Impact of agricultural development on grand skink (*Oligosoma grande*) (Reptilia: Scincidae) populations at Macraes Flat, Otago, New Zealand

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Abstract

Grand skinks (*Oligosoma grande*) are strongly saxicolous and occupy scattered rock outcrops in tussock grassland in Central Otago. A study of grand skink population performance in relation to agricultural development was undertaken between January 1994 and March 1995 on a 150 ha study area of relatively unmodified tussock grassland and an immediately adjoining 100 ha area that had been converted to introduced pasture in 1980-1982. In the relatively unmodified area local grand skink populations were distributed at random over outcrops, but not all outcrops offering preferred habitat were occupied. Documented local extinctions, recolonisations and extensive movements indicated grand skinks in this area existed as a metapopulation. In the adjoining area, in the 14-year period following conversion of the tussock to improved pasture, it appears both the number of local skink populations and the minimum total population density halved, and the spatial distribution of the remaining populations became markedly clumped. The lack of differences in a variety of population parameters (e.g., mean local population size, age and sex ratios, body condition, fecundity, home range size, behaviour) between sites in pasture and tussock indicated the causes of decline were not associated with "on-rock" factors, but neither could any detrimental "on-rock" factors be identified. The most likely cause of the collapse of the grand skink population in pasture was that the changed environmental conditions between the outcrops after agricultural development meant that the ability of grand skinks to move between sites was impaired. Important implications for conservation are that: dense tussock cover should be retained wherever grand skink conservation is planned; areas selected for the conservation of grand skinks should be large enough to contain sufficient local populations to maintain population dynamics and permit extensive between site movement; and grand skink populations will probably never survive for long after tussock grassland is converted to improved pasture.

1. Introduction

The grand skink (*Oligosoma grande* (Gray 1845)) is one of New Zealand's rarest lizards and a species for which there is grave conservation concern (Molloy & Davis 1994). It occurs only in Central Otago, is diurnal and heliothermic, and is strongly saxicolous (rock-dwelling), inhabiting deeply-creviced schist outcrops in tussock grassland (Whitaker & Loh 1995).

Extensive surveys into the distribution and abundance of grand skinks, made between 1984-1989 and covering all of Central Otago, showed they now occur over only about 8% of their potential range and even within this area their distribution is very patchy and localised (Whitaker & Loh 1995). Estimates of the total number of grand skinks remaining vary from 1,800 (Patterson 1992) to

5,000 (Whitaker & Loh 1995). Amongst the possible reasons advanced for the apparent decline in range and numbers of grand skinks are habitat destruction or degradation, predation by and competition from introduced species, and the impact of pest control operations (Whitaker & Loh 1995; Graeme Loh, pers. comm. 4 August 1995) - all factors that pose on-going threats to the long-term, or even medium-term, survival of the species.

Although studies to date have indicated that agricultural development - destruction of the tussock grassland through burning, ploughing, and re-sowing - is inimical to grand skink populations, and localised extinctions at several modified sites have been documented (Whitaker 1988), there has been no clear measure of this impact nor have the mechanisms causing it been identified. Development continues apace and is now encroaching on to the largest remaining populations of grand skinks.

Preliminary work undertaken early in 1988 in the vicinity of the Redbank Conservation Area (established by the Department of Conservation in 1993 to secure significant grand skink habitat and populations) showed that grand skink populations were depressed in modified habitats relative to those in less-modified sites nearby (Ian Southey, pers. comm. December 1988). The present study was designed to quantify and test this observation and, if proven, to try and identify the mechanisms involved and make recommendations on land management for the Redbank reserve.

2. Study area

The study site (45 25'58"S; 170 24'46"E) is 5 km due south of Macraes Flat, north Otago. It is on the north-western boundary of the Redbank Conservation Area, an area recommended for reservation because it contains some of the largest remaining populations of grand skinks (Whitaker & Loh 1995).

The topography of the Macraes district is typical of the Otago block mountain formations with prominent landforms (ridges, valleys) aligned NE/SW, the ridges having steeper slopes to the SE and more gentle slopes to the NW, and a rectilinear drainage pattern. The underlying lithology is chloritic quartzo-feldspathic schist in subzone IV of the Haast group, characterised by strong schistosity and strong foliation (hutch 1963). Erosion has created numerous free-standing outcrops (tors) on ridge tops and semi-continuous outcrops along streams. Subsequent weathering of these exposed rock surfaces has left most outcrops deeply creviced and created many loose slabs - the habitat of grand skinks.

In the mid-Holocene (from = 7,500 yr B.P.) the grasslands and shrublands of Central Otago were replaced at low elevations by podocarp, then podocarp beech (Nothofagus), forests which spread as a result of increasing precipitation and decreasing temperatures (McGlone *et al.* 1995). When the climate warmed and became drier in the late Holocene (2,000 yr B.P.) widespread natural fires led to increasing deforestation, and from =600 yr B.P. onwards anthropogenic fires accelerated the return to tussock grassland. In prehistoric times the vegetation of the Macraes district was predominantly tall tussock grassland (narrow-leaved snow tussock *(Chionochloa rigida)* in drier sites; red *tussock (C. rubra)* in damper places) with areas of shrubland (matagouri *(Discaria toumatou),* manuka *(Leptospermum scoparium),* kanuka *(Kunzea ericoides), Coprosma* spp., *Olearia* spp.). European pastoralists first moved into the district in the 1850s (Thompson 1949) and since that time the combined effects of burning, oversowing, grazing by livestock, and browsing by introduced herbivores have severely modified the indigenous vegetation. Today the district is dominated by close-cropped grassland of introduced pasture species; remaining areas of tussock grassland are subjected to continued extensive grazing of sheep and cattle, and infrequent burning, aerial fertiliser application and oversowing.

The study area covers =250 ha (very roughly 2.5 x 1 km, see Appendix 1) on the top of a broad, rounded, NE-SW ridge of around 600 m elevation. To avoid introducing variables caused by aspect it did not extend on to the slopes on either side of this ridge to any great extent.

The area selected is divided longitudinally by a property boundary along the ridge top, to the SE of which is 150 ha in the Redbank Conservation Area and to the NW of which is 100 ha on private farmland. Until 1980 the whole area was covered with relatively unmodified tussock grassland, was used for extensive grazing of sheep and beef cattle, had sporadic fertiliser application, and was occasionally burnt.

The area now within the Conservation Area has not been burnt or fertilised for many years, and has never been cultivated. It is still grazed by sheep and cattle at low stocking density. All of this part of the study area is covered with tall tussock grassland (predominantly *Chionochloa rigida,* with *Chionochloa rubra* (in damper sites), *Poa cita* and *Festuca novae-zelandiae),* the quality of which varies somewhat across the area. Where the tussock is tall and dense the inter-tussock species are mainly indigenous herbs, sub-shrubs and mosses; where the tussock cover is more open there is an increasing proportion of introduced pasture grasses and weeds; and at the few really modified sites (generally alongside large and elevated tors) the impacts of livestock camps and browsing by rabbits have combined to create a closely cropped sward largely composed of introduced pasture species and containing relatively few tussocks.

In the three year period (1980-1982) most of the private land NW of the property boundary was cultivated and the tussock grassland replaced with permanent pasture dominated by rye grass *(Lolium perenne)* and white clover *(Trifolium repens).* Over most of this area the ground was worked once and sown directly into permanent pasture; on the SW part the land was fallowed for a year, re-worked and sown in the second season. The extent of cultivation was limited only by insufficient depth of soil for the implements or slopes that were too steep to be safely worked with a tractor. Since 1982 the private land has been grazed semi-intensively with sheep and cattle, and has received regular applications of artificial fertilisers. All ground that was cultivated now supports improved pastures which are seasonally (summer, winter) very closely grazed and bare. The tussock grassland that remains on the uncultivated places (usually as narrow strips around outcrops and tors, or on steep slopes) is particularly tall and dense because of the added fertiliser.

The study area is in the Macraes Ecological District of the Lammerlaw Ecological Region (McEwen 1987).

3. Methods

The methodology applied broadly follows that recommended by Elliott (1994) which sought to identify differences of 20% or greater between the grand skink populations on the relatively "unmodified" tussock grassland and the "modified" pasture.

Because grand skinks are strongly saxicolous the sampling (=habitat) "unit", or site, was defined as an outcrop, or group of outcrops, separated by **at least 10 m** from the next nearest rocks. There was no limit to the size of a site beyond this but, within this definition, the size and rock form varied considerably.

All sites identifiable on a low level air photo were mapped (see Appendix 1) and individually numbered. A random sub-set of 120 sites was then selected, 60 in tussock and 60 in pasture, and these provided the core data for the study. At each of these sites a wide range of rock parameters were measured to quantify the habitat units (see Appendix 2).

The occurrence (presence/absence) of grand skinks at the 120 randomly selected sites was recorded during each of three separate survey periods (March 1994, January 1995, March 1995). In each of these survey periods occurrence was determined from a maximum of three separate observational visits, each undertaken in "good" weather conditions for skink activity (Murphy 1994). The search duration at each site could not be for a predetermined time because of the widely disparate size and complexity of the sites but, because search effort was standardised, duration was in proportion to the size of the site (searches always consisted of a slow approach and scan of the whole site from a distances with binoculars, a thorough search over the whole of the outcrop, and finally an examination of the crevices).

The population age structure, sex ratio and the condition of grand skinks was determined from a smaller sample of sites - 4 in tussock and 4 in pasture - selected because they were known to support relatively large local populations of skinks. At each of these sites as many lizards as possible were captured (with pole or crevice nooses), measured, weighed and individually marked with a permanent toe clip and a temporary paint mark according to the protocols outlined by Patterson (1992). Repeated sampling was undertaken at these sites until as many of the resident lizards as possible had been captured and marked. From these captured samples snout-vent length (SVL) was used to assign animals to one of four age-classes, the sex of animals in the 2 and 3+ year old age group was determined by cloacal examination (Whitaker 1994), and condition was derived from the ratio of length to weight.

Additional data on the spatial distribution (presence/absence at each site), minimum total population, and the age structure of the grand skink populations was collected during once-only surveys of as many of the outcrops in each area as possible in each of March 1994, January 1995 and March 1995. On these surveys search effort was standardised but not duration (as above). The minimum number of grand skinks in each age-class was derived from cumulative counts of lizards seen simultaneously, widely separated in space but not time, or individually recognisable from distinctive characteristics.

In March 1995 all toes removed from the grand skinks captured were saved and stored in DMSO (dimethyl sulfoxide) for later DNA analysis using RAPD PCR techniques (Williams *et a1.* 1990) with the intention of determining the genetic relationships of individuals in each rock population.

Differences between the population characteristics of the tussock and pasture study areas were statistical tested using Chi-square and Student's T-tests. Simple pair-wise comparisons of site parameters were made against land management and grand skink occurrence using a Kruskal-Wallis 1-way ANOVA and a Mann-Whitney U test for probability, and the significant variables were then modelled in a logistic regression to assess their relative importance. Significance was taken as $p \leq 0.05$.

Characterisation of grand skink habitat was determined by using canonical correlation to relate the numbers of grand skinks present on the randomly selected rocks in March 1994 to a linear combination of the rock parameters. This combination was a "super-variate" which showed the maximum correlation with skink numbers.

The influence of land management on grand skink populations was then assessed by modelling the numbers of skinks present in January and March 1995 (after removing the effect of the rock parameters by applying the canonical variate) and testing whether the application of a management factor significantly affected the models predictive ability. As the number of skinks per site was relatively low, the model was fitted using Poisson errors which approximate a multinomial distribution. Ideally the data from which the canonical variate was calculated should have been independent from that used in the subsequent analysis and also unrelated to the management practice. The fact that it is extremely unlikely the data from 1994 and 1995 are independent, and some rock parameters are at least partly a function of management (e.g., stock camps), only means this method of analysing skink abundance with respect to management is conservative and may not detect a genuine effect.

The spatial distribution of grand skinks was tested by using a randomisation method (Romesburg 1989) to compare the observed distribution of skinks in tussock and pasture with the probability that each rock is equally likely to be occupied. This technique avoids boundary effects that would otherwise be a particular problem in such an elongated study area (Manly 1991). The method uses the distribution of a random selection of *n* "occupied" rocks out of the total population of N rocks. Statistics to summarise the spatial distribution of the "occupied" rocks are derived from the empirical distribution function *H(t)* of the distances between the *n* "occupied" rocks (Diggle 1983). This function is the proportion of all the pair-wise distances between the n rocks that are equal to or less than *t* metres, and estimates the likelihood that another "occupied" rock will be encountered within t metres of the selected "occupied" rock. The simulation process was repeated a large number of times and for a range of distances - in this study 19 distances between 50-2600 m - and the resulting 95% limits used to define the expected distribution. For some simulations a correction index, derived from the canonical "super-variate" (see above) by using logistic regression to get an equation for the probability of skink occurrence, was applied so that the probability of a site being "occupied" reflected its suitability as skink habitat (this approach limited the analysis to the 120 sites that had been measured). In all spatial distribution tests, if the observed distribution of rocks occupied by grand skinks lay outside the 95% limits it is non-random.

4. Results

To ensure that any differences measured in the grand skink populations are a consequence of agricultural development it is first necessary to establish that their habitat is uniform over the whole study area, i.e., whether the rock density, distribution, size and shape is essentially the same in both parts. If this is the case, the impact of agricultural development on the lizard populations can be assessed by testing for significant differences between grand skink populations on "unmodified" tussock grassland habitat compared to those in "developed" farmland where the tussock has been ploughed and converted to exotic pasture. In this study the population features examined included:

1. type of rocks occupied by grand skinks
2. site occupancy
3. population density (skinks/ha and skinks/site)
4. age structure, sex ratio of adult skinks, condition (SVL:wt)
5. spatial distribution of the skink population

4.1 HABITAT FEATURES

(See Appendix 2 for definitions)

Only two physical site features differed significantly between the tussock and pasture areas on pair-wise comparison the number of loose blocks was higher in the tussock area (mean=5.15, S.E.=0.60 cf. mean=3.42, *S.E.*=0.53; p=0.007) but rock density was higher in pasture (mean=13.75, *S.E.*=0.51 cf. mean=10.85, *S.E.*=0.52; p=<0.0005).

Simple pair-wise comparison of grand skink occurrence with the physical site features was significant for only six of the measured parameters (see Table 1). Three of these (height, length and transect length) related to the size of the outcrop and two (the number of blocks and crevices) to the amount of available cover for skinks. Because only variables that differ between sites where grand skinks are present or absent are likely to affect grand skink occurrence, the relative importance of these six variables was determined by logistic regression

TABLE 1 PHYSICAL SITE PARAMETERS THAT DIFFERED AT SITES WHERE GRAND SKINKS WERE PRESENT (DATA FROM 60 RANDOMLY SELECTED SITES IN TUSSOCK AND 60 IN PASTYRE).

	GRAND SKINKS PRESENT		GRAND SKINKS ABSENT		
	x ± S.E.	Range	x ± S.E.	Range	p
Transect length (m)	18.3±1.16	5.2-50.3	11.7±0.58	4.1-25.8	<0.0005
Rock height (m)	3.7±0.22	0.9-9.0	2.7±0.20	0.6-10.0	<0.0005
No. blocks	4.9±0,59	0-20	3.7±0.55	0-20	0.003
Rock length (m)	33.5±2.72	6.0-105.0	25.4±2.57	3-98.5	0.01
No. crevices	8.7±0.76	1-27	6.6±0.65	0-22	0.01
Nearest rock (m)	19.3±1.46	10.0-59.0	21.7±1.75	10.0-75.0	0.04

modelling and tested by Chi-square analysis. On this basis only the transect length - a function of the "volume" of the tallest element - has a significant effect on grand skink occurrence (p=0.001)

The canonical variate chosen correlated well with the numbers of skinks present on the 120 randomly selected sites in March 1994 (Pearson's correlation coefficient, r=0.59). It had been hoped that only a few obvious rock features would be included in this variate but unfortunately the best correlation required about half of the measured parameters, the coefficients of which were not readily interpretable due, in part, to the intercorrelations between them. The parameters which were includedl largely relate to the skink niches available on the rocks.

4.2 SITE OCCUPANCY BY GRAND SKINKS

On the 120 randomly selected sites, around twice as many tussock sites were inhabited by grand skinks as those in pasture on each of the three surveys, and these differences were all highly significant (see Table 2). The difference in site occupancy was just as marked when all outcrops within the study area were considered (see Table 3).

Continuity of site occupancy also differed significantly between the tussock and pasture areas (χ^2, p=0.003) (see Table 4). Nearly twice the proportion of the sites in the tussock that were occupied by grand skinks had skinks present in each of the three survey periods compared to those in pasture; at about a third of all pasture sites with skinks the skinks were present on only one survey.

1 The 9 parameters included in the "best-fit" correlation were: rock lengthxwidth, rock height, transect length, rock form, number of elements, number of loose blocks, number of crevices, dip of strata, and ploughing.

TABLE 2 NUMBER <%) OF SITES OCCUPIED BY GRAND SKINKS OUT OF 60 RANDOMLY SELECTED SITES IN TUSSOCK AND 60 IN PASTURE (DATA FROM THREE CUMULATIVE SEARCHES ON EACH OF THREE SURVEYS).

	MARCH 1994	JAN 1995	MARCH 1995	1994-1995a
Tussock	32 (53.3)	33 (55.0)	35 (58.3)	36 (60.0)
Pasture	16 (26.7)	18 (30.0)	14 (23.3)	23 (38.3)
x^2	0.003	0.006	0.0001	0.018

' Number of different sites occupied over all three surveys.

TABLE 3 NUMBER (%) OF SITES OCCUPIED BY GRAND SKINKS OVER MOST SITES IN TUSSOCK AND PASTURE AREAS (DATA FROM SINGLE SEARCHES ON EACH OF THREE SURVEYS).

	MARCH 1994	JANUARY 1995	MARCH 1995
Tussock (*n*)	53 (48.2) (110)	73 (51.1) (143)	70 (49.0) (143)
Pasture (*n*)	30 (32.6) (92)	29 (26.6) (109)	25 (22.7) (110)
x2	0.025	0.0001	0.00002

TABLE 4 FREQUENCY (%) OF OCCURRENCE OF GRAND SKINKS, AT SITES OCCUPIED BY SKINKS, OUT OF 69 RANDOMLY SELECTED ROCKS IN TUSSOCK AND 60 IN PASTURE (DATA FROM EACH OF THREE SURVEYS).

	PRESENT 3x	PRESENT 2x	PRESENT 1x
Tussock (*n*=36)	30 (83.3)	4 (11.1)	2 (5.6)
Pasture (*n*=23)	10 (43.5)	5 (21.7)	8 (34.8)

4.3 POPULATION DENSITY

The minimum population density of grand skinks in the tussock area was significantly higher than that in the pasture area when expressed as mean number of skinks per site searched and consistently higher, but not significantly so, when expressed as the mean number at sites where skinks were present (=local population density) (see Table 5). In relation to the total area, the density of grand skinks in tussock was about twice that of the pasture area (1.99, 1.71, 2.21/ha cf. 1.17, 0.81, 1.01/ha in the three surveys, respectively).

TABLE 5 MINIMUM POPULATION DENSITIES (MEAN t S.E. OF GRAND SKINKS IN TUSSOCK AND PASTURE AREAS (DATA FROM SINGLE SEARCHES ON EACH OF THREE SURVEYS)).

		MARCH 1994	JANUARY 1995	MARCH 1995
Skinks/site searched	Tussock	2.74±0.52	1.80±0.29	2.31±0.38
	Pasture	1.27±0.37	0.74±0.21	0.92±0.30
	T-test	0.03	0.003	0.004
Skinks/site with skinks present	Tussock	5.75±0.94	3156±0.50	4.73±0.65
	Pasture	3.90±0.98	2.79±0.65	4.04±1.11
	T-test	0.20	0.38	0.59

When grand skink populations were modelled for 1995, using the canonical variate to remove the rock effect, the addition of a land management factor greatly increased the model's ability to explain skink density (t=4.56, p<0.001; regression deviance 166.4 *cf.* 146.3), clearly showing there were more skinks in the tussock part of the study area. However, from a plot of these results it was clear that three sites in the tussock were having a profound influence on the goodness of fit and examination of the canonical variate showed this was because they were not matched by sites with similar characteristics in the pasture (one was by far the largest site (length x width) with by far the greatest number of elements; the other two were large "monoliths"). As an extra precaution, therefore, the whole analysis (including the derivation of the canonical variate) was recalculated excluding these three sites. This time the correlation of the canonical variate to grand skink abundance was slightly less good (Pearson's correlation coefficient, r=0.54 for 117 sites), and the addition of a land management factor to the resulting model was not quite so effective at predicting skink densities (t=2.09, p=0.019; regression deviance 126.8 *cf.* 123.9), but it nevertheless showed a significant relationship.

4.4 AGE STRUCTURE, SEX RATIOS AND CONDITION

The SVL frequency of captured animals that were measured (n=439) showed that four age-classes could be distinguished, equivalent to young of the season (= "young", <51 mm SVL), 1-year old (= "juvenile", 51-68 mm SVL), 2-year old (= "sub-adult", 69-82 mm SVL), and 3+ year old animals (= "adult", >83 mm SVL) (see Figure 1). No new-born animals were present in January 1995 but they were commonly encountered in the March surveys - grand skinks give birth in February or March (Cree 1994). Generally speaking, skinks in the field could easily be assigned to these age-classes from observation alone.

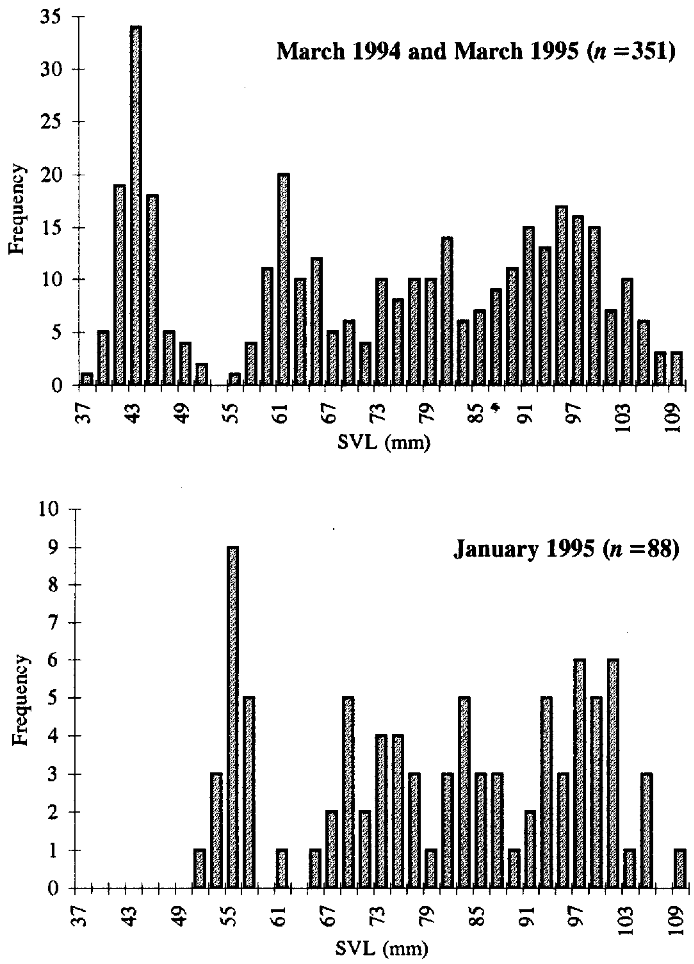

FIGURE I FREQUENCY DISTRIBUTION OF SVL OF GRAND SKINKS SHOWING FOUR AGE-CLASSES (TUSSOCK AND PASTURE AREAS COMBINED FOR ALL SURVEYS).

The proportion of grand skinks in each age-class did not differ significantly between the tussock and pasture areas whether assessed on the captured animals or the minimum counts, either during each survey or over the whole period (see Tables 6 & 7) (χ^2, p=0.052 to 0.92).

Sexual maturity for female grand skinks occurs when the animals are around 82 mm SVL (Cree 1994) or in their third year. Males are also assumed to be mature in their third year. The sex of all the adult and most sub-adult grand skinks captured was determined from cloacal examination (see Table 8). The maximum size recorded for adult female grand skinks was 109 mm SVL and the maximum weight was 30.5 g (n=97); the maximum size for adult males was 102 mm SVL and the maximum weight was 22.5 g (n=81). The sex ratio of adult grand skinks in the pasture and tussock areas differed significantly only in the March 1995 survey (χ^2, p=0.014).

TABLE 6 NUMBER (%) OF GRAND SKINKS IN EACH AGE-CLASS AMONGST THE ANIMALS CAPTURED AND MARKED (DATA FROM THREE SURVEYS).

		YOUNG	JUVENILE	SUB-ADULT	ADULT	TOTAL
	March 1994	32 (27.6)	23 (19.8)	14 (12.1)	47 (40.5)	116
Tussock	January 1995	-[1]	13 (27.1)	15 (31.3)	20 (41.7)	48
	March 1995	22 (21.8)	14 (13.9)	19 (18.8)	46 (45.5)	101
	Sub-total	54 (20.4)	50 (18.9)	48 (18.1)	113 (42.6)	265
	March 1994	14 (20.0)	17 (24.3)	15 (21.4)	24 (34.3)	70
Pasture	January 1995	-	13 (32.5)	4 (10.0)	23 (57.5)	40
	March 1995	18 (28.1)	14 (21.9)	14 (21.9)	18 (28.1)	64
	Sub-total	32 (18.4)	44 (25.3)	33 (19.0)	65 (37.4)	174
	TOTAL	**86 (19.6)**	**94 (21.4)**	**81 (18.5)**	**178 (40.5)**	**439**

[1] Grand skinks are not born until later in the season.

TABLE 7 NUMBER (%) OF GRAND SKINKS IN EACH AGE-CLASS AMONGST THE ANIMALS OBSERVED DURING MINIMUM POPULATION COUNTS (DATA FROM THREE SURVEYS).

		YOUNG	JUVENILE	SUB-ADULT	ADULT	TOTAL
	March 1994	72 (24.1)	63 (21.1)	82 (27.4)	82 (27.4)	299
Tussock	January 1995	-	72 (28.1)	70 (27.3)	114 (44.5)	256
	March 1995	57 (17.2)	55 (16.6)	77 (23.3)	142 (42.9)	331
	Sub-total	129 (14.6)	190 (21.4)	229 (25.8)	338 (38.1)	886
	March 1994	23 (19.7)	34 (29.1)	29 (24.8)	31 (26.5)	117
Pasture	January 1995	-	24 (29.6)	23 (28.4)	34 (42.0)	81
	March 1995	24 (23.8)	19 (18.8)	24 (23.8)	34 (33.7)	101
	Sub-total	47 (15.7)	77 (25.8)	76 (25.4)	99 (33.1)	299
	TOTAL	**176 (14.9)**	**267 (22.5)**	**305 (25.7)**	**437 (36.9)**	**1185**

TABLE 8 NUMBER (%) OF GRAND SKINKS OF EACH SEX IN THE SUB-ADULT AND ADULT AGE-CLASSES OF THE ANIMALS THAT WERE CAPTURED (DATA FROM THREE SURVEYS)

		SUB-ADULT		ADULT		TOTAL	
		MALE	FEMALE	MALE	FEMALE	MALE	FEMALE
Tussock	March 1994	6 (85.7)	1 (14.3)	19 (42.2)	26 (57.8)	25 (48.1)	27 (51.9)
	January 1995	5 (55.6)	4 (44.4)	8 (40.0)	12 (60.0)	13 (44.8)	16 (55.2)
	March 1995	7 (46.7)	8 (53.3)	28 (60.9)	f 1809.1)	35 (57.4)	26 (42.6)
	Sub-total	18 (58.1)	13 (41.9)	55 (49.5)	56(50.5)	73 (51.4)	69 (48.6)
Pasture	March 1994	4 (100)	0	10 (41.7)	14(58.3)	14 (50.0)	14 (50.0)
	January 1995	0	0	11 (47.8)	12 (52.2)	11 (47.8)	12 (52.2)
	March 1995	5 (38.5)	8 (61.5)	5 (27.8)	13 (72.2)	10(32,3)	21 (67.7)
	Sub-total	9 (52.9)	8 (47.1)	26 (40.0)	39 (60.0)	35 (42.7)	47 (57.3)
	TOTAL	**27(56-3)**	**21 (43.8)**	**81 (46.0)**	**95 (54.0)**	**108 (48.2)**	**116 (51.8)**

There was no difference in the body condition (SVL:wt) of grand skinks between the tussock and pasture areas either on the whole dataset (see Figure 2) or on each of the three surveys.

4.5 SPATIAL DISTRIBUTION

Analysis of the spatial distribution of local grand skink populations for the pasture and tussock areas was undertaken for each of the three survey periods using a count of at least one skink to indicate the site was "occupied". These analyses show grand skinks are randomly distributed in the tussock area (i.e., the distribution of "occupied" sites very closely parallels that of the outcrops) but are quite strongly clumped in the pasture area (i.e., at distances <500 m there is a significantly greater chance than random of encountering another population, at distances between 500-1,500 m there is significantly less likelihood, and beyond 1,500 m the distances are so great that all occupied sites within the study area are likely to be encountered) (see Figure 3 and Appendix 1).

Other data from this study suggested that many of the single animals observed may have been transient rather than resident (see sections 4.2 and 4.6). To overcome this potential bias the data were recalculated using the occurrence of at least two skinks in both January 1995 ***and*** March 1995 as the definition of

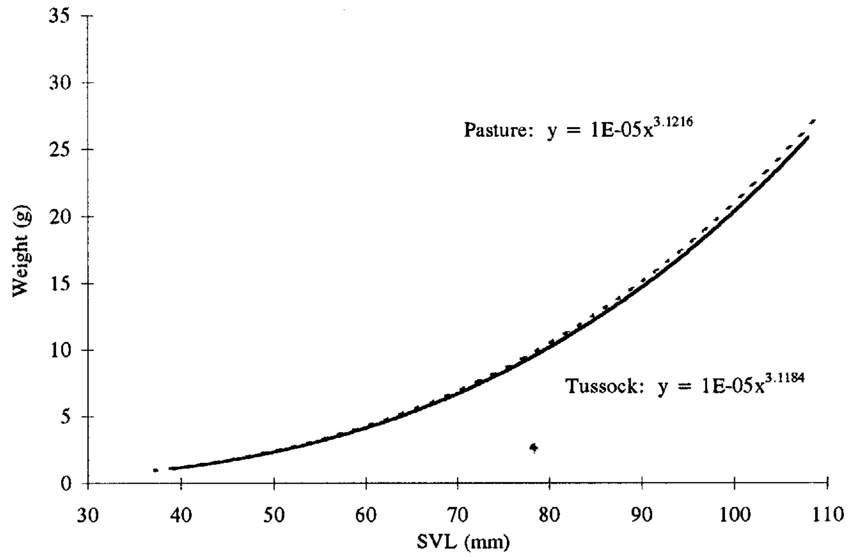

FIGURE 2 BODY CONDITION, EXPRESSED AS THE RELATIONSHIP BETWEEN SVL AND WEIGHT, FOR ALL GRAND SKINKS CAPTURED (DATA FROM THREE SURVEYS COMBINED).

"occupied". This analysis still showed grand skinks to be significantly more clumped in the pasture area compared to tussock (see Figure 4).

Finally, because various physical parameters had been shown to have an effect on site occupancy (see section 4.1) the calculations were run again but using only the 120 randomly selected sites and applying a correction index derived from the canonical "super-variate" for habitat that identified sites that might be preferentially occupied. The reason for doing this was to eliminate the possibility that the clumping observed in the pasture area might be because the rocks with the greatest likelihood of occupation were non-randomly distributed. This test was only done for March 1995 but clearly confirmed the same pattern of significantly greater clumping of skink populations in the pasture area (see Figure 4).

4.6 MOVEMENTS

One unplanned aspect of this study was acquisition of data on the movement of grand skinks between outcrops. During this research (January 1994-March 1995) 298 grand skinks were marked in the study area (a further 31 had been marked in the area since January 1988, including 9 in December 1993). 147 recaptures of 114 skinks (including two marked in the earlier period) were made and there were numerous re-sightings of paint-marked animals within each survey. Thirty-one (21%) of the recaptured skinks and two of the observed animals had moved between sites, i.e., movements of at least 10 m through tussock or across pasture[2]. The average distance moved was 71.3 m (see Table 9);

[2]Because many of the sampling units were large (see Table 1 above), movements greatly exceeding 10 m were frequently recorded for grand skinks that remained at the same site throughout the study.

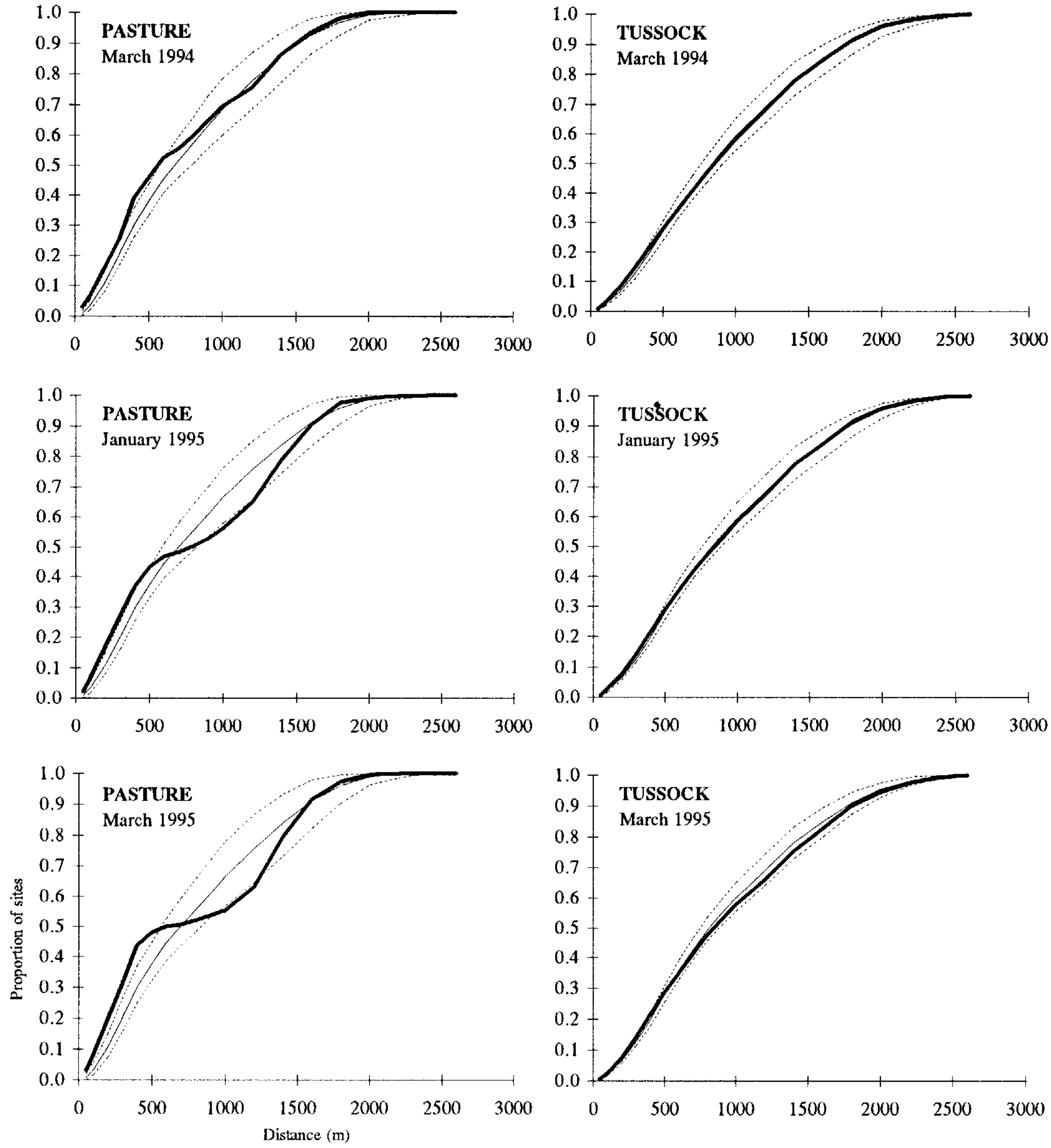

FIGURE 3 OBSERVED SPATIAL DISTRIBUTION OF SITES OCCUPIED BY GRAND SKINKS (-) IN RELATION TO THAT EXPECTED FROM A RANDOM DISTRIBUTION (MEDIAN (-) AND 95% PROBABILITY LIMITS (---)).

the elapsed time between recaptures/re-sightings ranged from one day to nearly six years (x=310 days). Only one movement of a young skink was recorded but roughly equal numbers from the other age-classes (12 juvenile, 10 sub-adult, 10 adult)[3]. There was no difference between the distances moved by skinks in the tussock or pasture areas, between males and females, or between younger and older animals (<2-years cf. 2+ years) (*T*-test, p=0.22-0.93). There was also no difference between the distances moved through tussock or over pasture (*T*-test, p=0.79) (see Table 9). Three of the skinks made two between site movements, including one adult male that made a 40 m movement through tussock between outcrops and later returned to the original site.

[3] Conservatively assumes that the age-class when the skink was last observed at the point of origin is the age at which it moved.

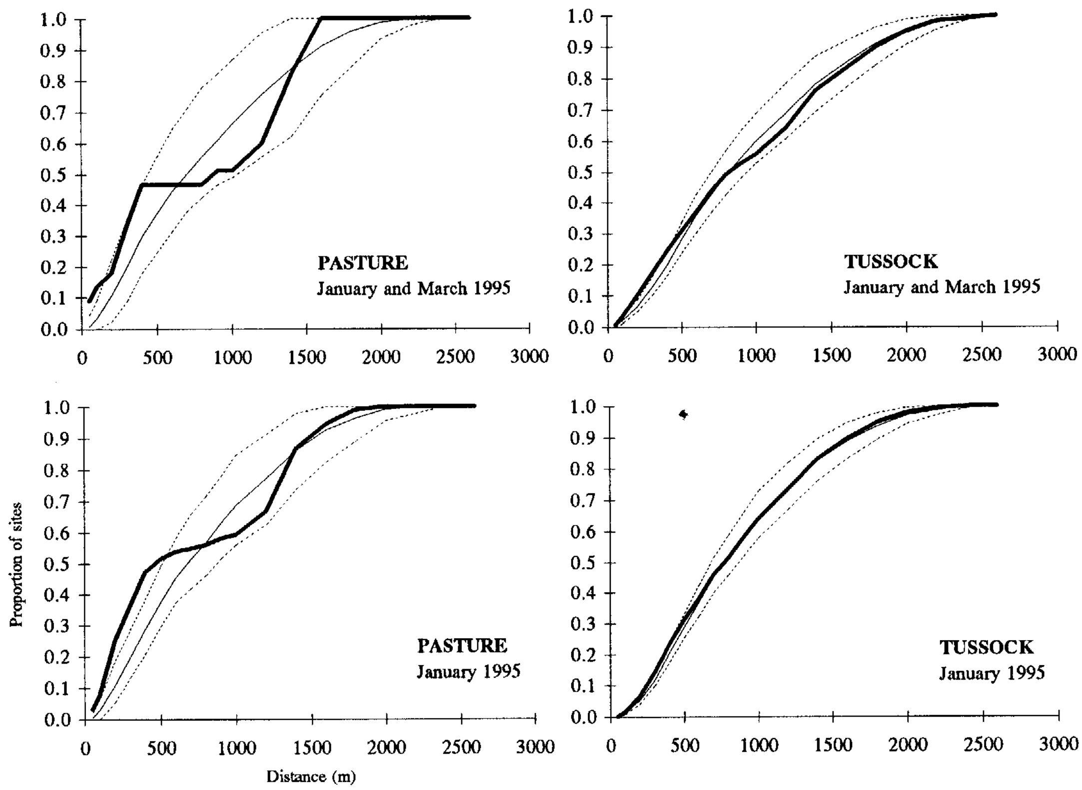

FIGURE 4 OBSERVED SPATIAL DISTRIBUTION OF SITES OCCUPIED BY GRAND SKINKS () IN RELATION TO THAT EXPECTED FROM A RANDOM DISTRIBUTION (MEDIAN (-) AND 95% PROBABILITY LIMITS (---)): *UPPER:* RESTRICTED DEFINITION OF "OCCUPIED" SITE, I.E., ONLY SITES OCCUPIED BY 2 OR MORE SKINKS IN JANUARY AND MARCH 1995. *LOWER:* FOLLOWING APPLICATION OF I NDEX TO SELECT SITES PREFERRED BY GRAND SKINKS, MARCH 1995.

Corroborating evidence of between rock movements comes from the occupation of sites that were previously unoccupied. Two clear instances of this occurred during the course of the study relating to outcrops that were repeatedly and thoroughly searched as part of the intensive marking programme. One site in tussock was in the centre of a group of sites (28 m and 45.5 m from the nearest outcrops) all of which were occupied by grand skinks on each of the three surveys. This outcrop had no lizards on it in 1994 but was inhabited by at least one sub-adult and two adult skinks in 1995, one of which was a marked animal that had moved 45.5 m. The other site was in pasture, on the periphery of a group of occupied sites and 20 m from the nearest occupied rock. It was unoccupied in 1994 and January 1995 but in March 1995 had 8 grand skinks on it including 3 adults and one sub-adult. A third instance involved a sub-adult grand skink which was present in January 1995 in the stone foundation of the but occupied by the field team. Grand skinks have never been seen at this location, which is 300 m through tussock from the nearest outcrops and grand skink populations, either before or since.

TABLE 9 MINIMUM DISTANCE (M) MOVED BY GRAND SKINKS OR DISTANCES TRAVELLED VIA OTHER OUTCROPS OVER A RELATIVELY DIRECT ROUTE.

	x ± S.E.	RANGE
Minimum distance between captures[a] (*n*=33)	71.3±14.89	16.8-403.3
Total "off-rock" distances[b] (*n*=45)	49.9±6.40	12.5-201.5
Distances through tussock[c] (*n*=26)	49.9±7.71	12.5-201.5
Distances across pasture[d] (*n*=19)	44.5±11.37	8.2-152.4

a Measured as the shortest straight-line distance between the two sites on which the skink was captured or observed; includes any outcrops that might lie along this line.

b Measured as the shortest distance between each site along a relatively direct route between the two sites on which the skink was captured or observed.

c Measured as the shortest distance between each site along a relatively direct route provided it passed only through tussock.

d Measured as the shortest distance of pasture between each site along a relatively direct route; because most sites in the pasture area had at least some tussock surrounding them these distances are frequently less than the site to site distance.

5. Discussion

The property boundary which divides the study area is an artefact - an arbitrary line that bears no relationship to the geomorphology, topography or natural biological features. The only physical differences in the rocks either side of this fence line (the density of outcrops and the number of loose blocks on them) were apparently not linked to grand skink occurrence. The different properties have been in different ownership for a very long time, and inevitably have been subjected to different management regimes, but both parts of the study area were covered in tall tussock vegetation until 1980. Although there are no early data on the lizard fauna there are no obvious or logical biological reasons why the whole study area should not have been equally populated by grand skinks prior to 1980. If so, this study (conducted in 1994-1995) indicates that in the pasture area, in the 14 year period to 1994, both the minimum population density and the number of sites occupied have roughly halved, and the spatial distribution has changed.

Density and distribution

With limited time available for field work and constantly varying weather conditions it was not possible for all counts/surveys to be done under identical conditions. Activity levels of grand skinks vary widely with even minor changes in the time of day or weather (Patterson 1992; Murphy 1994; Emma Coddington and Alison Cree, pers. comm. August 1995) such that 30-60% of a grand skink population is typically visible at any one time (Towns *et al.* 1984; Murphy 1994; Emma Coddington and Alison Cree, pers. comm. August 1995). A comparison of the numbers of skinks seen during the census surveys with the known minimum number alive in the marked populations suggests even this proportion is high in relation to the methodology used in this study. The estimates of minimum population numbers presented here must therefore be regarded as the *absolute minimum*.

A second consideration, given the variation in activity levels, is whether the data for occurrence are accurate. This is important because it has implications for both the total population density and for spatial distribution. Even when the prevailing weather is unsuitable for widespread activity one or two dominant grand skinks are visible (Towns *et al.* 1984; Murphy 1994; pers. obs.). For the 120 random sites, 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. The figures were higher in each case for the tussock (x=88.0%, 96.0%) compared to pasture (x=73.1%, 91.3%), presumably because a greater proportion of the sites in pasture had single animals and there was less continuity there in the sites that were occupied. Sites that have been missed are likely to be those at which the populations are small, so a 5-10% under-estimate on occurrence will not add significantly to the total population size. Similarly, the observed spatial distribution is unlikely to be affected by the few sites that were missed because there is no reason to presume those sites would be distributed any differently to the ones that were identified.

Taking the conservative approach, and using the proportions for visibility and occurrence given above, the number of grand skinks in the tussock part of the study area is likely to be 600-1,000 animals or 4-7/ha.

Possible reasons for decline - the "on-rock" problems

The reasons for the apparent dramatic decline in grand skink numbers on the pasture study area over the past 14 years are not necessarily the same as those involved in the apparent extinction of the species from most of its range. Possible causes advanced for the present patchy and localised distribution of grand skinks in Otago include habitat modification or degradation, predation by or competition from introduced species, and the multifarious impacts of pest control operations (Towns & Daugherty 1994; Whitaker & Loh 1995). Rather than a chronic impact, the most serious and damaging effect of these agents is likely to be sporadic when in concert with each other and/or independent factors (e.g., severe drought) (Towns & Daugherty 1994; Graeme Loh, pers. comm. 4 August 1995).

The potential threat posed to grand skink populations by agricultural development has been recognised for some time (Thomas 1982; Towns *et al.* 1984; Towns 1985; McSweeney 1989; Whitaker & Loh 1995). Various suggestions have been made regarding which aspects of the development are the causal agents including: reductions/changes in food resources (Towns 1985; Southey ND), microsite degradation by livestock through the fouling of crevices by faeces (Thomas 1982) or loss of lichen cover through hoof abrasion (Murphy 1994), reduction of cover (Towns *et al.* 1984; Towns & Daugherty 1994), and changes in predation levels (Towns *et al.* 1984; Towns 1985). Each of these will be discussed.

Grand skinks are omnivorous. No comparative assessment of invertebrate diversity or abundance on, or immediately around, outcrops in the pasture and tussock areas has been undertaken but significant differences in the invertebrate faunas of tussock grassland *cf.* pasture grassland have been recorded close to the study area (Alison Cree, pers. comm. August 1995). Although invertebrates contribute the bulk of the skink's diet soft fruits are seasonally an important component (Whitaker 1987; Southey ND). To measure the amount of available fruit per site (i.e., as size x number of individual fruiting plants) would be an enormous task. Instead, fruiting plant diversity was used as an index of fruit availability because, subjectively, it showed a strong correlation with the number and size of plants present. The difference in the number of fruiting plant species per site between the tussock and pasture areas was highly significant (x=5.30, *S.E.*=0.263 *cf.* x=3.60, *S.E.*=0.30; Mann-Whitney, p=<0.0001), presumably - because there was virtually no difference in the rocks per se - a consequence of different stocking regimes. Fruiting plant diversity was also significantly correlated to grand skink occurrence (x=5.02, *S.E.*=0.274 *cf.* x=3.90, *S.E.* =0.312; Mann-Whitney, p=0.01). Nevertheless, the lack of difference in body condition and reproductive performance between the two areas implies food shortage or quality is not an issue, and the correlation between skinks and fruiting plants may simply be that the rocks preferred by lizards (see Table 1) are also those which favour plant diversity.

Both sheep and cattle seek out outcrops for resting areas because of the shelter they provide, but only sheep actually climb up on to them. Although unmeasured, the use of outcrops by livestock did not seem to be different between the two areas. Grand skinks were present on many outcrops where sheep faeces were abundant and the surfaces worn bare of lichen, and, conversely, were conspicuously absent from others that were completely unaffected because they were too steep-sided for sheep to gain access.

The plant cover actually on the outcrops is minimal, due to an almost complete lack of soil, so is not an issue in skink occurrence. However, if grand skinks routinely venture off the rocks as part of their daily activities, the vegetation surrounding an outcrop may affect skink populations either through altered or diminished food resources, or reduced protective cover. The difference in vegetation cover (see Appendix 2 for definition) between the tussock and pasture areas was, predictably, highly significant (T-test, p=<0.00005) (but note that most outcrops in pasture were surrounded by a narrow band (<10 m) of tussock); the relationship between vegetation cover and grand skink occurrence was not significant (T-test, p=0.17). Furthermore, grand skinks are not known to forage off the rock surfaces to any extent (Southey ND; Patterson 1992; Murphy 1994; pers. obs.)

The most abundant mammalian predators in the Macraes Flat district are ferrets (*Mustela Airo*) and feral cats *(Felis catus);* stoats *(Mustela erminea)* and weasels (*M. nivalis)* are also present. All four species are known to prey on lizards (King 1990). As "sit and wait" predators, cats are renowned for their skink hunting skills (e.g., Karl & Best 1982; Pierce 1987; Fitzgerald 1990) and have been recorded eating grand skinks (Daugherty & Towns 1991); the mustelids are active foragers which also consume significant numbers of skinks (e.g., Fitzgerald 1964; King & Moody 1982; Pierce 1987). Two studies of the feeding ecology of feral cats and ferrets in the Macraes Ecological District have shown that lizards are an important prey item for both species. In one, 42% of cat faeces (*n*=165) contained lizard remains comprising a minimum of 3 "giant" skinks (= grand skink and/or Otago skink (*Oligosoma otagense*)), 186 other skinks (*Oligosoma* spp.) and two geckos (*Hoplodactylus maculatus*); cat gut analyses revealed 12% occurrence of lizard remains (*n*=34), including both geckos and skinks; and 7.5% of ferret faeces contained skink remains (*n*=40) (Baker 1989). The second study, in and around the grand skink research area and concurrent with this work on lizards, recorded 57.7% occurrence of skink remains in cat gut contents collected in late summer/autumn (*n*=33), including one cat with a minimum of 35 skinks and another with at least 49, and calculated that skinks comprised =12% by weight of all prey consumed (Anita Middlemiss, pers. comm. July 1995). One Otago skink was amongst the prey, but no grand skinks. 52% of cat faeces (*n*=23) and 32% of ferret faeces (*n*=25) also contained skink remains.

The research undertaken in the grand skink study area further revealed that feral cats and ferrets are equally distributed through pasture and tussock habitats, and that their diet in the two areas does not differ (Anita Middlemiss, pers. comm. July 1995). No detailed information is available on their foraging strategies in this district but it is extremely unlikely there are differences in the way either species hunts on and around outcrops in pasture compared to tussock, either by day or at night. When foraging by day, the time that grand skinks are active, both cats and mustelids prefer to be in cover so it is likely they would avoid the wide open spaces of the pasture areas.

Avian lizard predators occurring in the Macraes Flat district include the indigenous Australasian harrier (*Circus approximans*) and New Zealand falcon (*Falco novaeseelandiae*), and the introduced white-backed magpie (*Gymnorhina tibicen*) (Robertson 1985). Magpies are particularly abundant in the Macraes Ecological District where non-breeding groups of 15-20 birds are common and it is not unusual to see flocks of >60.

Lizards, presumably skinks, comprised 5.2% of prey items identified in harrier casts (*n*=20) and 1.1% of prey items in harrier guts (*n*=129) in Southland farmland (Redhead 1968 & 1969). Skink remains occurred in 4.8% of falcon casts (*n*=932) from Marlborough high country, representing 2.9% of prey items captured but only =0.4% of prey biomass (Fox 1977). Although white-backed magpies are regarded as primarily preying on terrestrial invertebrates they are known to include small vertebrates, including lizards, in their diet (McIlroy 1968; Vestiens & Carrick 1974; Veltman & Hickson 1989). In one New Zealand-wide study lizards occurred in 2% of the birds sampled (*n*=302) (McIlroy 1968)[4] and in Manawatu farmland, where lizards are scarce, there was one lizard amongst magpie faecal remains (*n*=78) (Veltman & Hickson 1989). Near Macraes Flat a magpie was seen carrying a skink (Whitaker 1988).

Falcons and harriers, but not magpies, may hunt lizards on outcrops but there is no reason to presume they would use different hunting strategies on outcrops

4 Most specimens would have been from intensively farmed areas where lizards are rare or absent.

in pasture compared to tussock. All three species forage over pasture areas but magpies must be considered as potentially the most serious predators. Not only is their density higher than the other predatory birds but they show a marked preference for feeding in short, open pasture (Hughes *et al.* 1983), using visual or aural cues to locate prey (Veltman & Hickson 1989). Any lizards in short pasture would be particularly vulnerable to magpie predation.

It must be stressed, even though a species may be important in the diet of a predator it is not necessarily true that this predation has a significant effect on the prey species numbers or populations but, conversely, a prey species insignificant in the diet of a predator may be incurring a serious predation impact. In the Macraes Flat district cats are calculated to eat an average of =4 lizards per day in summer and autumn, almost all of them common species (Anita Middlemiss, pers. comm. July 1995). This equates to =6 lizards/ha/yr - clearly a tiny proportion of the total skink population when it is considered that common skinks *(Oligosoma nigriplantare polychroma)* alone exceed 1100/ha in tussock grassland close to the study area (Alison Cree, pers. comm. August 1995). In Marlborough each pair of falcons eats about 20 skinks per year, equivalent to predation level of only 0.02 skinks/ha/yr (Fox 1977).

The fact that the mean population size for grand skinks on rocks where they are present is not significantly different in the pasture and tussock areas (this study); that the age structure, the sex ratio, and the body condition do not differ (Murphy 1994; this study); that reproduction appears to be equally successful in both areas (Hunter 1992; pers. obs.); that behaviour and activity is the same in both tussock and pasture (Murphy 1994); and that home range sizes are the same for both areas (Murphy 1994), shows that - on the rocks where they occur - the grand skinks in each area seem to be doing equally well. This, in turn, suggests that "on rock" problems are not an issue, ie. that there are no differences in the environment on, or immediately around, the outcrops on which the skinks live that are having a detrimental effect.

Metapopulation dynamics and movements - the "off-rock" problems

Grand skinks are strongly saxicolous and only live on rock outcrops. In the study area outcrops cover <2% of the total area, are widely spaced, vary widely in size and form, and are randomly distributed. In the tussock part of the study area, assumed to represent the most natural situation, the sites occupied by grand skinks are also randomly distributed but not all sites which offer preferred habitat have skink populations on them. Furthermore, the minimum population size and the population density of grand skinks varies greatly and not necessarily in proportion to the size of the site.

The largest minimum local populations recorded was 37, there were very few populations of >20 individuals, most were <15, and many <10. From the observed age and sex ratios this equates to around 2-4 adult females or an annual production of 4-9 young per site (mean annual reproductive output is 2.17 young/female (Cree 1994)). Small populations are more likely to become extinct through natural catastrophes or chance demographic, genetic or

[5] "Local population" = the population in one habitat patch, i.e., at one site.

environmental problems (Shaffer 1987; Caughley 1994). The present patchy distribution indicates local extinctions and recolonisations, and this is supported by evidence that over a relatively short time (1-5 years) some populations have disappeared and others established (Ian Southey, pers. comm. January 1994; this study). The rate of this population turnover is unknown. Whether these characteristics mean the grand skinks in the study area exist as a metapopulation is a matter for definition (Hanski & Gilpin 1991) but the continuity of the species in the area is clearly dependent on repeated recolonisation of sites where they become locally extinct.

Movements are an essential component of metapopulation dynamics to balance local extinctions with recolonisation. Grand skinks have only once been found on the ground away from rock outcrops[6] and the assumption has always been that, apart from some juvenile dispersal, they would remain on outcrops with only very rare movements across tussock or grassland (Towns *et al*. 1984; Whitaker & Loh 1995). Perhaps the most interesting result from this research, therefore, is the discovery that grand skinks are far from sedentary and a surprisingly high number of movements of adults and sub-adults were recorded despite the study not being specifically set up to detect them[7,8]. Additional evidence of movements comes from the arrival of new sub-adult or adult lizards into well-studied, marked populations or at sites which were previously unoccupied (Murphy 1994; this study), and from the number of single occurrences of single skinks (this study). Concurrent work on grand skink reproduction, emergence and behaviour at a nearby location has also detected unexpectedly high numbers of between rock movements (Cree 1993; Emma Coddington and Alison Cree, pers. comm. June 1995).

Movements between outcrops may be precipitated density-dependent or independent factors. The availability of suitable home crevices, basking sites, or just surface area on which to avoid intra-specific aggression are all factors which contribute to the "carrying capacity" of a site (Murphy 1994) and could lead sub-adult or adult grand skinks to emigrate. Adults are tolerant of young and juvenile skinks in their home ranges and the small skinks occupy crevices too narrow for adults (Murphy 1994) so the pressure for them to move away may be considerably less. During the breeding season males move more widely around their home outcrop in search of receptive females (Murphy 1994). This search for mates may extend to between rock-forays and account for the records of movements by adult males (Murphy 1994; this study). Finally,

[6] A juvenile 15 m from the nearest rock (Alison Cree, pers. comm. August 1995).

[7] Movements within a site were not recorded in this study but could include distances up to the length of the site (maximum=105 m). Adult males are more mobile than females and commonly traverse up to 75% of the available rock surface during the course of their normal activities, the dominant animal usually covering the entire site (Murphy 1994; maximum distance=65 m).

[8] Two long movements of Otago skinks were also recorded. The Otago skink is another endangered, saxicolous species confined to Central Otago. It occurs sympatrically with the grand skink in the Macraes Flat district where the species are broadly syntopic, although Otago skinks appear to show a preference for sites in valleys (Towns et al. 1984; Rebergen 1993; Whitaker and Loh 1995). They had also been presumed to be *relatively* sedentary as adults. No resident populations of Otago skinks occurred in the study area but a group of 6-8 animals was present in an immediately adjoining valley, including one that had recently moved there. This skink was probably one marked as a large adult (SVL=114 mm) 12 months earlier at a location just over 2 km away but it may have been one marked as a sub-adult 3.5 years earlier at a different site also 2 km away. Two adult Otago skinks were found on outcrops well within the tussock part of the study area; one of these skinks was never seen again but the other, marked in April 1994, had moved 375 m by March 1995.

differences in food availability and distribution between the tussock and pasture areas (e.g., the recorded difference in the number of fruiting plants/rock) may mean lizards in pasture have to move between rocks more frequently than those in tussock.

If the ability to disperse is impaired by some exogenous factor, such as habitat fragmentation, the non-equilibrium metapopulation so formed (Harrison 1991) begins to collapse and, as its structure breaks down, turnover increases and the remaining local populations become increasingly grouped, leading eventually to regional extinction (Gilpin 1987). Under these circumstances habitat specialists are generally less able to cope than habitat generalists as they find it more difficult to disperse through a modified landscape (Hanson 1991; Sarre et al. 1994). Additional variables affecting the success of dispersal and recolonisation created by conspecific attraction (Ray *et al.* 1991) and inter-specific competition (Case 1991) also change. The pattern observed in the pasture area, where significant clumping of the local populations of grand skinks was detected statistically[9] yet the less specialised *Oligosoma maccanni* remained widespread and abundant (this study), fits this scenario.

In the modified, intensively-farmed part of the study area the closely grazed pasture would be an inhospitable environment for grand skinks in which they are particularly vulnerable to predation or environmental factors (e.g., temperature extremes). Under such circumstances very low levels of predation - levels too low to seriously impact directly on the populations on the outcrops - may be sufficient to prevent effective movement. If grand skinks are unable, or unwilling, to cross the pasture recolonisation will be curtailed and collapse of the metapopulation will occur.

Just because a dramatic decline in the grand skink population has been demonstrated in the pasture area over the past 14 years does not necessarily mean it has been a gradual process. In fact, it is more likely that - whatever the cause(s) - there has been a series of sporadic declines, and maybe even some recovery between them, resulting in the net loss seen now. It is also likely, from evidence in highly modified areas elsewhere in the species' range, that the population in the pasture will continue to decline to extinction.

Similarly, it must not be assumed that the grand skink populations on the tussock area are necessarily stable or secure. It may just be they are declining very much more slowly or, given there has been no noticeable change in numbers since herpetological research began in the area in the mid-1980s, that the sporadic events which impact on tussock grassland populations, and caused the national decline of the species, may not have occurred recently.

9 Another way to test for clumping of the grand skink is through the genetic relationships of the individuals within the local populations - if movement is being prevented or restricted in the pasture area the animals there should show less genetic diversity (i.e., be more closely related to each other) than those in the tussock. Material (toes clipped during marking) has been collected to test this but results are not yet available.

Implications for conservation

Although this study has not identified exactly why grand skink populations are declining in developed areas it has confirmed that this decline is a serious and relatively rapid process. It has also shown that grand skinks exist as a metapopulation in which regular long distance movements appear to be an important element of population dynamics. Conversion of tussock grassland to pasture probably restricts or prevents movements and leads to population break down. Agricultural development, through the ploughing and re-sowing of tussock grassland, is continuing apace throughout the Macraes Ecological District and increasingly threatens the remaining skink populations, including those recommended for reservation in the Emerald Stream catchment (Whitaker & Loh 1995). Until such time as the exact causal agent/s of the decline of grand skink populations is/are determined the wisest management is to maintain the indigenous tussock grassland cover over all areas where the conservation of grand skink populations is important. If this interpretation of the problem is correct it probably means there is little that can be done to safeguard grand skink populations on private farmland where there are conflicts with development plans. It is just possible that the retention of extensive tussock "corridors", with landowner cooperation, may aid dispersal of grand skinks between outcrops but this remains to be proven.

If, as seems likely from the data, regular long distance movements are an integral part of the metapopulation dynamics of grand skinks it has added implications for reserve design. To maintain the population structure, any areas selected for reservation must not only be of sufficient size to encompass enough local populations to sustain normal dynamics but big enough that normal movements can be accommodated. The data from this study suggest areas of at the very least 1 x 1 km would be required, preferably much larger.

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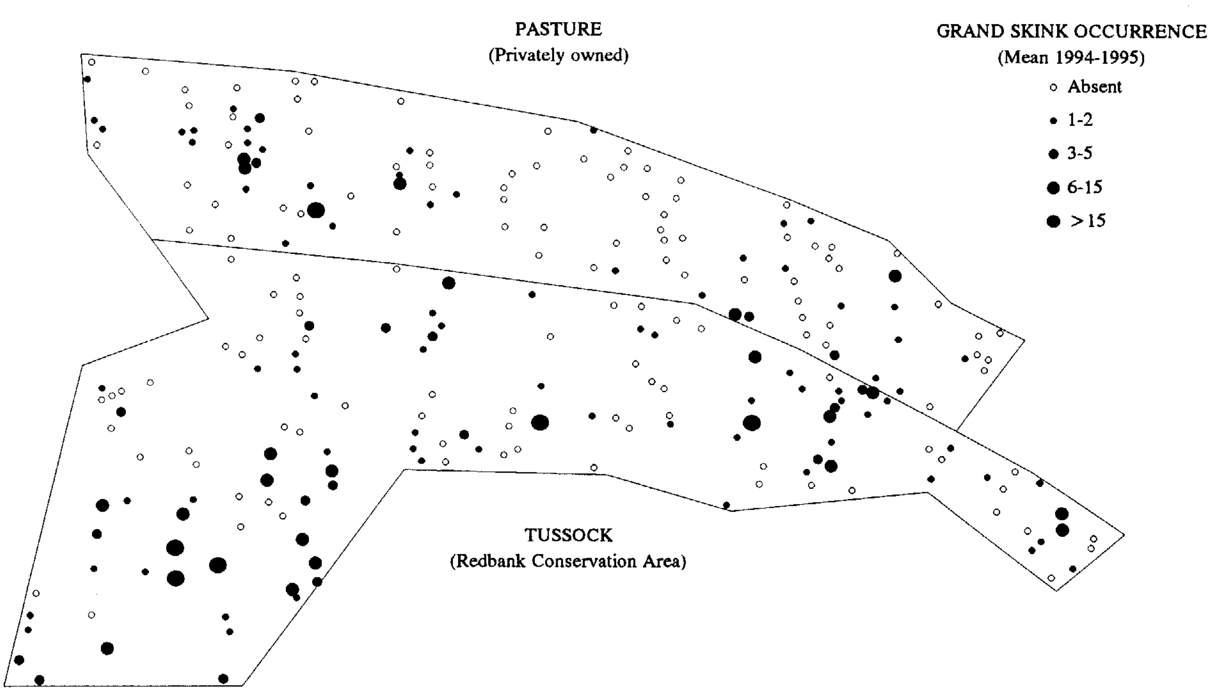
8. Appendix 1: Schematic diagram of the study area (to scale) showing distribution of rock outcrops and grand skink occurrence.



9. Appendix 2: parameters measured at each of the 120 randomly selected habitat units

SITE FEATURES:

Aspect	8 major points of the compass
Slope	Three categories: 0 10 , 11 20 , >20
Sun exposure	Four categories based on relative horizon height to E and W
Wind exposure	8 major points of the compass
Rock density	Number of habitat units in 10 ha centred on sample rock (radius 178.5 m)
Nearest rock	Distance in metres
Vegetation cover	Presence/absence of tussock within a metre radius of each of four points 10 m to N, S, E or W of sample rock
Ploughing	Presence/absence of cultivation at same sample points as "Vegetation cover"
Stock camp	Presence/absence
Rabbits	Presence/absence

ROCK FEATURES:

Elements	Number of separate rocks in habitat unit
Rock height	Height of tallest element in metres above ground
Rock length	Greatest dimension of the habitat unit in metres
Rock width	Maximum width, at right angles to length, in metres
Orientation	Direction of rock length as four compass points between E NW
Rock form	Three categories: simple, broken, complex
Dip of strata	Three categories: 0 10 , 11 20 , >20
Transect length	Combined length in metres of three transects from highest point of tallest element to the ground, oriented E, N and W
Crevices	Combined number of crevices (0.25 3 cm in height) intersected by the three transects (see Transect length above)
Loose slabs	Presence/absence. "Slab" is defined as a loose piece of schist where the width/length greatly exceeds thickness, often small
Loose blocks	Number. "Block" is defined as a loose piece of schist where the width/length not greatly exceed the height, always large
Element size	Four categories based on the relative sizes of the three largest elements
Plants	Number of plant species on rock with fruits eaten by lizards