Habitat use by chevron skinks (*Oligosoma homalonotum*) (Sauria: Scincidae) on Great Barrier Island, New Zealand

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Abstract: Habitat use of the endangered chevron skink (*Oligosoma homalonotum*) was investigated between 1997 and 2002 at three sites on Great Barrier Island, New Zealand. Habitat preferences were determined by pitfall trapping and radio-tracking studies, and a comparison of catchments with and without chevron skinks. Over the course of the research, 88 skinks were encountered. Significantly more skinks were caught in pitfall traps set in stream habitat than in alluvial terrace, boulder bank or ridge habitat. Eight chevron skinks were radio-tracked for periods between three and eight days, and 118 fixes were taken from 55 different retreat sites. When compared with randomly selected sites, chevron skinks were more likely to be found at sites that had crevices, debris dams and trees than those that did not. The further a site was away from the stream edge, the less likely it was to be a chevron skink retreat site. Chevron skinks were more likely to be found in catchments with narrow streams with rocky, as opposed to silty, substrates. We recommend that future management of chevron skinks incorporate sites that contain mature forest and rocky streams. While forest habitats on Great Barrier Island appear to be increasing in area, chevron skinks may still be declining due to the effects of introduced predators.

Keywords: chevron skink, habitat use, *Oligosoma homalonotum*, radio-tracking, Scincidae.

Introduction

Some of the rarest and most spectacular lizards have escaped detection because of their small population size and cryptic behaviour. For example, in the Canary Islands a cliff-dwelling population of the giant lacertid lizard *Gallotia bravoana*, which had been presumed extinct, was only revealed in 1999, and the original habitat range of the species is still unknown (Nogales *et al*., 2001; Hernandez-Divers *et al*., 2003). New Zealand has a number of similarly rare and cryptic species. The chevron skink (*Oligosoma homalonotum*) is one of New Zealand's largest lizards (snout to vent length (SVL) 143 mm; Gill and Whitaker, 1996), was ranked as vulnerable by the IUCN (2002) due to small or restricted populations, and has a New Zealand conservation ranking of nationally endangered (Hitchmough, 2002). Chevron skinks were first described at the beginning of the 20th century (Boulenger, 1906), but due to errors on collection data the species was effectively lost geographically for 70 years until Hardy (1977) located 13 specimens from Great Barrier Island (Fig. 1). Subsequently, a single individual was also found on Little Barrier Island (A.H. Whitaker, unpublished data). Towns and Robb (1986) considered the species to be an island "pseudoendemic", and both fossil evidence (Worthy, 1991) and anecdotal reports from the early 20th century (Towns and McFadden, 1993) suggest that the species may once have inhabited the northern North Island. Before our research began, only about 70 Great Barrier Island chevron skinks had ever been reported.

Chevron skinks present a particular challenge for conservation management because published information is mostly limited to the results of broad-scale surveys (Dick, 1981; Ogle, 1981; Newman and Towns, 1985). Ecology, biology and physiology of chevron skinks are poorly understood and these deficiencies have themselves hampered surveys aimed at determining the skinks' distribution and abundance (Towns *et al.*, 2002; A. H. Whitaker, unpublished data). Previous surveys, anecdotal reports (Robb, 1986), and a pitfall trapping study (Towns and McFadden, 1993) suggested that chevron skinks may be found near forest streams—a relationship supported by the species' susceptibility to high rates of evaporative water loss (Neilson, 2002).

Conservation options for rare species cannot be determined when the habitats used by wild populations are unknown. Habitat use by reptiles has been measured by direct observation (Schlesinger and Shine, 1994), pitfall trapping (Towns and Elliot, 1996; Freeman, 1997) and radio-tracking (Weatherhead and Charland, 1985; Warrick *et al.*, 1998). Radio-tracking can provide quite different habitat information for reptiles when compared with opportunistic sightings (Weatherhead and Charland, 1985). In the current research, we sought to define optimum habitats and microhabitats for future survey, monitoring, and management of chevron skinks using a combination of radio-tracking and pitfall trapping. These were identified as the most effective means of testing the relationship between habitat use relative to availability. Radio-tracking had never previously been used on New Zealand skinks, so we also had to overcome challenges posed by transmitter size and methods of attachment.

Methods

Study area

Great Barrier Island (27 760 ha) is in the Hauraki Gulf, 80 km north-east of Auckland (Fig. 1), and supports 13 species of lizards (Newman and Towns, 1985). Although the island is mostly covered in regenerating manuka (*Leptospermum scoparium*) and kanuka

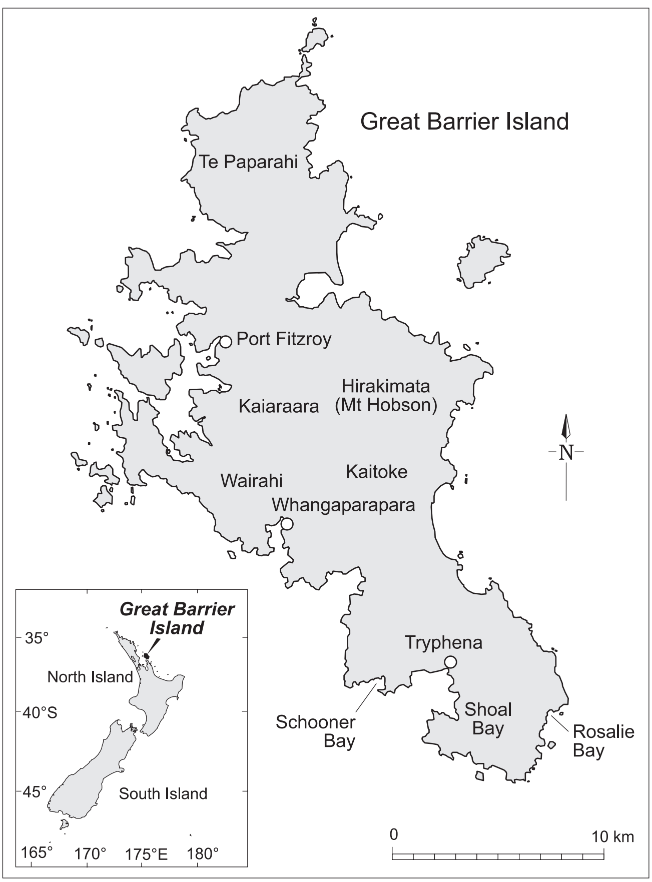

Figure 1. Great Barrier Island, New Zealand, indicating locations mentioned in the text.

(*Kunzea ericoides*), it was once renowned for its extensive kauri (*Agathis australis*) forests. Unlike the mainland North Island of New Zealand, Great Barrier Island is free of introduced mustelids, Norway rats (*Rattus norvegicus*), brushtail possums (*Trichosurus vulpecula*), and hedgehogs (*Erinaceus europaeus occidentalis*) (Towns and McFadden, 1993). However cats (*Felis cattus*), pigs (*Sus scrofa*), ship rats (*Rattus rattus*), kiore (*R. exulans*) and mice (*Mus musculus*) are abundant (Auckland Regional Council, 2002).

Study sites

A pilot study on Great Barrier Island during December 1997 – April 1998, and December 1998 – April 1999, located suitable sites for the research, and tested capture methods for chevron skinks. Catchments surveyed were at Te Paparahi, Port Fitzroy, Kaiaraara, Wairahi, Whangaparapara, Kaitoke, Tryphena and Shoal Bay (Fig. 1). Three long-term study sites were selected in the southern and central parts of the island (Tryphena, Kaiaraara, and Wairahi) where chevron skinks were present and site access was reasonably easy. Additional sites were surveyed on the island between 1998 and 2002. Records of skinks were also obtained from local residents on the island.

Intensive surveys were carried out in four habitat types (stream, alluvial terrace, boulder banks, ridges) at the three chosen long-term study sites. Stream habitats were surveyed at all three sites and encompassed all areas between the banks as well as debris on the beds of streams. Traps were set between 0 and 2.5 m from the edges of streams. Common plant species included tawa (*Beilschmiedia tawa*), silver fern (*Cyathea dealbata*), hangehange (*Geniostoma rupestre* var. *ligustrifolium*), mapou (*Myrsine australis*), kiokio (*Blechnum novae-zelandiae*), nikau (*Rhopalostylis sapida*) and puriri (*Vitex lucens*). The substrate was commonly a mix of soil, sand, boulders and small stones. These sites occasionally flooded during survey periods. Alluvial terraces (terrace) were surveyed at all three sites. All terrace sites sat above stream banks, and traps were placed between 3.5 and 26.5 m from the stream edge. Common plant species included nikau, taraire (*Beilschmiedia tarairi*) and silver fern. The substrate was almost always soil, with some sites having small stones. The forest floor tended to be shaded and to have a thick layer of leaf litter. Boulder banks were surveyed only at Tryphena. Traps at boulder bank sites were set between 4.0 and 28 m from the stream. Common plant species included karaka (*Corynocarpus laevigatus*), hangehange, silver fern and puriri. The substrate consisted of small to large boulders and stones of ranging depth over a soil base. Ridges were surveyed only at Kaiaraara and Wairahi. Traps were always set more than 30 m from the nearest stream's edge. Common plant species included kanuka, totara (*Podocarpus* spp.), silver fern, hangehange, tanekaha (*Phyllocladus trichomanoides*), Kirk's daisy (*Brachyglottis kirkii* var. *kirkii*) and maukurangi (*Blechnum fraseri*). Leaf litter was sparse at ridge habitats and the soil substrate tended to be very dry. In general, the Tryphena site consisted of a more mature forest than at Kaiaraara and Wairahi. Other lizard species previously recorded from all three sites were copper skinks (*Cyclodina aenea*) and ornate skinks (*C. ornata*) (K. Neilson, unpubl. data). Pacific geckos (*Hoplodactylus pacificus*) have also been recorded at Tryphena and Wairahi (D. Towns, unpubl. data.; A.H. Whitaker, pers. comm.), and moko skinks (*O. moco*) and forest geckos (*H. granulatus*) at Tryphena (D. Towns, unpubl. data; K. Neilson, unpubl. data).

Pitfall trapping

At Kaiaraara and Wairahi, three sites were randomly selected in each habitat type (stream, terrace and ridge), from a larger group of sites of the same habitat. At Tryphena, four stream, three terrace and three boulder bank sites were randomly selected.

Ten pitfall traps were placed at each site replicate. In all but the stream sites, a mixture of 10-L white plastic buckets and 4-L tin or black plastic buckets were used. The traps were set in two rows approximately 2 m apart. Trap type was alternated along each row. Traps along a row were also placed 2 m apart or as close to the 2-m point as possible if there were physical obstructions.

Trap lay-out was very similar at the stream sites except only 4-L tins and 4-L buckets were used. The 10-L traps were abandoned because they partly filled with water due to their depth. The pilot study indicated no detectable difference in capture effectiveness of 10-L and 4-L buckets for chevron skinks, with four and five skinks captured in these trap types respectively. In captive studies, chevron skinks did not escape from 4-L or 10-L traps when left for 24 h (K. Neilson, unpubl. data). Traps were placed in two rows, one on each side of the stream, and placed as close as possible to the 2-m point. Up to two traps per transect were placed over the stream in naturally formed debris dams. All traps were placed so that the top of the bucket was level with or slightly below the substrate surface. A handful of leaf litter was placed in the bottom of each trap as cover for captured lizards. Traps were loosely covered with natural vegetation, such as fern and nikau fronds, to provide protection from the sun and avian predators, and were baited with either banana or canned pear.

Trapping was carried out at all sites between 17 January and 27 February 2000 and 22 January and 1 March 2001, except when heavy rain forced trap closure. Further trapping was carried out at Tryphena between 12 and 20 March 2001 and between 22 January and 8 February 2002 in order to try to catch additional skinks for radio-tracking.

Visual searching was carried out each day only at the Tryphena site by one or two people walking slowly along the track looking for active or basking skinks. The searches were conducted while checking pitfall traps; and therefore, the same 450-m track was walked at least twice per day over a 6-week period throughout each summer from 1998 – 2002. Over this distance, 220 m were along stream habitat, 120 m through alluvial terraces and 110 m through boulder banks. Twenty-five person hours of searching for active chevron skinks were carried out at Tryphena during the hours of darkness.

All locations were also occasionally searched by hand. This involved physically searching in and under potential lizard refuges, such as leaf packs, logs and rocks, and checking crevices with a torch.

Data collection

For all chevron skinks captured, we recorded the capture method, habitat, microhabitat, time of capture, weather conditions and distance from a stream. Skinks were weighed and measured, and the ventral surface and both sides of the head of each animal were photographed for identification purposes. Toe-clipping of reptiles is not permitted on Great Barrier Island. All possible information was recorded for animals that were seen but not captured. Copper skinks (*Cyclodina aenea*) and ornate skinks (*C. ornata*) were also weighed, measured and marked with a xylene-free pen so that recaptures could be identified during each season.

Radio-tracking

Because transmitters had not previously been used on New Zealand skinks, attachment methods were tested on chevron skinks in captivity at Auckland Zoo during 1997. Harness-type attachments like those used by Ussher (1999) were easily and quickly slipped. Holohil model BD-2A transmitters (Holohil Systems Ltd, Canada) weighing less than 1.0 g (< 5% of chevron skink body mass) and attached to the base of the tail of the skink with Leucopor® surgical tape had the longest attachment period without apparently affecting the skink's daily activity. Keepers reported the skinks feeding, active, and retreating in similar frequencies to their normal daily patterns (B. Welch, Auckland Zoo, pers. comm.). Implanted transmitters were not tested due to the small body size of chevron skinks.

Radio-tracking of pitfall and hand-captured wild chevron skinks was conducted only at Tryphena. Eight skinks were tracked using a Telonics TR4 receiver and a 3-element hand-held yagi antenna (Sirtrack, Havelock North, N.Z.), until the transmitter fell off the animal or the battery lost charge. A retreat site was identified using the receiver at close range to get the strongest signal. At least two, but sometimes three, location attempts (fixes) were made each day. Fixes were also taken during the night for two animals, but as no nocturnal activity was observed this was discontinued. The following variables were recorded from a 1-m radius around each fix site at the completion of radio-tracking: canopy cover (%), canopy height (m), distance from stream edge (m), substrate (% of soil, boulders >10 cm, stones < 10 cm, solid rock, water, tree), microhabitat at fix site, surrounding microhabitat (% of debris dam, log, tree, leaf litter, herb cover, bare ground), presence or absence of crevices, shrub cover (%), and distance to nearest individual canopy species. To ensure consistency, all habitat data were collected by the same observer. The time of fix and distance travelled in a straight line since the previous fix was also recorded. Intervals of at least 4 hours between fixes were provided for every animal, to give adequate time for the skink to move between the major habitat types (ridge, boulder, alluvial terrace and stream).

Habitat assessment

Habitat availability compared with use by radio-tracked animals was assessed in the Tryphena catchment. The site was 400 m along the stream and approximately 50 m wide from ridge to ridge. The stream was divided into 21 points, each separated by 20 m along the length of the stream. A transect was walked from each point on both sides of the stream. The same variables as those selected for radio-tracking were recorded every 5 m, from 0 to 25 m, giving 252 points. Of these, however, only the 168 points between 0 and 15 m from the stream were used for the analysis of habitat availability, as no radio-tracked chevron skinks ever moved more than 13 m from the stream edge.

Catchment assessments

Twelve catchments were surveyed for chevron skinks over the 5 years of this research, although not all were surveyed every year. During 2002, the following variables were recorded from each of these catchments: the mean stream width (measured every 10 m along a randomly selected 200-m length of stream); total number of large debris dams (> $1 m^3$) along a randomly selected 200-m length of stream (these tended to be stable between years throughout the study); total number of small debris dams (< $1 m^3$) along a randomly selected 200 m length of stream (these tended to be very unstable and mobile); predominant substrate type within the stream – rocky, silty, or mixed; mean altitude of the catchment; catchment aspect; dominant and secondary vegetation types; and approximate age of forest in immediate vicinity [young (less than 50 years since last major disturbance), medium (50–100 years) or old (greater than 100 years)]. Catchments were categorised in terms of chevron skink presence, as either undetected, single report, or multiple reports. Catchments received the undetected label and surveys were discontinued if no chevron skinks were found during at least two summers of trapping and visual searching at that site.

Analyses

All analyses were carried out using S-Plus (Insightful Corporation, Seattle, Washington). A Poisson regression model was used to determine the effects of location and habitat type on chevron skink captures, and habitat type on captures of other skink species, taking into account different numbers of trap nights. The counts from each replicate gathered at each location and habitat were used as the response variables. The Poisson regression model assumes that the number of captures follows a Poisson distribution with means dependent on the values of the location and habitat variables. In particular, the logarithm of the means is assumed to be a linear function of the values of the location and habitat variables. To assess habitat differences using pitfall trapping data, we constructed a number of simple linear contrasts to examine differences between the means. Data in our study suffered from over-dispersion and did not appear to conform to the Poisson distribution as the variance was greater than the mean. Default test statistics in S-Plus were adjusted to account for this by using the F-test option (McCullagh and Nelder, 1989). The remainder of the contrasts could be estimated from the default output by taking differences of the contrasts that were provided. The associated standard errors could also be calculated by using the variances and covariances of the estimated effects.

Logistic regression was used to compare habitat features at radio-track sites with those at random sites. Logistic regression models the probability of observing skinks at a particular location as a function of the variables that describe the location. Quantitative information describing the substrate and ground cover, collected at each radio-track site and each random site as percentage data, were converted to presence-absence data for the purpose of the analysis. Logistic regression was used to determine which features in the catchments were important for the presence or absence of chevron skinks.

Results

Captures

In total, 88 chevron skinks were encountered over all sites surveyed on Great Barrier Island during the pilot study and subsequent habitat research. Thirty skinks were captured in pitfall traps, 56 were encountered as a result of visual searches and two were captured while hand searching. All skinks were captured between January and April except for one juvenile that was captured in November (during a trip to prepare study sites). At least one neonate was captured every year between 1998 and 2001 at Tryphena. Neonates were consistently seen only between 1 March and 20 March over all four years. Despite the regular appearance of neonates and juveniles, no gravid chevron skinks were captured at any of the three main study sites. One gravid chevron skink was captured by hand on 25 January 2001 during a short survey on private property at Rosalie Bay (Fig. 1).

During the study, 21 chevron skinks were captured at the three main study sites during 16 550 trap days (TD) at a pitfall capture rate of 0.13/100 TD. The Tryphena stream traps had the highest pitfall capture rate of any location and habitat type (0.75/100 TD; Table 1).

During visual searches at Tryphena through stream, terrace and boulder habitat, 35 chevron skinks were encountered along streams, seven in terraces and one on the boulder banks.

Recaptures

Comparisons of ventral photographs indicated that only six chevron skinks (one adult and five juveniles) were captured more than once during the entire study. None were captured more than twice. Time between captures was 5–29 days, except for one skink that was recaptured after 15 months. Of the five skinks captured within one month, four were within 5 m of the original capture site, and the fifth was over 100 m from the original capture site 28 days after first capture. The sixth skink was 57 m from the original capture site 15 months later. Chevron skinks were never captured twice by pitfall trapping.

Habitat use: trapping and searching

In addition to chevron skinks, ornate skinks and copper skinks were captured in pitfall traps at all three sites (Table 1). All three species showed no interaction between capture location and habitat type in a Poisson regression model. However in an additive model there was a significant effect of habitat on capture frequency by pitfall trapping for all three species (Table 2). Chevron skinks were only captured in pitfall traps in terrace and stream habitat, but there were significantly more captures in the stream habitat ($t_{48} = -2.87$, $P = 0.006$). Ornate and copper skinks were captured at boulder bank, terrace and ridge sites more often than at stream sites ($P < 0.05$; Table 2).

The combined chevron skink pitfall and manual capture data from the pilot study and research project (Table 3) emphasised the predominance of captures in stream habitat. Only one sub-adult and one adult were captured in boulder habitats and no chevron skinks were captured in a ridge habitat. The single gravid female was captured by hand-searching in a grassy area approximately 10 m from a stream.

Table 1. Trapping by habitat type of three species of skink (chevron *Oligosoma homalonotum*, ornate *Cyclodina ornata*, and copper *C. aenea*) at the three main study sites (Tryphena, Kaiaraara and Wairahi) on Great Barrier Island, New Zealand, between January 2000 and March 2001, with captures per hundred trap days in parentheses.

Location	Habitat	Trap nights	Chevron	Ornate	Copper
Tryphena	Stream	1739	13 (0.75)	2 (0.12)	2 (0.12)
	Terrace	1311	2 (0.15)	25 (1.9)	21 (1.6)
	Boulder	1344	0 (0)	52 (3.7)	36 (2.7)
Kaiaraara	Stream	2245	3 (0.13)	0	0
	Terrace	2235	2 (0.09)	3 (0.13)	1 (0.04)
	Ridge	2214	0	5 (0.23)	10 (0.45)
Wairahi	Stream	1802	1 (0.06)	1 (0.06)	0
	Terrace	1830	0	13 (0.71)	3 (0.16)
	Ridge	1830	0	3 (0.16)	5 (0.27)
Total		16 550	21	104	78

Table 2. Linear contrasts between habitat types for three skink species (chevron *Oligosoma homalonotum*, ornate *Cyclodina ornata*, and copper *C. aenea*) on Great Barrier Island, New Zealand. A contrast between boulder and ridge was not included, as these two habitats were never trapped at the same sites. Chevron skinks were only captured in pitfall traps at terrace and stream habitats. All tests have 48 df.

	Species					
	Chevron		Ornate		Copper	
Contrast	*t*	*P*	*t*	*P*	*t*	*P*
Boulder vs Stream			4.93	**< 0.000**	3.85	**< 0.000**
Terrace vs Stream	-2.87	**0.006**	3.96	**< 0.000**	3.23	**0.002**
Ridge vs Stream			2.52	**0.015**	3.99	**< 0.000**
Boulder vs Terrace			2.49	**0.016**	1.56	0.126
Terrace vs Ridge			1.36	0.181	-2.10	**0.041**

Table 3. Total encounters of chevron skink for all search methods by habitat type between 1997 and 2002 on Great Barrier Island, New Zealand (including pilot study results) ($n = 87$).

Habitat	Neonate	Juvenile	Sub-adult	Adult
Stream	9	46	15	5
Terrace	0	2	6	2
Boulder	0	0	1	1
Ridge	0	0	0	0
Total	9	48	22	8

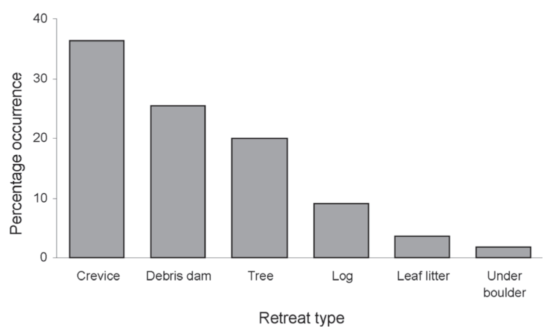

Figure 2. Percentage of retreats ($n = 55$) in each microhabitat type for eight chevron skinks (*Oligosoma homalonotum*) at Tryphena, Great Barrier Island, New Zealand.

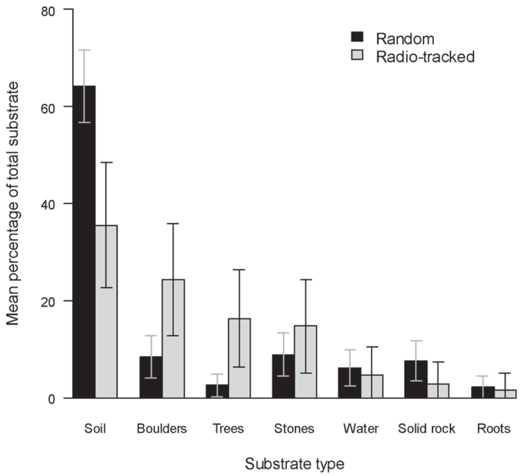

Figure 3. Mean (± SEM) percentage of substrate type found at random sites (n = 168) and sites at which chevron skinks (*Oligosoma homalonotum*) were radiotracked (n = 55) at Tryphena, Great Barrier Island, New Zealand.

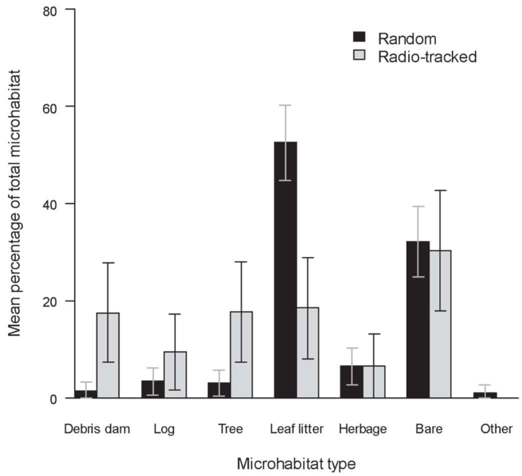

Figure 4. Mean (± SEM) percentage of microhabitat types found at random sites (n = 168) and sites at which chevron skinks (*Oligosoma homalonotum*) were radiotracked (n = 55) at Tryphena, Great Barrier Island, New Zealand.

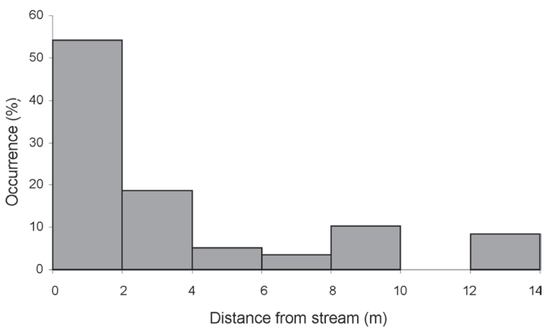

Figure 5. Percentage of radiotracking fixes (n = 118) as a function of distance to stream edge for eight chevron skinks (*Oligosoma homalonotum*) at Tryphena, Great Barrier Island, New Zealand.

Habitat use: radio-tracking

Eight chevron skinks were radio-tracked during summer at Tryphena between 1999 and 2002 for periods ranging from 3 to 8 days. A total of 118 fixes were taken from 55 different retreat sites. For the purposes of the analyses, each retreat site was counted only once regardless of the number of times it was used.

The most commonly used microhabitats were soil crevices and debris dams (Fig. 2) with all eight skinks spending some time in either of these habitat types. Two of the eight skinks spent time above ground in puriri trees or tree ferns, and a further two had retreats in the crownshafts of nikau fronds.

Chevron skinks were not distributed randomly through the Tryphena site. Within substrates, boulders, stones and trees were all used proportionally more often than they were available, and soil less often than available (Fig. 3). Within groundcover, debris dams, logs and trees were all used proportionally more than they were available (Fig. 4). The skinks were also most often found close to the stream edge; they were never located more than 13 m from the water's edge (Fig. 5).

A logistic regression model was used to compare the 168 random sites and the 55 radio-tracked retreat sites. The variable response was set to 0 for the random sites and 1 for the radio-tracked retreat sites. The initial model was as follows:

$$\text{logit}(response_i) = \mu + \beta_1 b_i + \beta_2 c_i + \beta_3 d_i + \beta_4 l_i + \beta_5 lo_i + \beta_6 s_i + \beta_7 t_i + \beta_8 dx_i$$

where b_i is the presence or absence of boulders at the ith location, c_i is the presence or absence of a crevice at the ith location, d_i is the presence or absence of a debris dam at the ith location, l_i is the presence or absence of leaf litter at the ith location, lo_i is the presence or absence of a log at the ith location, s_i is the presence or absence of a soil substrate at the ith location, t_i is the presence or absence of trees at the ith location, and dx_i is the distance from the stream of the ith location. Significant variables in predicting the presence or absence of a chevron skink retreat site were boulders ($\chi^2_1 = 8.50$, $P = 0.004$), crevices ($\chi^2_1 = 11.58$,

Table 4. Estimated effects for the habitat usage logistic regression model, for chevron skinks (*Oligosoma homalonotum*) at Tryphena, Great Barrier Island, New Zealand.

Variable	Estimate	Standard Error	Odds ratio
Crevice	0.85	0.41	2.34
Debris dam	1.09	0.51	2.97
Leaf Litter	-1.23	0.51	0.29
Tree	1.90	0.46	6.69
Distance from stream	-0.18	0.06	0.83

$P = 0.001$), debris dams ($\chi^2_1 = 19.51$, $P < 0.001$), leaf litter ($\chi^2_1 = 10.98$, $P = 0.001$), trees ($\chi^2_1 = 16.59$, $P < 0.001$), and the distance from the stream ($\chi^2_1 = 14.40$, $P < 0.001$). Therefore the model was refitted without the soil and log terms. For numerical stability reasons the boulder term was also omitted. The terms for crevice, debris dam and tree were all positive, indicating that the radio-tracked skinks showed a preference for these microhabitats (Table 4). Calculations of odds-ratios indicate that chevron skinks were more than twice as likely to be found at a site that had crevices present than not, nearly three times more likely to be found at a site with a debris dam, and more than six times more likely to be found at sites that have trees within them. The term for leaf litter was negative, indicating that skinks were less likely to be found at a site with leaf litter as a microhabitat. The coefficient for "distance from stream" was also negative, indicating that skinks were less likely to be found the further we travelled away from the stream edge (Table 4).

Catchment comparisons

Between 1997 and 2002, 12 sites were intensively surveyed for chevron skinks (Table 5). Logistic regression established that the significant variables in determining chevron skink presence in a catchment were stream width ($\chi^2_1 = 5.60$, $P = 0.018$) and stream substrate ($\chi^2_1 = 7.28$, $P = 0.007$). The directions of the contrasts (-129.60 and -114.50 respectively) indicated that chevron skinks were more likely to be found in catchments with narrow streams and a predominately rocky, as opposed to silty, substrate. Chevron skinks were found at all sites where the forest was classified as old but not at those classified as young, or at two of the sites classified as of medium age (Table 5). Chevron skinks were found in catchments facing all aspects. Two chevron skinks were found near the top of Hirakimata (the highest point on the island) during the study period although this area was not intensively surveyed. Therefore, chevron skinks were found throughout almost the entire altitudinal range on Great Barrier Island (40 – 500 m a.s.l.)

Skink activity

Active chevron skinks were captured from 0730 h until 1930 h. Searches during the hours of darkness did not

Table 5. Features of 12 catchments that were intensively surveyed for chevron skinks (*Oligosoma homalonotum*) on Great Barrier Island, New Zealand. Sites were surveyed between 1998 and 2002. UD = undetected. Debris dams were counted over a randomly selected 200-m stretch of stream.

Site	Chevron skinks	Mean stream width (m)	No. large debris dam	No. small debris dam	Mean altitude (m)	Aspect	Vege. type 1.	Vege. type 2	Forest age	Stream substrate
Kaiaraara	Multiple	2.08	4	19	80	SE	Kanuka	Kauri	Old	Rocky
Tryphena	Multiple	1.55	16	31	60	SW	Broadleaf	Kanuka	Old	Rocky
Port Fitzroy1	Multiple	2.81	7	13	40	W	Kanuka	Kauri	Medium	Rocky
Port Fitzroy2	Multiple	0.65	15	14	60	NW	Kanuka	-	Medium	Rocky/ silty
Port Fitzroy3	Single	0.39	11	53	40	SE	Kanuka	Broadleaf	Medium	Rocky/ silty
Shoal Bay1	Single	0.29	22	40	40	W	Kanuka	Broadleaf	Medium	Rocky/ silty
Rosalie Bay	Single	0.54	32	70	160	S	Kanuka	Broadleaf	Medium	Rocky
Schooner Bay	Single	0.83	6	12	150	W	Kanuka	Broadleaf	Medium	Rocky
Wairahi	Single	2.24	11	25	100	SW	Kanuka	Broadleaf	Old	Rocky
Shoal Bay2	UD	1.34	9	36	40	N	Pasture	Kanuka	Young	Silt
Kaitoke	UD	5.02	18	12	10	E	Wetland	Broadleaf	Medium	Silt
Whanga	UD	2.45	4	13	20	SW	Kanuka	-	Medium	Rocky/ silty

locate active skinks. Two skinks that were radio-tracked overnight were inactive between 2100 h and 0600 h. A total of 118 fixes were taken from eight animals during daylight hours, but only two revealed skinks that were active in the open. All other fixes were of concealed animals. While being radio-tracked, chevron skinks only moved an average of 2.8 m in a straight line (range 0 – 16.2 m) between fixes. There was no recorded movement for 35% of the fixes.

Discussion

Habitat use

The absence of any confirmed reports of New Zealand's largest skink for 70 of the last 100 years seems perplexing. However, our surveys and radio telemetry indicated that although diurnal, chevron skinks are secretive, infrequently forage in the open and prefer specific stream catchment types in mature forest. Furthermore, chevron skinks were not distributed uniformly within catchments, but were associated with stream edges. This distribution confirmed previous suspicions of an association with forested streams (Towns and McFadden, 1993) and is consistent with a physiological need for moist environments indicated by high rates of evaporative water loss (Neilson, 2002). It also indicates that past finds near streams are probably not just a reflection of survey effort (Newman and Towns, 1985).

Stream habitats appear to be particularly important for neonate and juvenile chevron skinks. Only two individuals out of 57 caught were outside this habitat type over four consecutive summers. Given the susceptibility to evaporative water loss in this species, younger and hence smaller animals, with their higher surface area to volume ratio, are likely to be more restricted by water loss than adult conspecifics (Dmi'el *et al*., 1997).

In summer, retreats selected by chevron skinks were most likely to be associated with debris dams, crevices, boulders and trees. Some skinks spent several days apparently inactive within crevices, although this behaviour is not unusual for reptiles (e.g.Huey *et al.*, 1989; Webb and Shine, 1998). Radio-tracking has also provided the first evidence of occasional arboreal habits in chevron skinks. Only one other New Zealand skink, *Oligosoma striatum*, is thought to spend substantial periods of time off the ground (Neilson *et al*., 2004).

The results described here have some limitations. Research on threatened species is often constrained by very small sample sizes (e.g. Tocher, 2003), that are not conducive to simple data analysis. Furthermore, statistically significant results may not be obtained, despite apparently strong trends (e.g. Thomas and Brown, 2000). Where this is the case with some of our results, we have made inferences from the magnitude and direction of the differences. Our radio-tracking data presents substantial difficulties for any statistical modelling technique. Measurements were made over different time periods on a small number of animals, meaning that measurements (counts) are not independent. However, we believe that the intervals between radio-track fixes were sufficiently large to allow us to assume that the presence of an animal at a location at a particular time was evidence of use of that as a retreat site. Furthermore, within reason, we assume that if the model exhibits a high degree of concordance with graphical display of the observed data, then we may take this as some degree of evidence that the effects are important in determining habitat preference.

Long-term radio-tracking studies outside New Zealand have been a useful tool for determining habitat use of cryptic or cautious reptiles where chance encounters may be biased towards certain habitat types (Weatherhead and Charland, 1985; Burger and Zappalorti, 1988; Warrick *et al*., 1998), and have been used to help produce restoration plans for endangered species (Webb and Shine, 1997). For example, Warrick *et al*. (1998) tracked radio-collared blunt-nosed leopard lizards (*Gambelia sila*) for up to 52 days. Implanted transmitters have been used to radio-track snakes over even longer periods (Weatherhead and Charland, 1985; Webb and Shine, 1997). In New Zealand, Ussher (1999) radiotracked tuatara (*Sphenodon punctatus*) for periods greater than 4 – 5 months by using a backpack and harness to attach the transmitter. In our study, information collected on habitat use was limited by the length of radio-tracking. The life of the transmitters used was expected to average about 21 days, and transmitter replacement could only be achieved if the animals were able to be physically located to attach a new transmitter. With the animals spending long periods in large debris dams and soil crevices, capturing the animal while tracking was usually impossible. Moreover, the streamside habitat generally chosen by the skinks meant that the tape used to attach transmitters was susceptible to dampness, losing adhesion and detaching from the skinks after a few days.

Capture techniques

A variety of survey methods may be necessary to ensure detection of some reptile species (Goldingay *et al*., 1996). Current survey techniques for chevron skinks are reasonably ineffective. For example pitfall capture rates for chevron skinks at known sites are amongst the lowest for any skink species in New Zealand.

Pitfall trapping success for lizards can be affected by escapes, bait type and activity periods (Duncan, 1999), predation in traps (Towns and Elliot, 1996), and history of capture, with trap shyness or trap-happy behaviour sometimes developing (Pollock *et al*., 1990).

Captive adult chevron skinks tested before the onset of fieldwork were unable to escape from 10-L or 4-L traps, and were attracted to banana as bait (Neilson, unpubl. data). Although rodents were often abundant at study sites, no sign of predation in traps was ever seen for lizards during the study. Therefore, infrequent activity on the ground surface almost certainly contributed to low trapping success in this species. This conclusion is supported by the results of radio-tracking and visual searching. Radio-tracking indicated that chevron skinks were not active on a daily basis and that there were relatively long periods when they remained concealed. However, the proportion of encounters by visual searching (64%) compared with pitfall trapping (34%) indicates that active animals rarely entered traps. On 12 occasions a chevron skink was captured by hand within 1 m of a pitfall trap, and on two occasions a skink was found sitting on foliage on top of the trap. The fact that no chevron skink was ever captured more than once in a trap certainly suggests that pitfall trap shyness is an issue with this species.

Radio-tracking emphasised the very cryptic nature of chevron skinks, which were almost always located in retreats difficult or impossible to search by hand. Debris dams, and in particular crevices, are very abundant along streams, and it would be extremely difficult and destructive to the skink's habitat to attempt a thorough search of such areas. Therefore, a priority for chevron skink research must be to identify new capture techniques, to enable the status of the species to be more accurately determined now and in the future.

Conservation implications

Information on habitat use is essential when selecting sites for future management of chevron skinks, especially where management involves intensive protection or habitat restoration. Conservation of chevron skinks on Great Barrier Island should be focused around rocky streams within mature forests. If translocations are considered for this species, selected locations should include such habitat. Once issues with capture techniques are resolved, Little Barrier Island should be resurveyed with intensive trapping and search effort being focused very close to, and within, suitable streambeds.

It must also be noted, however, that when species are restricted in distribution to relictual habitats or locations, perceived habitat use may represent only a subset of the species' full habitat spectrum (Gray and Craig, 1991). Furthermore, the presence or absence of competitors (Sexton *et al*., 1964) and predators (Downes and Shine, 1998) may alter the range of habitats used. Increased activity away from the forest floor in the presence of rodents has been recorded in the New Zealand Duvaucel's gecko (*Hoplodactylus duvaucelii*) (D.R. Towns, unpublished data).

The association of chevron skinks with rocky streams and crevices may also be related to the refuge that crevices provide from predators (Rubio and Carrascal, 1994; Martin and Salvador, 1995; Towns, 1996). On the other hand, unlike most birds and mammals, many species of reptiles rely on specific microclimates, often associated with certain retreat types (Webb and Shine, 1998). Boulder habitats have been shown to provide thermal stability for reptiles (Law and Bradley, 1990). The physiological need for moist environments shown by chevron skinks is an additional and unusual constraint. The extent to which these all influence habitat use by chevron skinks may only be determined where predator densities can be manipulated effectively over long periods.

Chevron skinks are certainly found in habitats other than those described here. Public reports between 1997 and 2002 identified chevron skinks from lawns, inside garages and in dry scrub. All of these reports were of sub-adult or adult chevron skinks, and it is possible that these apparently sub-optimal habitats are used while moving between catchments. Species with specialised habitat use are less likely to disperse through modified habitats than generalists (Sarre *et al.*, 1995); therefore, fragmentation of forested habitats is likely to have been particularly detrimental to chevron skinks on Great Barrier Island. Chevron skink habitat use from late autumn until spring has not been examined at all in this study. During the study 15 confirmed chevron skink reports in non- forested habitat were received from members of the Great Barrier Island public: only one of these was during the summer period (January-March), the other 14 being between April and December. Five of these skinks had been captured by cats or birds and five were run over by cars (K. Neilson, unpubl. data). This suggests that dispersal between fragments is most frequent during wetter months, but is also hazardous for these skinks.

Native forest clearance on Great Barrier Island ceased in about 1940, and the area under farming declined from the late 1960s (Clough, 2001). Approximately two-thirds (about 19 000 ha) of Great Barrier Island is now public conservation land (Wheeler, 2001), and early successional communities regenerating to more complex forests now cover a larger area than any other ecosystem on the island (Ogden, 2001). Additionally, since 2000 an intensive campaign has largely eradicated feral goats from Great Barrier Island, although feral cattle are still a localised problem (J. Boow, Auckland Regional Council, Auckland, pers. comm.). As forest gaps are filled and forest quality improves over a wide altitudinal range, chevron skinks should, in theory, become increasingly abundant and widespread along the numerous forested streams on the island.

However our data suggest that some chevron skink populations on the island are declining. In the mid-1980s, Towns and McFadden (1993) captured 14 adult-sized (> 110 mm SVL) chevron skinks during surveys over two summers between 1984 and 1986. We captured only eight adult animals over five summers at the same site between 1997 and 2002. At a second site monitored during the 1980s, chevron skinks were captured for three consecutive years (D. R. Towns, unpubl. data), but at the same site no chevron skinks were captured during our surveys between 1998 and 2000. Conceivably, these declines could be indirectly attributed to increased human habitation on the island. If an increasing population has increased the density of predators such as cats and rats, populations of chevron skinks are likely to decline irrespective of vegetation change. Until the intensity of these threats can be manipulated independently and capture methods can be improved, the relationship between chevron skink habitat use and carrying capacity will remain unclear, as will prospects for the species on Great Barrier Island.

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