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RESEARCH

Ecology of scree skinks (*Oligosoma waimatense*) in O Tu Wharekai Wetland, mid-Canterbury high country, New Zealand

Marieke Lettink[1*] and Joanne M. Monks[2]

[1]Fauna Finders, 45 Park Terrace, Corsair Bay, Christchurch 8082
[2]Department of Conservation, Ōtepoti/Dunedin Office, PO Box 5244, Dunedin 9058
*Author for correspondence (Email: marieke@faunafinders.co.nz)

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Abstract: Many of New Zealand's 104 lizard taxa are restricted to the country's main islands where they are vulnerable to a range of threats. Information on population trends and basic ecological data are lacking for most species, hampering conservation efforts. We monitored a population of scree skinks (*Oligosoma waimatense*; conservation status: Nationally Vulnerable) in an alluvial stream bed in O Tu Wharekai Wetland in the mid-Canterbury high country over 10 years (2008–2018) to understand aspects of the population's ecology, and to clarify potential threats and options for management. Although there was no linear trend in scree skink capture numbers over this time, an 84% decline was observed following severe and unseasonal flooding in May 2009. Capture numbers recovered over c. 8.5 years in the absence of any species management. Skinks ranged in size from 60–114 mm (snout-to-vent length). Home range size estimates varied from 39.5 to 950 m^2 (100% Minimum Convex Polygons) and their mean size was smaller than those reported for closely-related species. Photo-identification was not sufficiently accurate for long-term individual identification. Threats at our study site include severe flooding, predation by pest mammals, weed encroachment and human interference. Climate change is likely to increase future flood risk to this population and to other threatened species inhabiting the upland reaches of Southern Alps rivers. We recommend: (1) continued monitoring at our study site to assess long-term trends in a flood-prone population of scree skinks; (2) monitoring of four additional populations in scree habitat for 10 years to determine threats and management needs; (3) a survey of Black Jacks Island in Lake Benmore to determine whether the species (last seen there in the 1980s) is still present; and (4) the immediate removal of wilding conifers and other exotic trees from affected sites.

Key words: climate change, flooding, *Oligosoma*, predation, skink, Southern Alps

Introduction

The New Zealand lizard fauna comprises 104 formally or informally recognised species (61 skink and 43 gecko taxa), all but one of which are endemic to New Zealand (Chapple 2016). The majority (about 83%) of this fauna is currently regarded as threatened or at risk of extinction, primarily from predation (particularly by invasive mammals) and ongoing habitat loss (Towns et al. 2016). Major barriers to conservation include uncertainty in distribution, trend and basic ecological data for most lizard species, and the difficulties of managing invasive predators at the landscape-scale (particularly mice; Hitchmough et al. 2016a). While population recovery has been demonstrated in rare lizard species on offshore islands free of invasive mammals (Towns et al. 2016) and at mainland sites where invasive mammals are effectively controlled or excluded by pest-mammal resistant fences (e.g. Reardon et al. 2012), many lizard species are restricted to sites on the mainland of New Zealand where options are limited.

Approximately 10% of the New Zealand lizard fauna is found in Ō Tū Wharekai Wetland in the mid-Canterbury high country, South Island. This site is one of three areas managed by the New Zealand Department of Conservation (DOC) under its national Arawai Kākāriki Wetland Restoration Programme (Robertson & Suggate 2011; Sullivan et al. 2012). Ō Tū Wharekai is located c. 150 km south-west of Christchurch, and comprises the upper Rangitata River and Ashburton Lakes complex: a braided river complex and inter-montane basin of over 65 000 ha (Fig. 1). Just over a quarter of this area (17 452 ha of wetlands and braided rivers at elevations of 624–854 m a.s.l.) is intensively managed to protect and enhance its considerable wetland values (Sullivan et al. 2012). This management does not extend to any lizard population, partly due to a lack of basic ecological information.

Among Ō Tū Wharekai's notable ecological values are relatively pristine rivers and streams, glacially-derived kettleholes that support rare ephemeral turf vegetation, one of the largest breeding colonies nationwide of the threatened wrybill (*Anarhynchus frontalis*), and a diverse lizard fauna comprising 10 (seven skink and three gecko) species (DOC Herpetofauna Database, www.doc.govt.nz/nzherpatlas; Sullivan et al. 2012). The area has a long and

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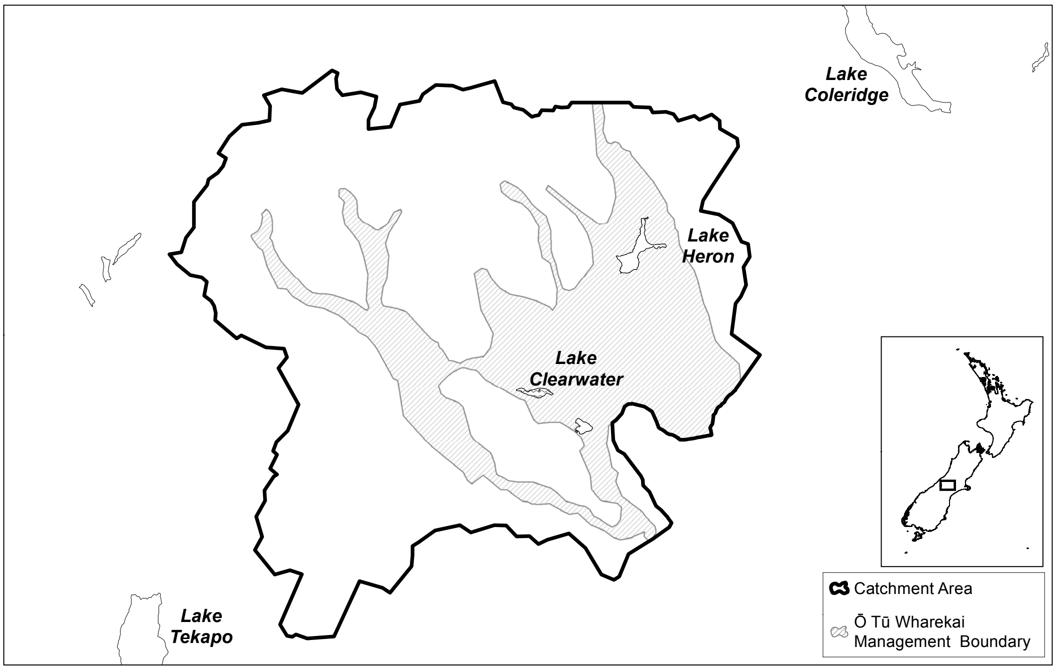

Figure 1. Map of Ō Tū Wharekai Wetland Project Area in the mid-Canterbury high country, South Island, New Zealand. The project area is defined by catchment boundaries and includes almost 18 000 ha of wetlands and braided rivers (see text). Skink monitoring was undertaken within this area over a 10-year period (2008–2018).

Table 1. Lizard species known from Ō Tū Wharekai Wetland in the mid-Canterbury high country, South Island (DOC Herpetofauna Database; unpubl. data), and their current conservation status (Hitchmough et al. 2016b). Species that have not been formally described are indicated by the use of provisional ("tag") names).

Common name	Scientific name	Conservation status
White-bellied skink	*Oligosoma hōparatea*	Nationally Critical
Scree skink	*Oligosoma waimatense*	Nationally Vulnerable
Spotted skink	*Oligosoma lineoocellatum*	Nationally Vulnerable
Mackenzie skink	*Oligosoma prasinum*	Nationally Vulnerable
Jewelled gecko	*Naultinus gemmeus*	Declining
Southern long-toed skink	*Oligosoma* aff. *longipes* "southern"	Declining
Canterbury grass skink[1]	*Oligosoma* aff. *polychroma* Clade 4	Declining
Pygmy gecko[2]	*Woodworthia* "pygmy"	Not threatened
Southern Alps gecko	*Woodworthia* "Southern Alps"	Not threatened
McCann's skink	*Oligosoma maccanni*	Not threatened

[1] The grass skink (formerly common skink) is a cryptic species complex. Grass skinks in Ō Tū Wharekai are assumed to belong to the "Clade 4" taxon based on phylogeographic information from Liggins et al. (2008).
[2] This taxon was informally named "pygmy gecko" following its discovery on Mt Harper in 2007 (Jewell 2007). Genetic analysis conducted since has revealed it to be part of an unresolved clade that extends into North Canterbury and South Marlborough (Rod Hitchmough, DOC Wellington, pers. comm.).

rich history of human use, and is valued by pastoral lease holders, tangata whenua, community groups, government agencies, recreationalists and conservationists (Robertson & Suggate 2011). The main threats to the indigenous terrestrial species and ecosystems of Ō Tū Wharekai are weed invasion (particularly of broom (*Cytisus scoparius*) and Russell lupin (*Lupinus polyphyllus*) in braided riverbeds), flooding, land-use changes (intensified farming, and water abstraction and storage proposals for irrigation) and predation by introduced mammals (Robertson & Suggate 2011; Sullivan et al. 2012).

One of the aims of the Arawai Kākāriki Wetland Restoration Programme is to conduct inventories, monitoring and management of threatened biodiversity. This aim is formalised under the Programme's National Objective 4: 'Maintain and enhance species diversity, including threatened species' (Robertson & Suggate 2011). Of the 10 lizard species present in Ō Tū Wharekai, four are classified as 'Threatened' and three are 'At Risk' of extinction under the New Zealand Threat Classification System (Table 1; Hitchmough et al. 2016b). Of greatest conservation concern are white-bellied skink (formerly Rangitata skink; *Oligosoma hōparatea*; Whitaker et al. 2018), scree skink (*O. waimatense*), Canterbury spotted skink (*O. lineoocellatum*) and Mackenzie skink (*O. prasinum*; nomenclature follows Hitchmough et al. 2016b, updated from Melzer et al. 2017 and Whitaker et al. 2018). Of the four threatened species, two (white-bellied skink and scree skink) are habitat specialists (saxicolous, i.e. restricted to rocky substrates), and all are terrestrial and relatively large (maximum snout-to-vent lengths of 91−114 mm; ML unpubl. data). These are all traits that confer an increased risk of extinction in the New Zealand lizard fauna (Tingley et al. 2013).

This paper presents the results of a 10-year study of a scree skink population in Ō Tū Wharekai Wetland. This species was considered a priority for monitoring because its population ecology is poorly known, and it is the largest and one of the most threatened lizard species present in the area, potentially making it a good indicator species for testing the effects of conservation management on the resident lizard fauna. The main objectives of this study were to: (1) provide information on aspects of scree skink ecology (including life-history, home range, abundance and population trends); and (2) clarify potential threats to the population and options for management. In addition, basic pest-mammal monitoring (targeting feral cats, mustelids, possums, hedgehogs and rodents) provided information on the composition and activity of the mammalian predator guild at our study site.

Methods

Study site

Lizard monitoring was conducted in a c. 0.5 ha area located at ~730 m a.s.l. in an alluvial stream bed in Ō Tū Wharekai Wetland (the exact location is withheld to reduce the risk of illegal collection; contact the corresponding author for further information). The stream bed contained coarse angular greywacke rocks and gravels, a small stream for most of the year (usually dry in the monitored area by mid-late summer), and sparse vegetation including black-stemmed willow herb (*Epilobium melanocaulon*), *Helichrysum depressum*, creeping pōhuehue (*Muehlenbeckia axillaris*), matagouri (*Discaria toumatou*), miki-miki (*Coprosma propinqua*), tutu (*Coriaria sarmentosa*), briar (*Rosa rubiginosa*), woolly mullein (*Verbascum thapsus*), mouse-ear hawkweed (*Hieracium pilosella*), and various native and exotic grasses. Invasive mammals present at or near the study site include feral cats (*Felis catus*), mustelids (feral ferrets *Mustela furo*, stoats *M. erminea* and weasels *M. nivalis*), European hedgehogs (*Erinaceus europaeus*), brushtail possums (*Trichosurus vulpecula*) and rodents (Norway rats *Rattus norvegicus* and house mice *Mus musculus*).

Study species

Scree skinks are restricted to mountainous regions of the South Island, east of the Main Divide from Marlborough to North Otago (Fig. 2; DOC Herpetofauna Database). They are diurnal, terrestrial and saxicolous (rock-dwelling), and occupy active greywacke screes, fractured bluffs, alluvial fans, stream and river beds, and associated terraces at elevations of c. 400–1700 m a.s.l. (the exception is one population that occurs on limestone; DOC Herpetofauna Database). Scree skinks are typically found in low numbers: an average of 2.4 ± 0.3 (SE) individuals (range = 1−17) per encounter were reported from 17 mountain ranges and one hydro-lake island (n = 87 records of the species; DOC Herpetofauna Database; accessed 20 July 2017). Five of the 26 known sites (See Appendix S1 in Supplementary Material) are in stream or river beds, and at least another 12 (48%) sites are in scree habitat that intersects montane streams or rivers.

The scree skink is one of the three 'giant skinks' of Otago (the other two species are grand skink *Oligosoma grande* and Otago skink *O. otagense*, both of which have a conservation status of Nationally Endangered). Despite its distinctive appearance and association with greywacke substrates, rather than with schist outcrops inhabited by grand and Otago skinks, the scree skink was not recognised as a distinct species until 1985 (Wells & Wellington 1985). Prior to 1977, it was subsumed within *O. grande* and from 1977−1985 it was known as the 'waimatense' form of *O. otagense*, named after the location (Waimate) from which the type specimen was collected in 1925 (Patterson 1997).

While grand and Otago skinks have been extensively researched (e.g. Berry et al. 2005; Tocher 2006; Germano 2007) and have benefited from management that has significantly improved their conservation status (consisting of landscape-scale predator trapping networks and mammal-exclusion fencing; Reardon et al. 2012; Norbury et al. 2014), little is known of scree skinks (Thomas 1982). Knowledge of their ecology is limited to incidental sightings (DOC Herpetofauna Database), two 'giant skink' surveys conducted in Otago (Whitaker 1985, 1990), and sporadic monitoring of two small sites in the Mackenzie Basin (DOC unpubl. data; site 'CLB' in Appendix S1).

Skink monitoring methods

From 2008 to 2018, skinks were monitored annually in the austral summer by pitfall trapping. Capture sessions started between 9 January and 7 February, and were timed to coincide with favourable weather conditions. A grid of 48 traps (4 L metal cans; Resene Colourshop, Christchurch) was deployed in the stream bed, consisting of three lines of 16 traps spaced 10 m apart to fit the terrain. Traps were left undisturbed for at least 2 weeks to allow lizards (skinks and geckos) to become used to their presence, and to counteract any negative effects associated with their installation (disturbance to the habitat). Pitfall traps were covered with plywood lids to prevent heat stress and potential predation on captive lizards. Lids were secured using pegs and rocks, and had wooden spacers glued

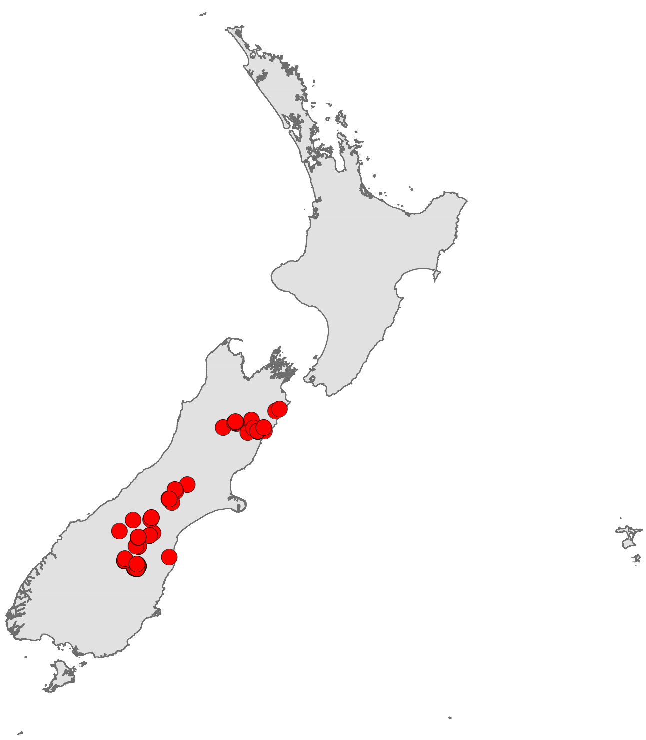

Figure 2. Distribution of scree skink (*Oligosoma waimatense*), New Zealand (DOC Herpetofauna Database).

under each corner to create a gap of c. 1−2 cm that permitted entry by lizards while excluding most mammalian predators. When not in use, traps were either filled with rocks, or removed and re-installed the following year. Minor adjustments to some trap locations (≤5 m) were required in some years to avoid flooding.

On the day before the first trap check each year, traps were baited with small pieces of canned pear (Whitaker 1967) and checked daily for 8 consecutive days thereafter. Therefore, total trapping effort was 4224 trap-days (48 traps × 8 days × 11 summers). Bait was replaced daily. All captured lizards were measured (snout–vent length (SVL), vent-tail length and the length of any tail regeneration, all to the nearest mm using a clear plastic ruler), sexed (adults only; by examination of the cloacal region and/or hemipene eversion in skinks, or by the presence of a hemipenial sac in geckos) and marked temporarily (uniquely numbered on the ventral surface and given a small dot on top of the head) with a non-toxic (Pilot extra fine tip) silver paint pen. The reproductive status of mature females (pregnant or not) was determined by visual inspection and/or gentle palpation of the abdominal region (Cree & Guillette 1995). In addition, all scree skinks were weighed to the nearest 0.2 g using a Pesola™ spring balance, and photographed (described below). With the exception of one Southern Alps gecko (*Woodworthia* "Southern Alps") apparently consumed by a scree skink (the skink had a gecko tail tip emerging from its mouth and distended belly), all lizards were released at their capture locations.

Detailed photographs of the dorsal, ventral and lateral (head-to-front-shoulder region only; right and left sides) surfaces of all scree skinks were taken with a Pentax Optio W*Pi* digital camera. These were compiled in a photo library to investigate whether photo-identification could be used to accurately identify individual scree skinks from their natural markings. Photo-identification is increasingly used as an alternative to toe-clipping for individual identification of New Zealand lizards, including for photo–resight monitoring of grand and Otago skinks (Reardon et al. 2012; Norbury et al. 2014).

Habitat use and home range size

Nine scree skinks (two adult males, four adult females and three sub-adults; size range 88−109 mm) were fitted with radio transmitters (<0.5 g BD-2N transmitters; Holohil Systems Ltd., Carp, Ontario, Canada) and tracked from 17 to 28 January 2011 to assess habitat use and estimate home range sizes. Transmitters were taped to the side of the tail base just below the vent using Leucopore® bandage tape for sensitive skin (Germano 2007). Beginning the day after transmitter attachment, skinks were located three times daily, in early morning (7:30−10:00h), mid-morning (10:30−14:00h) and late afternoon (16:00−18:00h), and their locations recorded using a GPS. To minimise researcher disturbance, we attempted to use binoculars to locate skinks during conditions that favoured skink emergence (sun, ambient temperatures of c. 12−25°C without strong winds or precipitation). One skink sloughed its skin and transmitter on the day following capture; data from this individual were excluded from analysis. All other transmitters were removed on 28 January 2011. Skinks fitted with transmitters ranged in body mass from 13.8–33.0 g, corresponding to a transmitter-to-body mass ratio of 1.6–3.8%.

We calculated home range using the 'adehabitatHR' package (version 0.4.2; Calenge 2006) in the statistical programme R (version 3.2; R Core Team 2016). All radio-tracked animals with greater than five fixes were included in analyses. We checked whether home range estimates reached an asymptote for all individuals, and opted to report 95% and 100% Minimum Convex Polygons (MCPs) based on this check and to allow comparisons with previously published estimates for similar skinks (Germano 2007; Gebauer et al. 2009).

Abundance, population trends and influence of flooding

Low capture and recapture rates of scree skinks in some years, coupled with an inability to confidently identify individuals from their natural markings, precluded the use of capture-mark-recapture (CMR) analysis to estimate population size. Therefore, we used the number of unique individuals captured per annum as an index of abundance to evaluate trends over time. Indices of abundance may be less accurate and precise than CMR estimates because they do not account for detectability (Thompson et al. 1998; Lettink et al. 2011). As temporal autocorrelation cannot be accounted for in a meaningful way in such a small dataset (n = 11 annual skink capture numbers), we evaluated population trend and its relationship with severe flood events descriptively after plotting time against skink captures (Fig. 3).

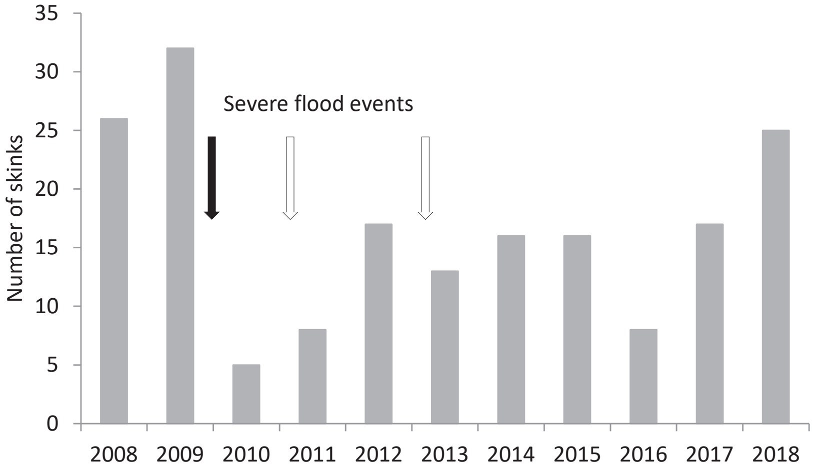

Figure 3. Numbers of individual scree skinks (*Oligosoma waimatense*) captured during annual pitfall-trapping sessions in Ō Tū Wharekai Wetland, mid-Canterbury high country, 2008−2018. Severe flood events (arrows) occurred on 17 May 2009, 28 December 2010 and 2−3 January 2013. The timing of the 17 May 2009 flood event (black arrow) was atypical in that it was the only severe flood event not during spring or summer over a 39-year period (river flow data from the upper Rangitata River; see text).

Definition of a severe flood event

Mean daily flow (in $m^3 s^{-1}$) of the upper Rangitata River (<10 km from our study site) was used to define severe flooding, and to examine its frequency, magnitude and timing over the 39-year period for which records were available (unpubl. data from 14 August 1979 onwards; Canterbury Regional Council). We defined a severe flood event as one day or several consecutive days with mean daily flows ≥1000 $m^3 s^{-1}$, i.e. more than 10 times the average (mean daily) flow over the study period (91.7 ± 1.31 (SE) $m^3 s^{-1}$). This definition was based on our observations of a flood event of 1175.5 $m^3 s^{-1}$ (the third highest flow during our study; recorded on 17 May 2009) inundating c. 75–80% of the monitoring grid, whereas the next highest flow of 968.7 $m^3 s^{-1}$ (recorded on 25 November 2008) had no apparent effects. The upper Rangitata River has a large catchment and it is acknowledged that flow data may not capture the effects of local (upstream) variation in rainfall distribution.

Pest-mammal monitoring

Casual observations of introduced mammalian predators were recorded throughout the study. In addition, basic pest-mammal monitoring was conducted on a 500 m transect adjacent to the lizard monitoring grid in January and February 2010, using a standard protocol developed for detection and monitoring of potential predators (feral cats, mustelids, European hedgehogs, brushtail possums and rodents) in Ō Tū Wharekai (as described by Sullivan (2010), except that lethal traps were not used at our site). The transect contained 10 standard corflute tracking tunnels (600 × 100 × 100 mm) placed 50 m apart and baited according to best practice (Gillies & Williams 2013), two large (1000 × 200 × 200 mm) corflute tracking tunnels placed 400 m apart and baited with fresh rabbit meat (Pickerell et al. 2014), and 20 wax tags attached to stakes 30 cm off the ground, lured with a flour and icing sugar blaze (Thomas et al. 2003). Data are presented as the percentage of tracking tunnels or wax tags that detected the target species.

Results

Summary of lizard capture data

A total of 776 captures of four lizard species were obtained over the study period (Table 2), almost all being Southern Alps geckos and scree skinks (61.2% and 37.5% of total captures, respectively). Only a small proportion of scree skinks could be confidently matched to reference photographs taken in previous years (discussed below); hence, the total number of individuals caught during the study is unknown. The number of scree skinks captured per annum ranged from 5 to 32 individuals, with considerable variation, including a large (84%) decline between 2009 and 2010 (Fig. 3). This decline was attributed to severe flooding of the river bed on 17 May 2009 (described below). Capture numbers of Southern Alps gecko did not decline following this flood event, presumably because it is not restricted to the active stream bed (it is abundant on the flanking terraces).

Life history characteristics

Scree skinks ranged in size from 60–114 mm SVL (Fig. 4). The smallest identifiable male and pregnant female captured had SVLs of 88 mm and 93 mm, respectively (Table 3). Therefore, we defined adults as individuals with SVLs ≥93 mm (i.e. the size of the smallest pregnant female). Almost half (24 of 51 captures) of adult females were pregnant at the time of capture, and most were in an advanced stage of pregnancy in January. One female gave birth in early February, between her first capture on 1 February 2017 and her recapture 6 days later. In addition, two females captured on 4 February 2017 and 23 January 2018, respectively, had loose abdominal flanks, suggesting recent births. Size of neonates at birth remains unknown because there were no captures (or sightings) of newborn skinks.

Photo-identification

Photo-identification was time-consuming because many skinks

Table 2. Number of lizard captures from a pitfall-trapping grid operated for a total of 4224 trap days (48 traps × 8 days × 11 summers) in Ō Tū Wharekai Wetland, mid-Canterbury high country from 2008 to 2018. Numbers in parentheses indicate the number of individuals caught.

Year	Scree skink	Southern Alps gecko	Canterbury grass skink	McCann's skink	All species
2008	39 (26)	11 (11)	0	0	50 (37)
2009	63 (32)	29 (23)	0	0	92 (55)
2010	7 (5)	27 (23)	0	0	34 (28)
2011	8 (8)	51 (34)	0	1 (1)	60 (43)
2012	24 (17)	31 (23)	0	0	55 (40)
2013	22 (13)	30 (25)	0	1 (1)	53 (39)
2014	22 (16)	42 (38)	0	2 (2)	66 (56)
2015	19 (16)	38 (30)	1 (1)	1 (1)	59 (48)
2016	15 (8)	101 (68)	0	0	116 (76)
2017	24 (17)	55 (39)	1 (1)	0	80 (57)
2018	48 (25)	60 (47)	2 (2)	1 (1)	111 (76)
Total captures	291	475	4	6	776

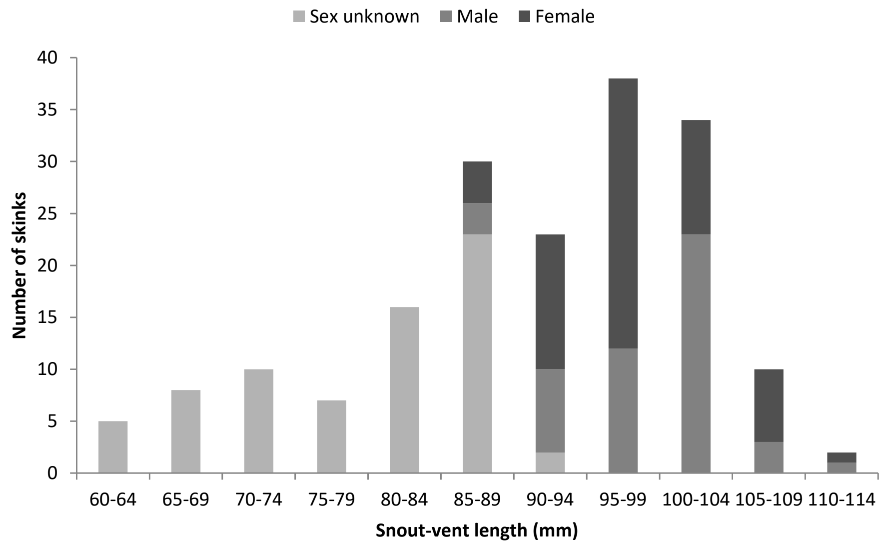

Figure 4. Size-class distribution of scree skinks (*Oligosoma waimatense*) caught in Ō Tū Wharekai Wetland (n = 183 observations). Sex could not be assigned to animals with snout-vent lengths <88 mm (see text).

Table 3. Ecological characteristics of scree skinks (*Oligosoma waimatense*) in Canterbury, compared with grand (*O. grande*) and Otago (*O. otagense*) skinks from Macraes Flat, Otago. Data in the first four columns are for adult females only. Unless stated otherwise, data for grand and Otago skinks were obtained from Cree and Hare (2016). Longevity estimates in parentheses are for captive individuals. SVL = snout−vent length, ND = no data.

Species	Mean adult SVL (mm)	Minimum SVL at maturity (mm)	Age at sexual maturity (y)	Timing of births	Longevity in wild and captivity (y)	Home range size (m^2) based on 95% or 100% Minimum Convex Polygons (MCPs)
Scree skink	99.4	93	ND	Early Feb (n = 1; see text)	13[1] (36)[2]	Range: 39.5−950 (N=8; 100% MCP; see also Table 4) Mean (95% MCP): 233.2 ± 1018.1 Mean (100% MCP) 279 ± 110m^2
Grand skink	94.5	78	3−5	Feb–Mar	23 (30)	Range: 50−1233 (N=5)[3] Mean: 407.1 ± 495.4
Otago skink	112.3	101	4−6	Feb–Mar	21 (44)	Range: 200−5400 (N=13)[4] Males (M) > females (F) Mean M: 820 ± 174.4 (N=5) Mean F: 385 ± 80.0 (N=7)

[1] Estimated from the recapture of a toe-clipped individual in the Mackenzie Basin (DOC unpubl. data)
[2] Adult male sourced from the wild as a 1- or 2-year old juvenile in 1982 (Dennis Keall, Wellington, pers. comm.)
[3] 95% MCPs from Gebauer et al. (2009)
[4] 100% MCPs from Germano (2007).

had similar markings, and subtle changes (e.g. increased or decreased speckling) occurred in some individuals over time. Therefore, only a small percentage of scree skinks (0−25% of individuals captured per annum) could be confidently matched to photos (typically, of the nose-to-forelimb region) taken in previous years. Photo-identification was useful for identifying within-session recaptures that had lost their pen marks. It was not uncommon for numbers written on the ventral surface of scree skinks (and less often, the dot on the top of the head) to be illegible or lost within a few days of application.

Frequency and timing of severe flood events

Severe flooding (mean daily flow ≥1000 m^3 s^{-1}) of the upper Rangitata River was rare, recorded on just 12 days over 39 years (0.09% of 13 927 observations since 14 August 1979). These 12 days corresponded to nine severe flood events (including two multi-day events), three during our study: on 17 May 2009 (1175.5 m^3 s^{-1}), 28 December 2010 (1352.7 m^3 s^{-1}) and 2−3 January 2013 (1358.2 m^3 s^{-1}); all values are mean daily flows. Mean daily flows of the six severe flood events prior to our study ranged from 1028.8 to 1418.3 m^3 s^{-1}. The timing of the 17 May 2009 flood event was atypical in that it was the only severe flood event since records began that did not occur during austral spring or summer. All other severe flood events were in November (n = 1), December (n = 5) or early January (n=2). The unseasonal late autumn May 2009 flood event inundated c. 75–80% of the habitat in the monitoring grid, removed most of the vegetation used by lizards for foraging and cover, re-routed the stream, and deposited the crushed remains of pitfall traps up to 0.6 km downstream.

Habitat use and home range

Skinks fitted with radio transmitters were seen on 30.9% (51 out of 165) of fixes, and were always located in the stream bed. Retreat sites were typically in areas of the stream bed that had rocks rather than fine gravels. On two occasions, skinks were observed sharing their over-night retreat with another individual. The eight skinks included in home range analyses were each located between 17 and 22 times during the telemetry study. Home range size estimates ranged from 39.5 to 950 m^2 (Table 4). Mean values (233 ± 108 m^2 (SE) and 279 ± 110 m^2; 95% and 100% MCPs, respectively) were smaller than those reported for grand and Otago skinks (Table 3). Home range estimates for all individuals appeared to asymptote between 70–80% MCPs, suggesting the home range was fully revealed at this point. However, estimated areas increased beyond that range for some individuals. Occasionally during tracking, animals moved away from the observer, suggesting that home ranges may have been artificially elevated by the activity of radio-tracking, and estimates should be interpreted with caution.

Abundance and population trends

Scree skink captures declined dramatically (an 84% decline in capture numbers between 2009 and 2010) following the large, unseasonal flood in May 2009 and slowly recovered to pre-flood levels over c. 8.5 years (Fig. 3). Recovery was greatest in the final year of the study, possibly reflecting increased recruitment and reproduction of adult females, which are likely to be a minimum of c. 4−5 years old at first breeding based on comparison to closely-related species; Table 3). Capture numbers declined to a lesser extent following the January 2013 severe flood event, but not following the December 2010 flood event. The relatively low number of captures obtained in 2016 did not follow any severe flood events. Data from a nearby weather station revealed comparable mean day-time temperatures but higher wind speeds for the 2016 capture session compared to others. High winds could potentially have reduced skink activity, and therefore, trappability. There was no overall linear trend in skink numbers (Fig. 3).

Predator guild

Feral cats and stoats were observed in the riverbed on four and two occasions, respectively, and one mouse was captured in a pitfall trap. Possum and hedgehog scats were frequently encountered on or near the lizard monitoring grid, particularly in native shrublands on terraces flanking the stream. Predator monitoring confirmed the presence of the following pest-mammal species in the summer of 2010: cat (0% and 20% tracking rates in two monitoring sessions), mustelid spp. (0% and 20%), hedgehog (20% and 80%), mouse (20% and 30%) and possum (15% and 25% bite mark indices).

Discussion

This is the first formal ecological study of the threatened scree skink, a little-known inhabitant of the South Island's high country and alpine zone. It is one of few long-term studies of large-bodied, terrestrial skinks persisting on the mainland of New Zealand (Hoare et al. 2007; Reardon et al. 2012; Nelson et al. 2016). Long-term monitoring of such species has consistently revealed significant declines and/or imminent local extinction despite attempts to mitigate threats (e.g. Tocher 2006; Hoare et al. 2007; Dumont 2015). Large-bodied, terrestrial skinks appear to be extremely vulnerable to predation by introduced mammals (Hitchmough et al. 2016a; Nelson et al. 2016) and require very high levels of pest suppression and/or exclusion before populations can recover (e.g. Reardon et al. 2012). In this context, we anticipated that our unmanaged study population would similarly be in decline.

Contrary to our expectations, capture numbers of this streambed population of scree skinks did not show an overall declining trend during 10 years despite the confounding influence of occasional, severe flooding. Capture numbers declined by 84% following severe and unseasonal flooding in May 2009, and gradually recovered over c. 8.5 years with no management. This recovery does not indicate population stability or guarantee long-term persistence, which will continue to be challenged by the intrinsic instability of New Zealand's distinctive and exceptional braided river ecosystems (O'Donnell et al. 2016). For scree skinks living in stream beds (c. 20% of known populations), severe flooding during cold weather and/or at night has the potential to cause significant mortality, because animals are inactive and therefore unable to move to unaffected areas.

Although flooding is a natural feature of New Zealand's braided rivers, particularly in spring and early summer following

Table 4. Data for individual scree skinks (*Oligosoma waimatense*) used in a radio-telemetry study at Ō Tū Wharekai Wetland, mid-Canterbury high country. SVL = snout-vent length, SA = sub-adult, A = adult, MCP = Minimum Convex Polygon; see Methods. Data for one individual (a pregnant female) that sloughed her skin on the day following transmitter attachment are not included.

Skink	SVL (mm)	Age	Sex	Reproductive status	Mass (g)	Number of fixes	Number of unique locations	Home range size (95% MCP)	Home range size (100% MCP)
51	89	SA	F	Not pregnant	13.8	22	11	180.5	457
53	92	SA	F	Not pregnant	16	22	7	296	352
57	99	A	F	Pregnant	25.5	21	10	74	102.5
61	96	A	F	Not pregnant	17.8	20	4	950	950
63	103	A	M	-	20.5	20	6	40.5	49.5
67	88	SA	F?	Not pregnant	15	17	6	49	49
69	97	A	F	Pregnant	26.5	20	8	236	236
71	109	A	M	-	28.2	20	7	39.5	39.5

snow-melt in the Southern Alps, climate change is predicted to increase the frequency and intensity of severe flooding in the upland reaches of Southern Alps rivers (including the Rangitata River near our study site), and to produce more extreme weather events nationwide (including heavy rainfall, drought, strong winds and very high temperatures; Mullan et al. 2008; Ministry for the Environment 2016). It may multiply risk by exacerbating current pressures facing native species, including birds that nest in braided river habitats (McGlone & Walker 2011) and resident lizards, for example by increasing the risk of unseasonal flooding leading to mortality of lizards in torpor.

Given enough time, species affected by climate change may be able to compensate by dispersing to new environments and/or through *in situ* adaptation (e.g. changes in their behaviour or physiology), but a failure to adjust or adapt will result in demographic collapse and extinction (Sinervo et al. 2010). In a recent global analysis of the vulnerability of reptiles to climate change, the vast majority (80.5%) of species were found to be highly sensitive to climate change, primarily due to habitat specialisation (Böhm et al. 2016). Adaptability of reptiles was poorest for long-lived species with barriers to dispersal and low reproductive outputs: all traits exhibited by scree skinks. The percentage of reptiles estimated to be highly sensitive to climate change by Böhm et al. (2016) exceeded figures reported in previous global analyses on birds (64%) and amphibians (72%; Foden et al. 2013).

Capture-mark-recapture (CMR) estimates of abundance and other parameters (e.g. survival) may have allowed more accurate assessment of population trend and the viability of our study population. Unfortunately, we could not use CMR analysis because there was no ethically-acceptable permanent marking method, and natural marks were not sufficiently distinctive nor completely stable. Photo-identification may be useful for southern (i.e. north Otago) populations of scree skink, which have more variable and distinct markings (ML pers. obs.), a likely result of hybridisation with Otago skink during the Pleistocene interglacial periods (Chapple et al. 2012). Regardless, we are confident that trends in capture numbers reflect abundance trends, because we conducted relatively long capture sessions (8 trapping days cf. ≤5 in most pitfall-trapping studies of New Zealand lizards) in favourable weather during summer, thereby minimising the influence of weather conditions on skink capture numbers.

Predatory mammals captured in lethal traps on nine transects (five located ≤5 km from our study site) that traversed a range of wetland habitats in Ō Tū Wharekai were stoats, ferrets, cats, Norway rats, hedgehogs and weasels (listed in decreasing order of numbers captured by Sullivan 2010). At our study site, tracking rates for mustelids (all species combined), hedgehogs and mice fell within the range reported for other wetland sites (Sullivan 2010), but were higher than their mean values. All of these species prey on lizards (Reardon et al. 2012; Hitchmough et al. 2016a). Mice have been observed attacking adult Otago skinks, which are larger than scree skinks (Norbury et al. 2014).

Although we did not detect an overall decline in capture numbers in one population of scree skinks studied over a decade, their life-history traits and behavior appear to make them inherently vulnerable to predation. Specifically, they have a relatively large body size and hence fewer places to hide from small predatory mammals such as mice and weasels, and are relatively confiding (i.e. tolerant of close approach). Individual predators can have a major impact on lizard populations, as suggested by large numbers of skinks recovered from gut content analysis (e.g. the remains of 49 and 70+ skinks from individual feral cats in Otago; Middlemiss 1995; James Reardon, DOC Te Anau Office, pers. comm.). As such, episodic predation is a potentially important but difficult to detect mechanism by which native skink populations are decimated in stages and cannot recover adequately in between (Reardon et al. 2012), and should be considered in management of the species.

Scree skinks did not venture out of the rocky stream bed during telemetry monitoring, confirming that they are saxicolous. Home ranges were smaller than those reported for grand and Otago skinks, and were potentially inflated by researcher disturbance (as recorded for Otago skinks; Germano 2007). The stream-bed habitat offers a variety of interstitial spaces that may provide sufficient refuge to withstand the level of predation by introduced predators in that landscape. Experimental reduction of predator abundance, ideally at multiple scree skink sites not prone to flooding, using a Before-After-Control-Impact (BACI) study design, would be enlightening.

Options for management

There is currently no management of any population of scree skink. Fortunately, scree skinks occur over a large area and scree habitat at higher elevations appears to be relatively stable (Whitaker 2008). This study did not detect any significant decline in one stream-bed population. However, in the context of other scree skink populations of which we have some knowledge (Appendix S1) and the plight of other mainland lizard populations without comprehensive management (e.g. Hoare et al. 2007; Reardon et al. 2012; Nelson et al. 2016), we suspect that most populations are likely to be declining. As such, more comprehensive monitoring to determine trends and management needs, and mitigation of obvious localised threats (e.g. weed encroachment; Appendix S1) is warranted.

Known and potential threats to scree skinks at our study site include flooding, predation, weed encroachment (causing habitat degradation by shading and/or loss of open rockland habitat) and human interference (illegal collection, mortality from off-road vehicles and stream diversion). Threats observed at other sites include earthquakes (e.g. a magnitude 7.8 earthquake near Kaikoura on 14 November 2016), hydro development (e.g. inundation of former scree skink habitat by the creation of large artificial hydro lakes), and shading and eventual slope stabilisation by wilding conifers and other exotic tree species (Whitaker 2008; ML unpubl. data). The latter could be managed relatively easily for some populations (e.g. site CLB; Appendix S1).

Other threatened New Zealand skink species have benefited from translocation to pest-mammal free islands (Towns et al. 2016), and exclusion and intensive control of pest mammals (Reardon et al. 2012). The latter requires landscape-scale trapping to be conducted well beyond the core area of skink habitat due to constant predator reinvasion (e.g. 2100 ha at Macraes Flat; Reardon et al. 2012). Such extensive management is difficult to justify for our study population given the lack of an observed decline over a decade of monitoring and that any gains could be undone by future flooding. There are currently no pest-mammal free sanctuaries that offer suitable habitat for scree skink within the species' range. Single individuals were found on Black Jacks Island in Lake Benmore in the upper Waitaki catchment during surveys in 1984 and 1985, but the species was not encountered there again during a recent (2017) visit that entailed 7.5 h of searching (by ML), albeit mostly in sub-optimal conditions (DOC unpubl. data). This island offers potential sanctuary if exotic plant species (particularly wilding conifers) and predatory mammals are removed; however, it would require on-going pest-mammal management (including the ability to detect and swiftly respond to new incursions) due to its proximity to the mainland (c. 200 m at the nearest point).

Based on our current knowledge of the stream-bed scree skink population in the Ō Tū Wharekai Wetland, together with limited information on other scree skink populations and other mainland lizard populations, we recommend: (1) continued monitoring at our study site to assess long-term trends in a flood-prone population; (2) population monitoring in scree habitat at four additional sites that are not prone to flooding (given periodic inundation confounds the results) for a 10-year period to understand threats and management needs; (3) a survey of Black Jacks Island on Lake Benmore in optimal weather conditions to determine whether the species persists there (which would inform management options for the species); and (4) the immediate removal of wilding conifers and other exotic trees at sites where these threaten the long-term persistence of scree skink populations.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Summary of threats and other relevant information for scree skink (*Oligosoma waimatense*) sites.

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