to a range of mammalian predators during the time when they initially disperse from their home bush (e.g. where they were born) in search of their own territory. Further research could compare the survival rates or proportion of juveniles between populations in grazed and un-grazed habitats to test whether predation on juveniles is higher in un-grazed shrub-lands.

Research on rodent diet in shrub-lands containing jewelled geckos would also be of value to determine whether rodents (a) predate on jewelled geckos as suspected and/or (b) compete with jewelled geckos for food (e.g. insects and fruit). This research may also provide insights into ways of controlling rodent abundance by reducing the amount of food available (e.g. removal of grass seed).

It has been suggested that domestic stock may graze on and prevent the establishment of native bush. Therefore further research on the impact of domestic grazers on shrub-land habitats would also be valuable. In my opinion, although some damage to shrubs such as

Coprosma may occur, the benefits to jewelled geckos of controlled grazing (e.g. reducing the number of rodents) far outweigh the negatives. If the aim is to increase jewelled gecko abundance, there is no use in having an abundance of jewelled gecko habitat with no jewelled geckos in it. However, if the aim is to restore the native bush, then this may present a dilemma. In this case, other means of reducing grass height such as the use of grass cutters is recommended.

It has been suggested that sheep may only eat *Coprosma* when no other food (e.g. grass) is available. Therefore as long as the stocking rates are appropriate, damage is likely to be minimal. New seedlings can be fenced off from grazing stock using chicken wire if deemed necessary. Controlled grazing can be used as a form of predator control. It may be that intermittent grazing is the best way to conserve populations of jewelled geckos because, in theory, this will keep rodent numbers low whilst minimising the potential damage to the habitat. In addition, grazing may only be beneficial (or necessary) in areas of fragmented shrub-land (surrounded by pasture) and not beneficial in areas where the canopy is intact (see *fig.* 20). As illustrated above, it is currently not known which level of grazing is most effective for conserving jewelled gecko populations or increasing abundance; therefore further research on this matter is clearly needed.

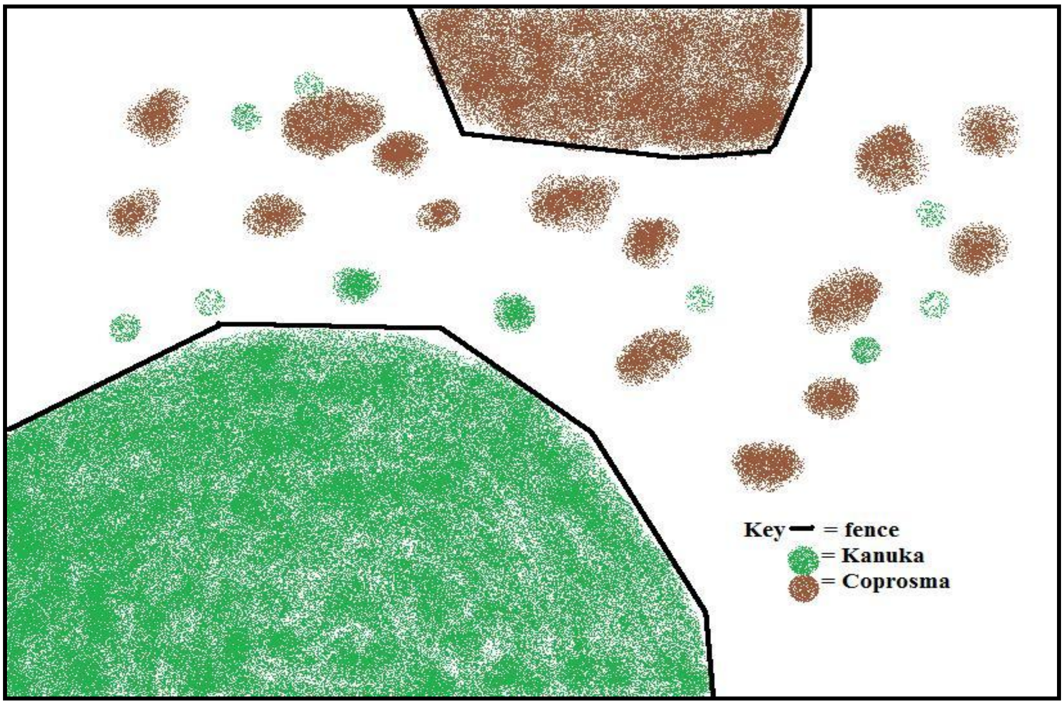

Fig. 20. In this hypothetical example, areas where grazing is likely to be beneficial can be prioritised. For instance, areas where the habitat is consistent and there is little rank grass can be fenced off from grazing animals; whereas areas of fragmented habitat which are surrounded in rank grass can be grazed in order to control rodent abundance.

7.4 Management recommendations:

The final section of the report will outline appropriate suggestions for effective management of the NGLR and the hilltop site. These recommendations will be listed in order of priority.

NGLR

1) Grazing: Introduce an appropriate stocking density of sheep to the NGLR which will prevent introduced grasses seeding in large quantities and thereby keep rodent abundance low. Sheep should be closely monitored to determine their effect on the *Coprosma*. If sheep are observed grazing on *Coprosma* seedlings, these may need to be fenced off with chicken wire. It would also be advantageous to graze or remove rank grass from the area immediately surrounding the reserve, in order to further reduce rodent abundance.

2) Removal and control of weeds: Remove all gorse from the NGLR. Remove mahoe, ngaio and broom from areas where it is shading jewelled gecko habitat. Working bees could be held a couple of times per year to remove weeds and keep the reserve in good condition. This should promote the growth and spread of *Coprosma* sp. and kanuka/manuka thereby providing more potential habitat for jewelled geckos.

3) Frequent monitoring: Frequent monitoring is necessary to determine the effect of the manipulations. Monitoring of rodents and mustelids should continue in order to determine whether the re-introduction of grazers / removal of rank grass results in the predicted reduction in rodent and mustelid activity. In addition, visual searches should continue at the site to determine whether re-colonisation of jewelled geckos occurs. If any re-colonisation occurs or a translocation takes place, it is vital that the reserve and any jewelled geckos present are constantly monitored due to the ongoing potential threat of poaching. The neighbours and anyone visiting the reserve should keep an eye out for any suspicious activity.

4) Removal / modification of fence: The fence should either be removed or the height of the fence modified. The fence should also be breached in several locations in order to

prevent animals from becoming trapped inside. This may also assist re-colonisation by jewelled geckos by making it easier for them to enter the reserve from the outside (although apparently they can move through the chicken wire). Make the reserve less conspicuous to poachers by reducing fence height.

The hilltop site

1) Grazing: The hilltop site provides a unique opportunity to test the response of jewelled geckos to the removal of grazing stock. As previously stated, this site was being intermittently grazed until approximately one year ago. Grazing is not likely to be re-instated in the immediate future. Therefore this provides an opportunity to assess the impact of the removal of stock on predator numbers and jewelled gecko abundance. If a decline in jewelled gecko abundance is detected, re-introduction of stock is recommended. If stock is not available, rank grass could be removed using grass cutters.

2) Increasing the habitat available: At the hilltop site the population appears to be isolated and may be constrained by a lack of habitat (e.g. *Coprosma* sp.). Therefore with the permission of the landowner, the habitat available could be increased by planting of *Coprosma*. In the long-term planting could be used to link the population on the hilltop to the NGLR. There is currently little habitat between the NGLR and hilltop site except for a few, isolated patches of *Coprosma*. Therefore planting in the gaps between these patches to reduce the distance needed to be travelled between bushes is recommended. This may provide a corridor of habitat to promote the spread of the population on the hilltop in the direction of the NGLR and thereby assist re-colonisation.

3) Frequent monitoring:

Frequent monitoring of the hilltop site is necessary to access the impact of the removal of stock. Monitoring of rodents and mustelids should continue in order to determine whether the absence of stock results in an increase in rodent and mustelid activity as predicted. In addition, visual searches should continue at the site to access the impact of the removal of stock on jewelled gecko abundance.

7.5 Conclusions

The original motivation behind the establishment of the NGL reserve was to gain basic knowledge needed for the conservation of jewelled geckos. Protection against most mammalian predators (except rodents) and habitat modification should have caused the population in the NGLR to increase, however it is apparent that the opposite has occurred and the population has declined to the point of likely extinction. Nonetheless, it is thought that through this eventuality, valuable knowledge necessary for the conservation of jewelled geckos has been gained.

After establishment, the reserve was fenced off and introduced stock removed in an attempt to protect the habitat for the benefit of the jewelled geckos present. In a time where information on the basic habitat requirements of jewelled geckos was virtually non-existent, this was considered the best way to conserve populations. However, this strategy may have inadvertently contributed towards population decline by providing conditions indicative of high rodent abundance.

Even though (prior to recent efforts) the management of the reserve has been largely ineffective, much can be learned from what has occurred. For instance, those in charge of management at other sites where jewelled geckos are present should consider the potential repercussions of removing stock from fragmented shrub-land habitat.

Preliminary findings from this report have influenced the future management direction taken by STOP at the NGLR. The new management direction aims to restore the habitat to a similar state to when the site supported a large population of jewelled geckos. It is hoped that this new management regime will result in either the re-colonisation of the reserve or the production of a site suitable for future translocation. Either way, it is hoped that one day jewelled geckos will again be abundant in the *Coprosma* bushes at the NGL reserve.

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Thanks

Photo: Carey Knox

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Appendix

List of figure titles

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