Population decline in the skinks *Oligosoma otagense* and *O. grande* at Macraes Flat, Otago

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ABSTRACT

It is thought that grand skinks (*Oligosoma grande*) and Otago skinks (*O.otagense*) now only occupy 8% of potential habitat in Central Otago. Surveys of the Macraes Flat area were conducted on privately owned land (pasture) and tussock land under Department of Conservation stewardship, and the data were compared with those from earlier surveys. Grand skink populations showed a decline in rock occupation in the north-east end of the pasture site, in which nine populations were lost. Mean population numbers and habitat characteristics indicated that these were once large and established populations. In addition there was a loss in the occupation of 'transient' rocks, i.e. rocks that occasionally have skinks which are not considered to be resident. These results indicate that there have been sporadic declines in grand skink populations in the pasture area: one, in 1995, appeared to be the loss of transient populations, and a second, in 1999, was a decline of larger populations. In the tussock site, lost populations were balanced by gained populations and evenly distributed throughout the tussock study area, suggesting that these were fluctuations of a healthy metapopulation. Wider distribution surveys showed a dramatic decrease of 124 grand skinks in the Emerald Stream catchment from 1996 to 2000; there was also a decline in Otago skinks, although this was less pronounced. The south-western catchment of Manuka Stream showed a decrease in Otago skinks since 1995, while Deighton Creek showed an increase of 80 Otago skinks. The factors which cause skink populations to decline are still unknown, although they are thought to involve habitat degradation. The decline in the wider distribution may also be due to modified habitats. The greater decline in grand skinks, which inhabit the tops of ridges, than Otago skinks, which inhabit gully sites, might have occurred because ridge habitats are more likely to be modified by agriculture than gully habitats.

Keywords: grand skink, Otago skink, *Oligosoma* spp., population surveys, habitat change, rock tor occupation, Macraes Flat, Otago, New Zealand.

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1. Introduction

The grand skink (*Oligosoma grande*) and the Otago skink (*O. otagense*) are two of the largest species of lizards endemic to New Zealand. Like most endemic species, their range has been reduced over the past 150 years, probably due to loss of habitat and introduced predators. They are strongly saxicolous, inhabiting the deeply creviced schist rocks that are prevalent in the Cental Otago area. It is here that the only remaining populations are found (Whitaker & Loh 1995). Extensive surveys of the entire Central Otago area in 1984–89 have revealed that their distribution is patchy and localised, these skinks occupying only 8% of their potential range (Whitaker & Loh 1995).

Estimates of population numbers vary from 1400 Otago skinks and 1800 grand skinks (Patterson 1992) to 5000 of each species (Whitaker & Loh 1995). The largest remaining populations occupy a small area 5 km due south of Macraes Flat, whilst smaller populations exist between Hyde and Macraes Flat, in the north, and Sutton and Pukerangi, in the south. Scattered populations can be found in the Lindis River catchment, and a small population of grand skinks has been found near Lake Hawea (Whitaker & Loh 1995). Although populations of both species are small and scattered, they exhibit population densities that are sufficiently high in some localised areas to allow management and protection (Whitaker & Loh 1995).

Predation from introduced animals, pest control operations, and habitat degradation causing intra and inter- specific competition for reduced resources are postulated causes for the decline in skink numbers for both species (Daugherty & Towns 1994; Whitaker & Loh 1995). A demographic feature which increases the vulnerability of these populations is that they exist as small fragmented populations spread over a wide area (Whitaker & Loh 1995). However, it has been hypothesised that both grand skink and Otago skink populations exist as metapopulations in which local (rock tor scale) extinctions are balanced by recolonisations through dispersal between rock tors (Stanley 1996; Whitaker 1996; Houghton 2000).

Grande Ridge lies on the north-western boundary of the Redbank Conservation Area at Macraes Flat (45°24´ S, 170°24´ E) and has a relatively dense skink population (Whitaker & Loh 1995). The ridge is divided by the boundary fence line between tussock grassland (Redbank) and farmed pasture (Sutton's). Redbank is a tussock grassland reserve purchased by the Department of Conservation (DOC) in 1993 for skink conservation and Sutton's Farm is private land converted from tussock to pasture in 1980–82.

Preliminary surveys of Grande Ridge in 1986 and from January 1994 to April 1995 have indicated that grand skink populations are depressed in modified habitats (Whitaker 1996). Whitaker (1996) showed that both the minimum population density and the number of sites occupied in the pasture area were much less than in the tussock area. Assuming there was an equal population density in the whole study area prior to 1980 (Whitaker 1996), there has been a considerable decline in grand skink populations in the pasture habitat (both individual skink numbers and local population numbers). Monitoring of this area has continued on an annual basis (1996–2001), with presence/absence surveys of all rock tors in the Grande Ridge area.

The greater area to the east and south-east of Grande Ridge has also been surveyed, although at less regular intervals and not as vigorously as the Grande Ridge study area. These wider distribution surveys record the occurrence of grand skinks and Otago skinks every 2–5 years.

Recently completed surveys suggest that both skink species are declining (D. Houston pers. comm., G. Loh pers. comm.). This report makes an assessment of the data collected to date, from the study area and the wider distribution, and determines if the populations of these skinks are declining in these areas.

2. Study area and wider distribution

Vegetation in the Macraes district is dominated by close-cropped grassland of introduced pasture species. Remnants of indigenous vegetation (tall tussock (*Chionochloa rigida* and *C. rubra*), matagouri (*Discaria toumatou*), manuka (*Leptospermum scoparium*), kanuka (*Kunzea ericoides*), *Olearia* spp. and *Coprosma* spp.) are subject to extensive grazing, infrequent burning, oversowing and aerial fertilisation (Whitaker 1996).

The Grande Ridge study area is approximately 250 ha and extends NE/SW along a ridge top. A fence line marks the boundary of two properties and divides the study area roughly in half, between the Redbank Conservation Area (tussock) and Sutton's Farm (pasture). The tussock side has never been cultivated, has not been burnt since 1984, and was only partly fertilised once in 1990. The vegetation surrounding tors here consists predominantly of tall tussock grasses (*Chionochloa rigida, C. rubra, Poa cita,* and *P. novae-zealandiae*) with mosses, sub-shrubs and herbs interspersed among them. Where the tussock is less dense, there is an increasing proportion of introduced pasture grasses and weeds (Whitaker 1996). Between 1980 and 1982 the property owned by Sutton (pasture) was cultivated and tussock was replaced with permanent pasture, notably ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). The area has since been intensively grazed by sheep and cattle and artificially fertilised on a regular basis. Some tussock remains in the pasture area where cultivation was not possible due to steep slopes or shallow soil depth.

Deighton Creek and Manuka Stream were catchments identified in addition to Redbank Reserve and Emerald Stream as areas critical to the conservation of Otago skinks and grand skinks (Whitaker 1987). Consequently these areas and the Black Rock catchment have been included in wider distribution surveys. The first intensive survey was in 1983. Not until 1996 was a similar survey undertaken, and since then, notably in the last 5 years, the wider area has been geographically subdivided, labelled, and surveyed again (see map, Appendix 1).

As well as annual presence/absence surveys of the Grande Ridge study area, current management by DOC involves assessing the effects of grazing and predation on skink populations. An intensive mark and recapture programme has been undertaken at three sites on Grande Ridge (population study sites) and two gully sites in Emerald Stream catchment. This programme runs from 1996 to 2002 (M. Tocher unpubl. report 1997).

To detect decline in the grand skink metapopulation, the total loss of local populations must be determined. A metapopulation is a collection of local populations in which local extinctions can be balanced by recolonisations. When the loss of local populations outweighs the number of recolonisations it may indicate that there has been a total population decline.

In addition, to detect if there has been a decline in their wider distribution, surveys of total numbers of both skink species will be compared in areas that have been surveyed more than once.

3. Methods

3.1 ROCK OCCUPATION ON GRANDE RIDGE

Rock count surveys (1994–2001) were combined with additional survey data from 1986 (collected by Ian Southey) and population counts obtained during skink captures from DOC population study sites (up to Feb 1996 only). Although survey methods differed, the combination of all data was deemed appropriate for determining presence and absence of skinks on particular rock tors over time. Moreover, different survey methods were thought to mainly influence minimum skink numbers, because the emphasis has been on finding skinks at a site rather than the total number there. The pressure to use good weather to cover as much habitat as possible means that rocks with high numbers were only visited briefly. Survey information from January 1985 and April 1992 that recorded only skink presence was included as additional information for categorising rock population types (see below).

Rock count surveys after 1995 followed the methodology used by Whitaker (1996), so data could be combined for analysis. Whitaker found that where a maximum of three separate searches was made during each survey period, > 80% of the sites where grand skinks are known to occur were identified on the first visit and > 93% by the second count (Whitaker 1996). The surveys after 1995 included once-only scans of all rock tors in tussock and pasture in the study are,a assuming an 80% chance of finding skinks on an occupied tor. The 120 randomly selected 'study' rocks continued to be surveyed three times each year. Survey methods in 1986 consisted of single searches of all rock tors on Grande Ridge, with presence/absence and minimum skink numbers recorded for occupied rocks. It was assumed that the probability of detecting skinks in 1986 was the same as in later surveys. There was some uncertainty over the area surveyed in 1986 as it was undefined at that time, but it was assumed that the area covered was similar in later surveys. Population data at the study site consisted of the number of skinks counted on a rock during a single capture session. Survey methodology for January 1985 and April 1992 involved recording skink numbers on occupied rocks in smaller study sites on Grande Ridge and did not include unoccupied rocks.

To determine accuracy of measurements of population decline from the survey data it was recognised that there were several factors that might contribute to any changes in rock occupation, namely local population extinctions, local population colonisations, and rocks that sometimes had skinks where they were not usually resident (here called 'transient' rocks). Not all rocks were surveyed every year, but rocks that had been searched for at least six of the ten surveys were considered to have relevant information for determining rock population types. By using the survey data as an historical record for each rock tor (years 1986, 1994–2001), rock populations were categorised into the following rock population types.

Occupied rocks

Stable skink populations (Mostly occupied). Rocks that had been occupied in five or more of the ten surveys and occupied during 2000–01.

Occupied transient rocks (Occasionally occupied). Rocks that have been occupied in four or less of the ten surveys and occupied at least once during 2000–01.

Gained populations. Rocks that established a population between 1996 and 2001.

Rarely surveyed. Currently occupied rocks which were surveyed less than three times so that not enough data exist to accurately categorise them.

Unoccupied rocks

Never had skinks. Rocks that had not once been occupied.

Unoccupied transient rocks (Occasionally occupied). Rocks that were occupied in four or less of the ten surveys and unoccupied during 2000–01.

Lost skink populations. Rocks that had an established population but were unoccupied during 2000–01.

Rarely surveyed. Currently unoccupied rocks which were surveyed only since 1999 so that not enough data exist to accurately categorise them.

Unknown rocks

Rocks that once had skinks. Data that showed skink occupation, but the rocks were not surveyed in recent years, thus making categorisation impossible.

It was decided that transient rock populations should be analysed separately as lost and gained populations. In a metapopulation there will be a certain number of unoccupied rocks at any point in time. These rocks have the potential to become recolonised and are considered available skink habitat. Transient populations were considered to be neither lost or gained, but these rocks could be occupied or unoccupied at any time. It was therefore difficult to differentiate between unoccupied transient rocks that were temporarily unoccupied and transient populations that had subsequently become extinct. It was deemed a more conservative approach to categorise potentially lost transient populations as transient populations. This allowed for the detection of population decline in two parts of the population dynamic, namely the difference between lost and gained populations, and the change in the proportion of transient rocks occupied over time.

In this report we attempted to determine if grand skink populations on Grande Ridge have declined by investigating the following:

- Rock occupation by skinks between 1986 and 2001.
- Change in rock occupation of established skink populations (extinctions and recolonisations).
- Change in transient rock occupation (number of transient rocks occupied).
- Mean population sizes for different rock population categories.
- Means of physical habitat characteristics of rock tors relating to rock population categories.

The proportion of total rocks occupied was calculated for each year (all rock population categories combined) in tussock and pasture separately.

To detect any decline in grand skink populations, the net change in rock occupation (difference between local extinctions and colonisations) was determined for both tussock and pasture habitat separately. The difference between lost populations and gained populations was divided by the original total number of rock populations (excluding occupied and unoccupied transient rocks, i.e. total populations = stable skink populations + lost skink populations. A final percentage change in grand skink occupation was determined and compared between tussock and pasture to determine if one habitat type had declined more than the other.

The proportion of transient rocks occupied currently and in past survey years was also calculated for both tussock and pasture habitat. As the purpose of this report was to determine the decline in the number of local skink populations from the existing population, rock tors that had never had skinks were not included as unoccupied rocks.

All proportions (proportion of total rocks occupied and proportions of transient rocks occupied) were compared using the *G*-test (the log likelihood ratio test: Sokal & Rohlf 1991; Zar 1996). This was chosen as an alternative to the chi-squared test, χ^2, for analysing frequencies as it is computationally simpler, especially in more complicated designs (Sokal & Rohlf 1991). The outcome of a *G*-test is a statistic, *G*, which is compared with the distribution of χ^2 in the same tables as the χ^2 test (Zar 1996). Differences in the percentage change in rock occupation between tussock and pasture were analysed by *G*-tests also.

3.2 ADDITIONAL POPULATION AND HABITAT FACTORS

To determine factors that might cause a decline in grand skink populations additional characteristics of rock tors and rock tor populations (including those that were stable, lost or gained, and transient) were compiled and compared.

Mean minimum skink numbers were calculated for every rock tor that had been occupied by skinks throughout the survey years 1986–2001 and the median and range of mean minimum skink numbers were calculated for rock population types. Habitat characteristics were collected for 60 randomly selected rock tors in tussock and in pasture (a total of 120 sites during the 1994/95 study). Additional characteristics collected at the DOC study sites (during 1997/98) were also included in the analyses (see Table 1 for description of habitat characteristics; these were not available for every rock tor in the Grande Ridge study area).

Means of continuous characteristics were calculated and compared between rock population type categories by analysis of variance, ANOVA (Datadesk 4.1). Of the eight rock characteristics, two related to isolation of a rock (rock density, nearest rock), three related to the size of a rock (rock size, transect length, number of elements), and three were related to available cover for a skink (number of crevices, number of loose blocks, number of plant species). The relative importance of all habitat characteristics (that describe the physical features of the rock habitat and its spatial location) to grand skink occurrence was determined by logistic regression (a multiple regression model: SAS 1995).

TABLE 1. CHARACTERISTICS MEASURED AT ROCK TORS.

Rock features	
Slope	Slope of terrain to degrees with slope meter 0–10° = 1, 11–20° = 2, > 20° = 3
Rock density/10 ha	Number of rocks within 178.5 m radius (of a rock tor) measured on an aerial photo
Distance to nearest rock	Straight line distance (m) to nearest skink-inhabited rock
Height	Measure or estimate
Length	Greatest distance of rock or rock cluster on ground
Width	Greatest width perpendicular to length on ground
Rock size	(Length × Width) × (1/2 Height): an approximate estimate of surface area
Orientation	Four compass points to define orientation of length measurement: NW = 0, N = 1, NE = 2, E = 3
No. elements	Number of rocks in a cluster
Rock form	Simple = 1, Broken = 2, Complex = 3
Dip strata	Slope of rock to the ground measured with a slope meter: 0–10 = 1, 11–20 = 2, > 20 = 3
Slope length	Combined length in metres of three transects from highest point to ground at west, north, and east
Crevice no.	Number of crevices within 0.05 m of the three transect lines
Loose slabs	Presence (= 1) or absence (= 2) of loose slabs
No. blocks	No. of blocks within the rock
Habitat quality	
Management	Modified = 0 (pasture), unmodified = 1 (tussock, and all gully sites)
Sun exposure	Record as early (E) or morning (M) to afternoon (A) or late (L): E – L = 1, E – A = 2, M – L = 3
Vegetation	Point analysis 10 m out from north, east, south, and west rock faces. Number of plots tussock, otherwise assumed to be pasture. 0 plots tuss. = 0, 1–2 plots tuss. = 1, 3–4 plots tuss. = 2
Plant species	No. of different fruiting plant species
Hetero-specifics	Presence (= 1) or absence (= 2) of other lizard species such as skinks *O. otagense, O. maccanni, O. polychroma* and the common gecko *Hoplodactylus maculatus*
Stock camp	Presence (= 1) or absence (=2) of stock camps within 10 m of rock
Rabbit sign	Presence (= 1) or absence (=2) of rabbit sign (droppings /scratching/burrows)
Possums	Presence (= 1) or absence (=2) of possum sign (animals or droppings)
Distance from origin point	
Distance from NE Point (m)	Origin point established far NE of the study site in line with the boundary fence line W
Distance from NW point (m)	Origin point established far NW of the study site perpendicular to the boundary fence line

3.3 WIDER DISTRIBUTION SURVEYS

To determine population fluctuations of grand skinks and Otago skinks, the same geographical location must be re-visited on separate occasions and the numbers of skinks observed at a particular location must be compared. 1983 surveys in the wider area were combined with surveys from 1996 and the two years 2000–01. Surveys were conducted when the weather was generally suitable for skink activity (Coddington & Cree 1997), although these conditions would have been different from year to year. First a tor or outcrop was scanned from a distance using binoculars. Secondly the tor was quietly approached and walked around and over, and thirdly all crevices were 'eyeballed'. This method of surveying will detect the minimum skink number at locations where skinks are present and absence cannot be reliably recorded.

In 1997 the entire wider area surveyed in 1983 was subdivided, based on geographic relativity. All skink rocks (tors considered possibly suitable for habitation) were subsequently labelled according to these areas. Redbank Reserve was divided into areas I, L, O, and Q, and the Emerald Stream catchment was divided into five areas, Wildlife, Falcon, Canyon, Emerald Stream, and Trig J. The Wildlife, Falcon, and Canyon sites carry (relatively) dense localised populations that have been surveyed independently on numerous occasions. For the wider distribution studies, the Wildlife and Falcon sites included the peripheral tors around these core populations. In 1983 these core populations were counted, but in 1996 population sizes were simply estimated to be > 15. To maintain consistency, core populations were also estimated to be > 15 for the 2000 survey. Data collected at localised populations in Urnip and Canyon during studies undertaken at different periods were also included. The lower Emerald Stream was surveyed in 1999/2000, but has been omitted from this analysis as it was surveyed for the first time.

South-west of Emerald Stream are the catchments Black Rock, Manuka Stream, and Deighton Creek, which were surveyed in 1984 and again in 1998/99. A Manuka Stream survey in 1995 is also included in the analysis.

Total numbers of Otago skinks and grand skinks observed in each year for Redbank, Emerald Stream, and south-west of Emerald Stream were compiled to provide an indication of whether population numbers were stable or in decline in the wider distribution area.

4. Results

4.1 ROCK OCCUPATION BY GRAND SKINKS

The proportion of available rock habitat occupied was similar over years in both tussock and pasture (Fig. 1). More than 47% (range 14–58) of available rock habitat in tussock was occupied between March 1994 and January 2001, with no significant difference between years ($G = 11.86$, d.f. = 9, $P > 0.05$; excluding Jan 1986 with 14% of rocks occupied; Fig. 1). The proportion of rock tors

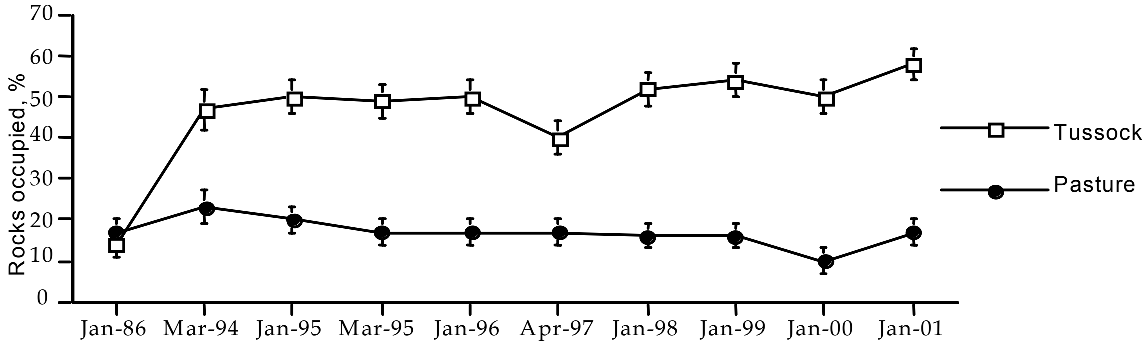

Figure 1. Proportion of total numbers of rocks occupied (percentage + SE) in tussock and pasture on Grande Ridge in survey years between 1986 and 2001.

occupied in pasture was below 23% (range 10–23) in all years, with no significant difference between years in the percent of rocks occupied (G = 7.65, d.f. = 9, $P > 0.05$). The proportion of total rocks occupied by skinks differed significantly between tussock and pasture habitats in all years (with the exception of Jan 1986; Fig. 1).

The investigation of local extinctions versus local recolonisations in tussock habitat showed seven local populations lost and eight populations gained. Lost populations were more or less evenly distributed throughout the tussock habitat between occupied rock tors consisting of both stable and gained populations (Fig. 2). In pasture habitat, seven populations had been lost at the north-east end of the pasture and two at its south-west end. There were only three gained populations at the south-west end, resulting in a total net loss of six populations (Fig. 2).

The net number of rock tors occupied in the tussock habitat increased by 1.5 ± 1.5%. However, pasture showed a 21.4 ± 7.9% decrease in the number of

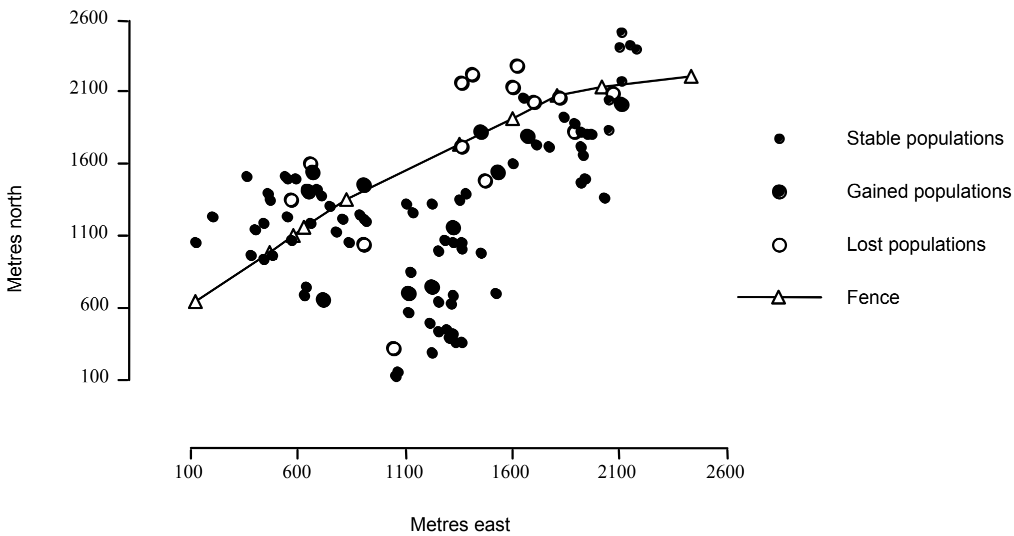

Figure 2. Lost and gained populations at the various rock tors in tussock and pasture at Grande Ridge between 1986 and 2001.

occupied rock tors resulting in a significant difference between the change in proportion of rocks occupied between tussock and pasture habitat (G = 10.7353, d.f. = 1, $P < 0.005$). When considering total population loss, the total number of rock tors occupied (tussock and pasture combined) had decreased by 5.2 ± 2.3%.

When the proportion of transient rocks occupied in each habitat were compared between survey years (Fig. 3), there was a significant difference between years for both tussock and pasture (G = 18.8804, d.f. = 9, $P < 0.001$; G = 32.5703, d.f. = 9, $P < 0.001$ respectively). The proportion of transient rocks occupied in the tussock habitat fluctuated between years, being low in Jan 1986 (6.7 + 3.8) and Jan 2000 (7 + 3.9) and high in Jan 2001 (34.1 + 7.2), while in other years it was between 15.6 + 5.5 and 25.6 + 7.1. In the pasture habitat there was no difference in the proportion of transient rocks occupied between Jan 1986, March 1994 and Jan 1995 (range 37.6 + 10.9 to 44.4 +12; G = 0.7066, d.f. = 2, $P > 0.05$) and there was no significant difference between tussock and pasture for these years. However, in March 1995 the proportion of occupied transient rocks in the pasture dropped to less than half of that in Jan 1995 (40.9 + 10.7 to 4.6 + 4.5), this being a significant difference (G = 9.2614, d.f. = 1, $P < 0.005$); from then onwards it was consistently low, with no significant difference between Mar 1995 and Jan 2001 (range 4.4 + 4.3 to 9.1 + 6.3; G = 2.8036, d.f. = 6, $P > 0.05$). In addition, the proportion of transient rocks occupied in the pasture was significantly lower than the proportion of transient rocks occupied in the tussock in all these years (except Jan 2000).

Transient rocks were evenly distributed within each habitat (Fig. 4) separated by rock tors that had stable populations, and those that had lost or gained populations (Fig. 2). Tussock had a higher proportion of occupied rocks (40 ± 7.4%) than pasture, in which only 13 ± 7.1% of rocks were occupied, with a significant difference between habitats (G = 5.6860, d.f. = 1, $P < 0.025$).

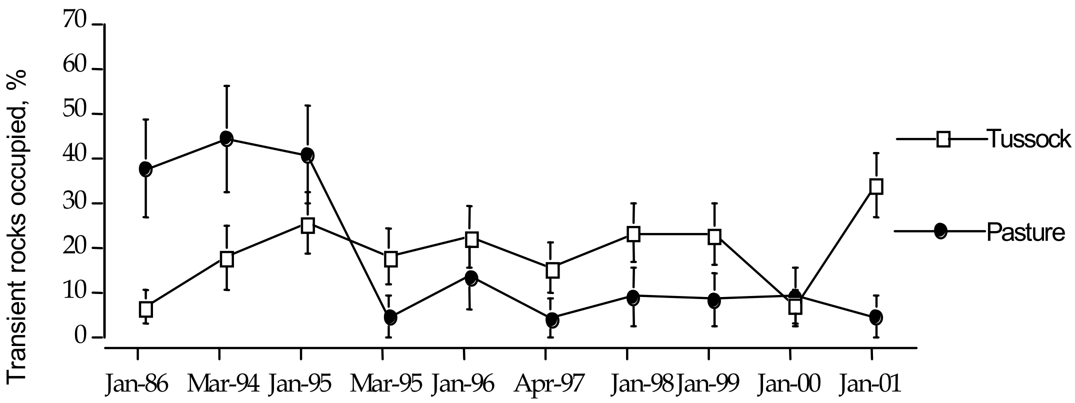

Figure 3. Proportion of transient rocks occupied (percentage + SE) in tussock and pasture on Grande Ridge in survey years between 1986 and 2001.

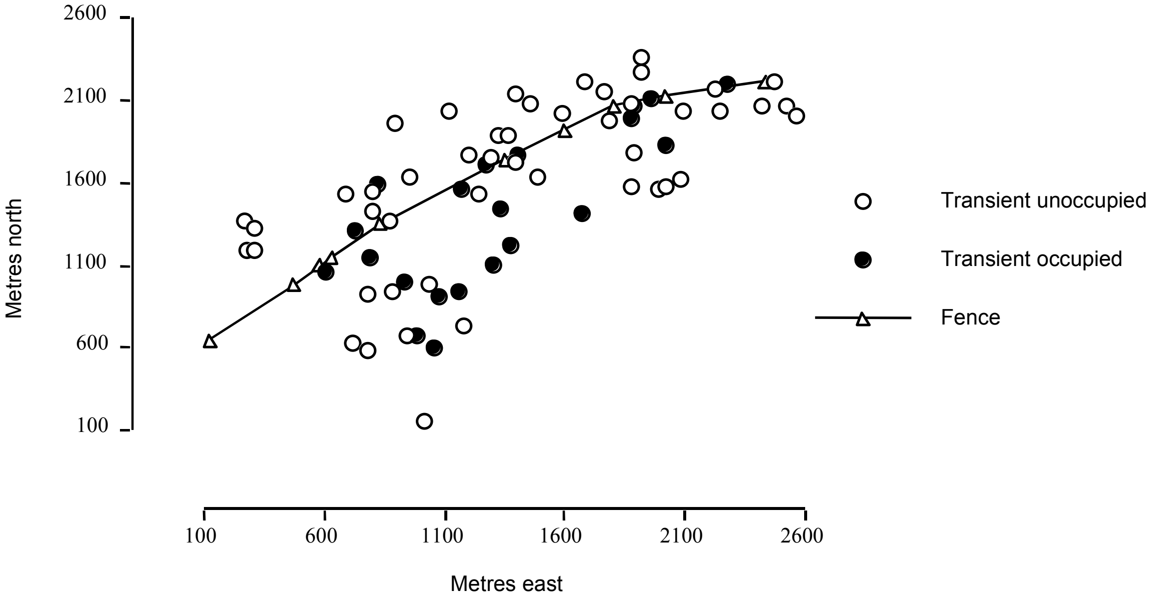

Figure 4. Transient rocks in tussock and pasture habitat that are currently occupied and unoccupied (determined from surveys between 1986 and 2001).

4.2 ADDITIONAL POPULATION FACTORS

4.2.1 Mean population sizes

Although differences between the medians of mean skink population sizes (over years) between rock categories in tussock were small (and tended to fall at the low end of the range of means), the median and range of means for stable populations was greater than for any of the other rock tor categories (Fig. 5). The median mean population size for stable populations in the tussock was 2.4 skinks, but mean population sizes ranged up to 13.2 ± 0.86 in this category.

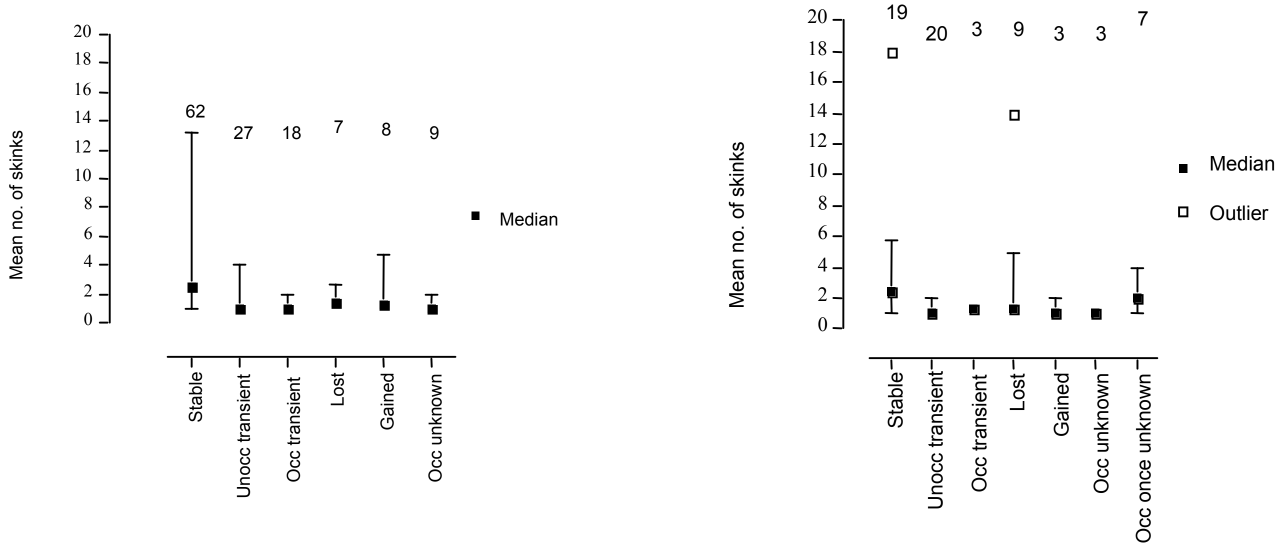

Figure 5. Range and median of mean skink numbers (in surveys of each rock tor between 1986 and 2001) for populations in tussock (left) and pasture (right).

In the tussock, both unoccupied transient rock populations and gained populations showed the next largest range of means compared twith the stable population category, with mean number of skinks ranging between 1–4 and 1.3–4.7 respectively. The upper mean of the range for unoccupied transient rocks (4 skinks per rock) was, however, distorted by the mean population size from only one rock tor, and the majority of the means were below 2.5 skinks per rock. The median mean size of skink populations for all rock types in tussock other than stable populations was between 1 and 1.3 skinks, therefore rock populations with a small range either side of the median mean population size (occupied transient rocks, lost rocks and occupied unknown rock tors) were likely to have only 1 or 2 skinks inhabitants when occupied (Fig. 5).

Stable populations in the pasture showed a similar median mean population size to stable populations in the tussock (2.5 skinks per rock). Pasture mean population sizes ranged primarily between 1 and 5.8; however, there was a single value of 18 skinks per rock (DOC Study site), so this rock was treated as an outlier to allow the mean population sizes for the majority of the rock tors in this category to be shown (Fig. 5). Lost populations in the pasture, unlike tussock habitat, showed the next largest range of mean population sizes. Means ranged from 1 to 4.9 in this category, with the median at the lowest end of the range (median mean number = 1). Unoccupied transient rocks and gained populations in the pasture both had a low range of mean population sizes (1–2 and 1–1.7, respectively). Median mean sizes of skink populations in pasture were similar to tussock with rock populations other than stable populations (between 1 and 1.3). Therefore rock categories with a small range either side of the median mean population size (unoccupied and occupied transient populations, gained populations, and occupied unknown populations) were likely to have only one or two skink inhabitants when occupied. There were also seven rock tors in the pasture habitat that had once had skinks but an unknown history. The mean population sizes for this category ranged between 1 and 4 which was similar to the higher-ranging categories.

4.2.2 Habitat features

In tussock habitat only two rock characteristics, transect length and number of plant species, differed significantly between the six rock types when all means were compared by ANOVA. Occupied rocks had a greater mean transect length than unoccupied rocks (mean 21.2, SE = 1.40; mean 12.6, SE = 0.45; $P = 0.0001$) and a greater mean number of fruiting plant species (occ mean 6.3, SE = 1.17; unocc mean 4.1, SE = 0.25; $P = 0.0126$). Although rock size showed no significant difference between rock types when all means were compared, there was a significant difference detected between the mean rock size of occupied rocks and unoccupied rocks (mean 21.2, SE = 1.40; mean 12.6, SE = 0.45; $P = 0.0001$). The highest mean values for rock size, transect length, and number of fruiting plant species were for the stable populations category in the tussock habitat.

Transect length showed a significant difference between means for the six rock types in pasture habitat, but there was no significant difference in number of plant species between categories in this habitat. The additional variable, number of crevices, was significantly different between rock type categories. There were no significant differences between occupied and unoccupied rocks for any of the rock characteristics, although lack of habitat data for rocks that had gained populations and occupied transient populations (both occupied categories) made comparisons difficult in this habitat. However, the highest mean numbers for rock size, transect length, and number of crevices were for lost skink populations. In addition, mean number of loose blocks and number of fruiting plant species, were highest for lost skink populations in pasture habitat.

The relative importance of the above eight variables with additional habitat characteristics describing type of habitat, habitat quality, and the position of rock tors in the study area were determined by logistic regression (a multiple regression model: SAS 1995). Both transect length and management (tussock or pasture) had a significant effect on grand skink occurrence ($P < 0.0001$ and $P < 0.0001$, respectively). The model predicted that rocks with greater transect lengths in tussock habitat would have a higher probability of being occupied by grand skinks, but when heterospecific lizards were present on a rock tor it was less likely that grand skinks would occur. Additionally the presence/absence of heterospecific lizards showed a significant relationship to the occurrence of grand skinks (this variable was run through the logistic regression individually, as missing data reduced the number of observations entered into the model when included with all other variables),

4.3 WIDER DISTRIBUTION SURVEYS

4.3.1 Emerald Stream catchment

Higher numbers of both Otago skinks and grand skinks were seen in the 1996 survey in the Emerald Stream catchment area than in surveys in 1983 and 2000 (Table 2). The decrease from 1996 to 2000 was most noticeable in the grand skink population, which declined from 415 to 240. Otago skinks declined from 178 to 155, although both years were higher than 1983 (Table 2).

When the Emerald Stream catchment was divided into the present five areas and the core sites Urnip and Canyon, thus enabling comparisons of populations between areas within this catchment, numbers of Otago skinks decreased in all areas between 1996 and 2000 except Wildlife, where there was an increase from 23 to 31. There was a sizeable decrease in the number of grand skinks observed from 1996 to 2000 in all areas except Trig J and Urnip, where numbers increased from 30 to 38 and remained at 27 skinks, respectively. The largest decline was in the Emerald Stream area between 1996 and 2000, where skink numbers decreased from 166 to 42 (Table 2).

4.3.2 Manuka Stream, Black Rock, and Deighton Creek catchments

There was a decrease in Otago skink numbers in the Manuka Stream catchment from 19 to 13 between 1995 to 2000; grand skink numbers at this site, however, had remained constant at 10 skinks for the same period (Table 2).

Black Rock and Deighton Creek have only two survey periods to compare from (1984 and 1999) and may have been influenced by the surveying errors as described above. However, at Deighton Creek there was an increase of 80 Otago skinks and four sightings of grand skinks in 2000, and at Black Rock grand

TABLE 2. NUMBERS OF OTAGO SKINKS AND GRAND SKINKS RECORDED IN THE WIDER DISTRICT AROUND MACRAES FLAT IN VARIOUS SURVEYS DONE SINCE 1983.

	OTAGO SKINKS						GRAND SKINKS					
Emerald Stream catchment	1983	1992	1993	1996	1999	2000	1983	1992	1993	1996	1999	2000
Urnip	0		0	1		0	0		27	26		27
Canyon		15		8	6			29		45	8	
Trig J	0			1	('98)5		17			30		38
Chloronoton	31			40		39	18			88		59
Falcon	33			50		28	21			65		45
Wildlife	34			23		31	25			40		29
Emerald	22			63		57	63			166		42
Total	120			178		155	144			415		240
Southern catchments	1984			1995	1999		1984			1995	1999	
Manuka Stream	10			19	13		0			10	10	
Black Rock	4				3		10				49	
Deighton Creek	39				119		0				4	
Redbank Reserve	1983			1997			1983			1997		
I gully	0			1			1			87		
L gully	0			5			60			95		

skink numbers increased from 10 to 49, while Otago skink numbers remained low (Table 2).

4.3.3 Redbank Reserve

Population sizes at catchment areas I, L, O and Q in Redbank Reserve were compared between 1983 and 1997. Grand skinks in L gully were estimated at 60 in 1983 compared with 95 in 1997, and there was an estimated increase from one in I gully in 1983 to 87 in 1997 (Table 2), although a large proportion of I gully had not been surveyed in 1983.

5. Discussion

The proportion of available rock tors occupied by grand skinks in both tussock and pasture between 1986 and 2001 did not provide any indication of decline in the total number of rock tors occupied by grand skinks. However, results were consistent with findings from Whitaker (1996). Less than half the available rock habitats were occupied in the pasture compared with the tussock habitat. The observed disappearance of particular rock tor populations in the pasture during the last two years of surveys (2000–01) suggested that 'Total number of rocks occupied' does not reveal the subtler factors of population decline, as a population that is lost will not be detected if another population becomes established at the same time. It was therefore concluded that factors such as local population extinctions and local population recolonisations may be more indicative of local population decline in the grand skink metapopulation.

5.1 LOCAL EXTINCTIONS AND COLONISATIONS

There has been a decline in the number of pasture rocks occupied as shown by the greater number of population extinctions compared with colonisations. The initial rock occupation in the pasture was low (less than half that of tussock), but the high decline there (21.4%) was to some extent counterbalanced by the increase in rock occupation in tussock habitat, which, though much lower as a percentage (1.5%) occurred in a much larger metapopulation. However, there was a net decrease of 5.2% in the total number of rock tors occupied.

5.2 OCCUPATION OF TRANSIENT ROCKS

An additional factor that may be related to the decrease in local populations in the pasture habitat is the significantly lower number of transient rock tors occupied than in tussock habitat. This difference appeared to be a result of a drop in the number of transient rocks occupied in the pasture between January 1995 and March 1995, prior to which the proportion occupied in the pasture was similar to tussock. Transient rock tors were considered to have a low number of skinks and erratic occupation making it difficult to distinguish between unoccupied transient populations and lost transient populations, so this drop in the pasture in 1995 may indicate transient populations that have become extinct. On closer inspection, there were six transient populations at the north-east end of the pasture habitat that could be considered lost as the rock tors have not been occupied since Jan 1995 and a further three at the south-west end have not been occupied since 1994. If these transient populations have been lost, it indicates an earlier decline further exacerbating the total decline of local grand skink populations in the pasture habitat. This decline occurred over a two-month period. The survey method was consistent over this period, so the result cannot be attributed to differences in data collection. It appears that the survey in Jan 1995 might have recorded the last existence of some of these populations. The speed of such a decline is of concern, although it has been suggested that a population decline is likely to be due to a number of sporadic declines rather than a slow decline over time (Whitaker 1996).

5.3 REASONS FOR DECLINE

Smaller transient skink populations may have been the first to be affected by habitat degradation, with habitats becoming vacated due to reduced food resources or they became extinct due to lack of vegetation cover for dispersing skinks (Whitaker 1996; Houghton 2000). The population distribution of grand skinks in the pasture is strongly clumped (Whitaker 1996). This may indicate loss of smaller transient populations (as shown in the analysis). These populations will have been important for linking larger populations together through dispersal. The loss of this connection may have resulted in increased isolation of some rock populations in the pasture. The limited ability of skinks to respond to habitat degradation when resources become scarce due to habitat degradation can result in regional extinctions (Gilpin 1987). Factors such as these may have influenced the subsequent loss of larger populations after 1999.

Habitat availability may additionally be influencing the decline in grand skink populations. A certain number of transient rocks will be unoccupied at any point in time and are considered important in a metapopulation as potential available habitat for recolonisations or dispersing skinks (Houghton 2000). In the pasture, habitat modification may have made much of it unavailable. Whitaker (1996) suggested that 'on rock' problems are not an issue for skink occupation as skinks appeared to be doing equally well on occupied rocks in both tussock and pasture. Habitat availability has been shown to influence the persistence of a species (Sarre et al. 1994). It is therefore suggested that reduced available habitat may be a factor causing the decline of grand skink populations in the pasture habitat. Agricultural development has been considered previously to be a threat to the survival of grand skink populations (Towns 1985; Whitaker & Loh 1995; Whitaker 1996). Livestock grazing can reduce vegetation on and around the rock tors, reducing key plant species important for shelter and food resources.

The fluctuating proportion of transient rocks occupied in the tussock habitat may indicate a healthy population with higher population numbers and greater dispersal survival. On the other hand, as transient populations have low numbers of skinks, fluctuations in the tussock habitat may have been a result of errors in detecting skinks between survey years. In any case, decline within local populations was not investigated. There has been concern over the decline at T46 (G. Loh pers. comm.), a population study rock in the tussock habitat, where numbers have dropped from 14 to 2 (minimum skink number; this study) between 1994 and 2001. In addition T43 in the same study area has shown a decline from 10 to 2 skinks over the same period. P60 (a large population in the pasture habitat) showed a drop in population numbers over six years previous to its eventual extinction. This suggests that a drop in skink numbers is an early indication of population decline. It should not be assumed that grand skink populations in the tussock area are necessarily stable or secure until the decline in numbers within local populations is investigated.

The accuracy of the survey data is important for the above analyses. Even when the weather is unsuitable for widespread skink activity, one or two dominant skinks are visible (Towns 1985; pers. obs.). The sites that were visited three times had a greater probability of detecting skinks than those visited only once. Probabilities of detecting skinks was shown by Whitaker (1996) to be higher in tussock than pasture, probably because a greater proportion of sites in the pasture have single animals. Additionally this suggests that there may be a larger error in detecting transient populations compared to stable populations, particularly for rock tors that are only visited once. However, there was no relationship between rocks visited only once and those that were categorised as transient rocks. Therefore the surveying method was considered to detect the majority of rocks that had skinks.

5.4 MEAN SKINK NUMBERS

With a limited time for field work and varying weather conditions it was not possible for all surveys to be done in identical weather conditions (Whitaker 1996). Activity levels of grand skinks vary widely with even minor changes in the time of day or weather (Patterson 1992; T.Murphy unpubl. report 1994; Coddington & Cree 1997). Therefore mean skink numbers were determined from minimum estimates of population size for each rock tor and were considered an indication of large and small populations. Mean population sizes indicated that stable skink populations were the largest populations in both tussock and pasture habitat, as was expected. Population sizes, however, were greater in the tussock than in the pasture. This result was not surprising as differences in minimum population density have previously been documented (see Whitaker 1996). Survey techniques that included minimum population numbers of large-population study rocks during capture periods would provide higher estimates than any other survey methods. Therefore differences between stable population sizes and other rock population categories might not be as great as shown in these results.

Transient populations in tussock and pasture were primarily small, with approximately 1–3 skink inhabitants when occupied. A single population in the tussock that may have been lost (unoccupied transient rock) with a mean of four skinks, indicated that originally transient populations in a healthy population might have been able to sustain larger skink numbers. Colonisations of empty available habitat and the establishment of new populations might have occurred readily due to the overflow of full rock populations. However, it has been some years since rock populations have been considered full, and current transient populations appear to be primarily roaming skinks that are unable to establish a population due to lack of mates (pers. obs.).

Gained populations in the tussock appeared to be well established (based on higher population sizes) compared with gained populations in the pasture. This may have been due to dispersal from large stable populations in the tussock. In the pasture habitat the low number of populated rock populations that are in close proximity may explain why there were few gained populations. In addition, habitat degradation may have reduced the carrying capacity of many potentially available habitats, restricting the establishment of new populations. Dispersal may also be more perilous in open terrain due to predators and extreme temperatures (Whitaker 1996), an it was suggested that skinks might have to move between rock tors to a greater extent to obtain resources when these are limited (Houghton 2000). Therefore individual skinks in the pasture may be continually moving between rock tors rather than establishing new populations.

Only small populations were lost in the tussock habitat whereas populations lost in the pasture habitat showed similar mean sizes to stable populations. This result was representative of the nine skink populations at the north-east end of the pasture habitat that had disappeared since 1999 (described as lost populations). These populations ranged in mean numbers of 1–5 skinks/rock over the years they were occupied, indicating that there were well established rock populations among them. Skink densities in pasture habitat have previously been considered low, with severely clumped distribution (Whitaker 1996). The lost populations in the pasture area were in close proximity to each other and therefore were probably a large clumped area of skink occupation, which would indicate a significant loss to the larger pasture population. As the mean population size range for rock tors once occupied but with unknown history may also indicate additional lost rock populations in the pasture habitat, it is imperative that additional information be gained for these rocks.

5.5 HABITAT CHARACTERISTICS

Stable populations in the tussock occurred on large rock tors with a high number of fruiting plant species. All occupied rock tors tended to be large (rock size and transect length) and have a high number of plant species in this habitat. Abundance and distribution of grand skinks has previously been related to the size of a rock tor (Stanley 1996; Whitaker 1996), and the distribution of grand skinks was related to the number of fruiting plant species on a rock tor (Whitaker 1996). The size of a rock tor will determine the carrying capacity of the habitat, the availability of basking areas, and competition for space and food (Murphy 1994). Fruiting plants are representative of habitat quality, providing fruit for the diet of grand skinks (Whitaker 1987) and often providing shelter from the heat of the day (Houghton 2000). In addition it has been suggested that rocks preferred by lizards might be those that favour plant diversity (Whitaker 1996).

In the pasture habitat, the lost populations were those that had inhabited larger rock tors as opposed to stable populations. This was contrary to what was shown in the tussock and what was expected for lost populations, as small populations are usually considered to be more likely to become extinct than large populations. The diversity of fruiting plants species is often reduced in degraded habitats (Whitaker 1996) such as the pasture and may be the factor that causes the disappearance of these populations, even though the mean number of fruiting plant species was higher for lost rocks than other pasture rocks. The number of crevices (significantly high for lost populations) may be important for shelter particularly when there is limited vegetation cover. Additional variables relating to rock size (rock size) and available cover (loose blocks), although not significant, suggested that lost populations in the pasture were from larger rocks, further indicating that lost populations were once established populations. P60 is an example of a large population in pasture that was lost from a large rock tor with high vegetation cover, which had been considered a ‘good rock’ for skink occupation and had had a reasonably high number of skinks (10, minimum number). The loss of this population and other similar populations in the pasture suggests that there may be other factors involved in the loss of populations.

On Grande Ridge also, transect length (rock size) and management (tussock or pasture) were important in determining the occurrence of grand skinks on Grande Ridge. This result was consistent with results of Whitaker (1996). Grand skinks were also less likely to occupy rocks where there were other lizard species, suggesting competition from these species, although the persistence of common skinks in the modified habitat suggests their presence is more likely to represent degraded habitat (Houghton 2000).

It was hoped that additional variables that located the position of each rock tor in the wider area (in relation to two chosen origin points) might have detected the low occupation in the north-east end of the pasture habitat where populations have become lost. However, neither variable was indicated as important for skink occupation. This suggests that the position of a rock tor on Grande Ridge has no relevance to skink occurrence, although the difference between pasture and tussock in skink occupation might indicate a different measurement for the position of a rock tor on Grande Ridge might be more likely to show a relationship to rock occupation.

5.6 WIDER DISTRIBUTION

Factors of weather (sun exposure, air temperature), and observer skill and familiarity with the sites all contribute to potential errors in data collection. The apparent 'increase' in numbers of both Otago skinks and grand skinks in the Emerald Stream catchment from 1984 to 1996 might have been due to better knowledge of the site, better knowledge of the species, more experienced personnel and longer time spent surveying (T.Whitaker pers. comm. 1998). This might indicate that more skinks were present in 1984 than were observed. With the continued use of experienced personnel and detailed survey areas, the data collected from 1997 to 2000 were likely to be at least as accurate as the 1996 surveys.

Taking this into consideration, the data show a dramatic decrease in the grand skink population in the Emerald Stream catchment from 1996. When the smaller areas of the catchment are analysed, it is found that the greatest decrease comes from the Emerald Stream area itself (not to be confused with whole Emerald Stream catchment).

In comparison the Otago skinks have declined in numbers as a whole, but not nearly to the same extent as grand skinks. This might be due to the difference in habitat preferences (Towns 1985). Habitat degradation is more pronounced in the ridge habitats favoured by grand skinks than gullies, suggesting grand skink populations are more at risk.

6. Conclusions

The evidence of lost populations on Grande Ridge in pasture since 1999 and the loss of small transient rock populations in 1995 could indicate that there has been a semi-continuous decline over time that began with the loss of small populations and continued with loss of larger populations. Some larger pasture populations have been lost at the north-east end of the pasture habitat since 1999. These populations were in close proximity to each other, representing a significant change in grand skink distribution in this habitat. Gained populations were not enough to balance these local extinctions.

In tussock, lost populations balanced by colonisations were distributed evenly throughout the habitat, suggesting changes in rock occupation of a healthy metapopulation, especially as transient rock occupation also fluctuated over the years. However, this does not consider the observed declines of numbers in local populations, which may indicate early population decline.

The wider distribution analyses suggested that there might be declines in some areas, but additional surveys in areas surveyed previously will allow for more accurate comparisons. This is important if there are actual declines, as numbers can decrease rapidly over the few years that elapse between the wider distribution surveys.

It was suggested in 1995 that the decline in grand skinks in the pasture might have been due to a series of sporadic declines resulting in a net loss, and that the decline in the grand skink population was likely to continue to extinction (Whitaker 1996). The present analysis indicated two sporadic declines in skink populations in the pasture habitat since 1995; the first was the disappearance of transient populations, and the second started with a drop in skink numbers within larger local populations that resulted in their eventual extinction.

It is still not certain what is causing this decline, although habitat degradation appears to be an influential factor at both Grande Ridge and the wider area. It has been noted that ploughing and resowing of tussock grassland threatens remaining skink populations in the Emerald Stream catchment area (Whitaker & Loh 1995).

Grand skink populations are best maintained by the protection of tussock grassland where conservation of grand skinks is important (Whitaker 1996). However, on private land the only option appears to be to protect rock tor habitats from the effects of stock grazing by erecting deterrent fences to increase habitat quality or providing tussock corridors between rock tors (as suggested by Whitaker 1996). There would need to be negotiations with landowners if such projects were to proceed.

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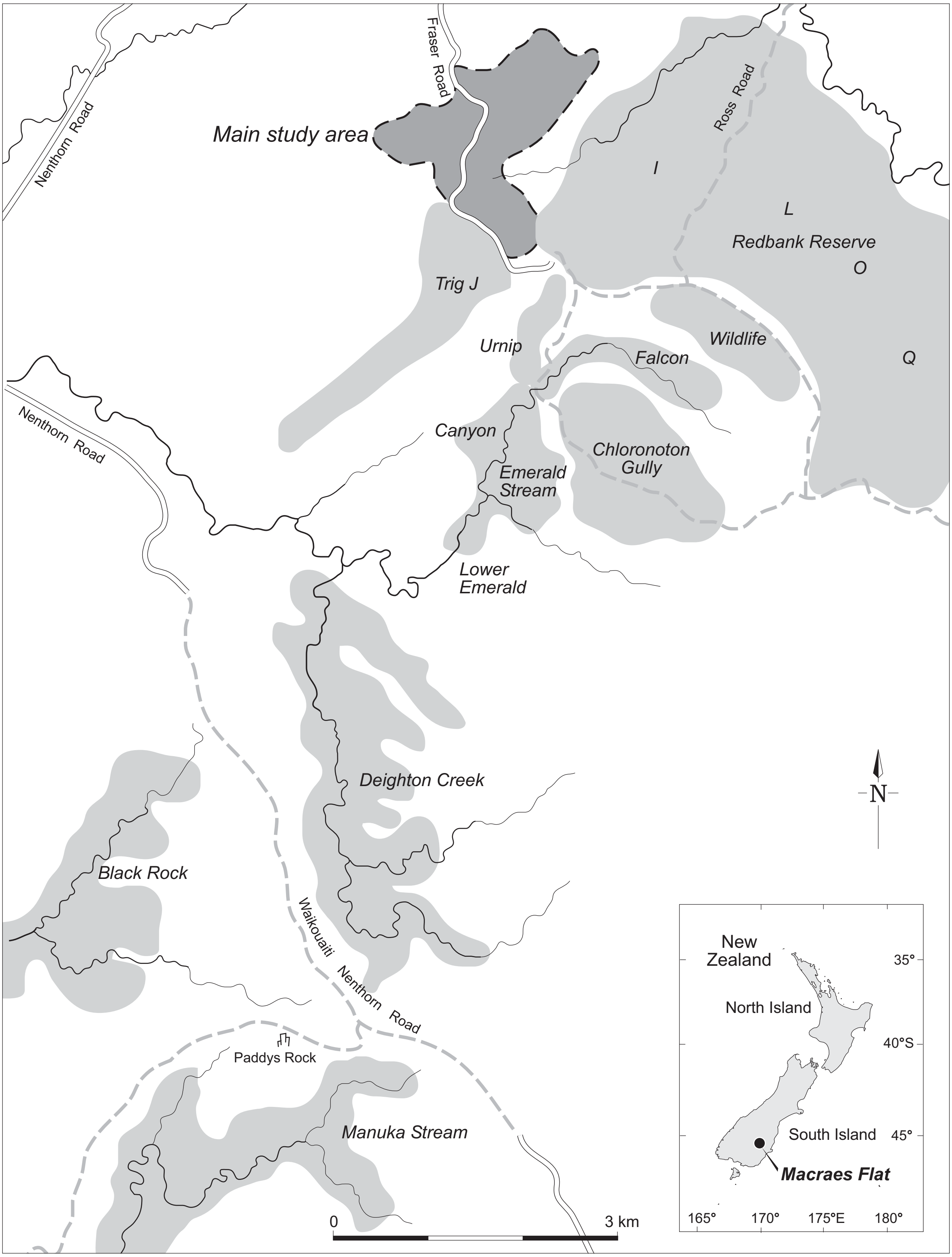
Appendix 1. Map of Macraes Flat



Location of Macraes Flat, showing study area (dark shading) and wider distribution sites (light shading) of skinks.