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RESEARCH

Ecology of orange-spotted geckos (*Mokopirirakau* "Roys Peak") in Central Otago and Queenstown-Lakes districts

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Abstract: New Zealand's mountainous environments support unique flora and fauna specially adapted to the extreme cold and harsh conditions of the alpine zone. The orange-spotted gecko (*Mokopirirakau* "Roys Peak") is a rare undescribed gecko that is currently known only from the alpine zone of Otago. The species was discovered in 1998 and is only known from the Central Otago and Queenstown-Lakes districts, with populations spanning a ~ 3000 km^2 area. We aimed to improve knowledge of orange-spotted geckos by collating existing survey data, assessing abundance and distribution at known sites, collecting biological data, comparing detection methods, and searching for new populations. Search techniques involved rock-lifting and spotlighting at night. A large population was identified at one site (Queenstown-Lakes A) where 95 orange-spotted geckos were recorded. All other populations (n = 5) appeared small with 20 or fewer geckos found, but require further surveying to better understand numbers and distribution. Females examined contemporaneously exhibited a range of reproductive conditions, suggesting production of successive progeny may take 2 or more years. Orange-spotted geckos use scree slopes, rock jumbles, and boulder fields at known sites. Threats to remaining populations may include predation by introduced mammals, habitat modification, illegal collection, and climate change. Future priorities for New Zealand's alpine geckos include undertaking more research on how to monitor populations, evaluating reproductive cycles at different altitudes, and assessing whether predators and other factors threaten population viability. Genetic analyses could test whether populations have been recently isolated, or whether there is a long history of fragmentation.

Keywords: alpine zone, herpetofauna, high altitude, lizard, New Zealand, reptile

Introduction

The alpine zone is typically defined as altitudes above the climatic tree-line, or comparable altitudes in non-forested environments (Mark & Dickinson 1997; Mark et al. 2000). Alpine plants and animals display a range of physiological and behavioural adaptations to help them persist in extremely cold, and often unstable, mountainous environments (Ramløv et al. 1996; Dragon et al. 1999; Sandercock et al. 2005; Scridel 2014). Many of the species that are specialised to alpine environments are threatened globally (Franzén & Molander 2012; Scridel 2014). Harsh climatic conditions can limit fecundity (Cree & Guillette 1995), and this increases susceptibility to population decline. Threats to alpine species include browsing, predation (MacDonald & Bolton 2008; O'Donnell et al. 2017), hunting (Sandercock et al. 2005), habitat loss or land use changes (Laiolo et al. 2004; Rolando et al. 2007; Patthey et al. 2008), fire and, increasingly, climate change (Dirnböck et al. 2011; Chamberlain et al. 2013).

In New Zealand, alpine areas are a significant component of the landscape covering c. 11% of the land area (O'Donnell et al. 2017). Following geologically-recent tectonic activity and glaciations, phylogenetic radiations of plants, invertebrates, birds and lizards have been extensive in the alpine zone (Wallis & Trewick 2009). Alpine New Zealand has a reasonably diverse lizard fauna, with at least 13 gecko and 17 skink species extending into alpine areas (out of 106 described and undescribed lizard taxa in Hitchmough et al. 2016), of which five have only been recorded in the alpine zone (Jewell 2008; O'Donnell et al. 2017). However, some of these species may represent relicts of former, more widespread, distributions as a result of anthropogenic factors, such as habitat modification and predation by introduced mammals (Worthy 1987; Jewell 2006; Bell & Patterson 2008). Other species formerly considered to be alpine specialists have been discovered at low elevations (e.g. in forested environments), suggesting that the alpine zone provides refugia for some formerly widespread species, for example, the Takitimu gecko (*Mokopirirakau cryptozoicus*; Jewell 2006; Bell & Patterson 2008).

The orange-spotted gecko (*Mokopirirakau* "Roys Peak"; Tocher & Marshall 2001; Jewell 2006; Nielsen et al. 2011) is a secretive, largely nocturnal and saxicolous gecko, and appears

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to be confined to mountainous areas of central and western Otago (Jewell 2006). The orange-spotted gecko was first discovered in 1998 (Tocher & Marshall 2001) and currently has a threat ranking of ‘Nationally Vulnerable’ (Hitchmough et al. 2016). As with many cryptic and poorly known species, there is some uncertainty surrounding this threat status, due to a lack of information on abundance and distribution across their known range. Current records indicate that orange-spotted geckos occupy a minimum altitudinal range of 1150–1620 m a.s.l. The one specimen found at a much lower altitude in a garden rock wall at 500 m a.s.l. may have been translocated there by children from a nearby mountain. At altitudes below 1150 m a.s.l., *Woodworthia* geckos (e.g. the Southern Alps gecko, *Woodworthia* “Southern Alps”, or korero gecko, *Woodworthia* “Otago/Southland large”) often use similar rocky retreats. It is not known to what degree orange-spotted geckos can co-exist with the different *Woodworthia* species in rocky habitats at low-moderate altitudes, although overlap with the much smaller Southern Alps gecko has been noted at one site.

From 1998–2007 approximately 35 individual orange-spotted geckos were located across five sites in the Queenstown-Lakes and Central Otago districts, with populations spanning across an approximate 3000 km^2 area (Tocher & Marshall 2001; Jewell 2006). Each site appears to be no more than 20 hectares in size, based on the extent of suitable rocky habitat, and is isolated from all other known sites. Only 1–3 individual geckos were found at three of these sites. Five different populations reduces the perceived risk of extinction; however, the species remains poorly understood and known from few specimens. We aimed to improve knowledge of orange-spotted geckos by collating existing information on the species, revisiting known sites and assessing numbers and distribution, collecting biological data, and searching for new populations. We also trialled two detection methods on orange-spotted geckos: double-layered single corrugation Onduline retreats (Lettink 2007; Lettink & Cree 2007) and tracking cards installed in small tunnels among suitable habitat (Jarvie & Monks 2014; Siyam 2006); neither method had previously been trialled on alpine *Mokopirirakau* geckos. In addition, we continued with spotlighting and rock-lifting (methods that have yielded sightings in the past) to help us assess population numbers and distribution. The following key questions were addressed: (1) What is the current known distribution of the species and how abundant do they appear to be at known sites?; (2) What method(s) appear most effective for detection or monitoring of orange-spotted gecko populations?; (3) What is their reproductive frequency?; (4) What characteristics define the habitats used by orange-spotted geckos (e.g. rock size, rock-type, altitudinal range, aspect)?

Methods

All habitats surveyed for orange-spotted geckos were in the Central Otago or Queenstown-Lakes alpine zone. They comprised the steep upper slopes of mountains with extensive exposed rock from 1000–1800 m a.s.l. Rocky habitats surveyed for geckos can be described as alpine boulder fields, rocky bluffs, scree slopes, and loose rock aggregations. Snow cover is normally present for 3–4 months of the year. Vegetation was typically dominated by *Chionochloa rigida*, with a wide range of intersecting mat-forming plants and alpine shrubs growing around and between rocks including: *Dracophyllum rosmarinifolium*, *Celmisia lyallii*, *Aciphylla aurea*, *Pimelea oreophila*, *Leucopogon fraseri*, *Raoulia subsericea*, and *Lycopodium fastigiatum*.

Population surveys

Surveys took place at eight sites over 2015–2017 (Table 1). In addition, data from a further three sites that were surveyed between 2002 and 2007 are included. Due to the high potential risk of poaching we have avoided making any references to exact localities. Instead, all 11 sites are coded from north to south and by the district in which they occur, as follows: Central Otago (CO-A to CO-F) and Queenstown-Lakes (QL-A to QL-E). Most sites were surveyed on only 1 or 2 days, except for CO-C and QL-A, which received much higher search effort (Tables 1 & 2; Appendix S1 in Supplementary Material). In

Table 1. Data from orange-spotted gecko (*Mokopirirakau* “Roys Peak”) surveys in Queenstown-Lakes and Central Otago districts. PH = person hours of searching.

Site	Year(s) surveyed	No. found	Search effort and area surveyed (ha)	Altitude (m a.s.l.)	Aspect	Habitat
QL-A	2015–17	95	179 PH, 20 ha	1360–1600	NE	Most geckos (n = 91) in scree and scattered loose rock. Four in a boulder field with large boulders surrounded by smaller rocks.
QL-B	2016	0	6 PH, 7 ha	1400–1550	NE	Fine scree, erosion prone.
QL-C	2002	2	15 PH, not recorded	1200	W	Open alpine grassland with occasional schist tors or loose slabs. Large screes within 1 km.
QL-D	2017	0	18 PH, 7 ha	1200–1450	NW	Boulder field with large boulders.
QL-E	2017	0	6 PH, 1.5 ha	1700–1800	NE	Boulder field with large boulders and smaller rocks.
CO-A	2003	1	3 PH, not recorded	1200	E	Isolated boulder beside greywacke scree in open alpine grassland.
CO-B	2016	0	2, 2 ha	1300–1400	N	Boulder field with large boulders and smaller rocks.
CO-C	2005–07	20	30 PH, 3 ha	1100–1150	SW	Only boulder field within an expansive area where only tors are present.
CO-D	2017	0	1 PH, 4 ha	1300–1400	SE	Boulder field with large boulders and smaller rocks.
CO-E	2017	9	6 PH, 1.5 ha	1580–1620	N	Boulder field with large boulders and smaller rocks.
CO-F	2017	5	2 PH, 2 ha	1380–1420	NE	Boulder field with large boulders and smaller rocks.

Table 2. Data from orange-spotted gecko (*Mokopirirakau* "Roys Peak") surveys in Queenstown-Lakes and Central Otago districts.

Site	No. of geckos	Demographic make-up (juv = juvenile, N/A = not assessed)	Mean SVL (all)	Mean, and max SVL ♂	Mean, and max SVL ♀	Min SVL (all)
QL-A	95	41 ♀, 25 ♂, 24 juv, 5 N/A	73	77, 83	80, 90	43
QL-C	2	1 ♀, 1 N/A	-	-	92	-
CO-A	1	1 ♀	-	-	89	-
CO-C	20	Not recorded	N/A	N/A	95 (max)	-
CO-E	5	2 ♀, 1 ♂, 2 juv	70	74, 74	81, 83	49
CO-F	9	2 ♀, 2 ♂, 2 juv, 3 N/A	72	87, 87	89, 89	40

total four trips to QL-A were undertaken between 2015 and 2017 with the main survey taking place over five and a half days in January 2016 (Appendix S1).

Search techniques at all sites involved day-searching (looking for active or basking geckos amongst vegetation or on rocks) and rock-lifting (looking for geckos sheltering under rocks). Spotlighting (looking for emergent geckos at night or their eye-shine with the aid of head-mounted spotlights) was undertaken at QL-A, QL-C, and CO-E only. Searching during good weather conditions (i.e. warm, sunny days or warm nights) was prioritised in an attempt to maximise captures.

Photographs of the dorsal (back) surface of all individual geckos found were taken to form an ID library (Fig. 1; see Knox et al. 2013 for a comparable method). Where photographs were available from prior surveys, all geckos found were compared with previously photographed individuals to identify any recaptures or geckos found for the first time. With repeat surveys, this method allows for information on survival and life history (e.g. age to maturity and frequency of reproduction) to be gathered. Other data collected from each individual gecko included capture date/time, capture method, habitat at point of capture, location (GPS), sex, life history stage, size (SVL, snout to vent length; and VTL, vent to end of tail, including any regeneration), and reproductive status of females using palpation. Palpation has proven an effective and accurate technique for assessing reproductive condition of small lizards including New Zealand geckos (Cree & Guillette 1995; Wilson & Cree 2003 and references within). Reproductive condition

Figure 1. Examples of the variation in dorsal patterns of orange-spotted geckos (*Mokopirirakau* "Roys Peak") in Otago. This variation is used to identify individuals and may assist long-term monitoring of individuals and populations.

was classed as vitellogenic (firm, spherical structures felt in the mid-abdominal region), early-mid pregnant (softer, more ovoid structures felt along the sides of the posterior abdomen), late pregnant (large, gecko-shaped embryo(s) present) or non-reproductive (no detectable follicles or ova detected). We recorded the number of ova present in pregnant geckos.

Trial of detection devices

Onduline retreats (a lightweight building material that can be used to construct artificial lizard retreats) have detected many different types of lizard in New Zealand, including *Oligosoma* skinks, and *Woodworthia*, *Hoplodactylus*, and *Mokopirirakau* geckos (Lettink 2007; Lettink & Cree 2007). Tracking tunnels are typically used for monitoring introduced mammalian pests; however, they also provide a useful tool for detecting or monitoring lizards (Jarvie & Monks 2014; Siyam 2006). Fifty single corrugation onduline retreats (double-layered stack, made up of two 400 mm × 100 mm sheets separated by small short lengths of 10-mm diameter pine dowel spacers; purchased from: https://www.composite-nz.co.nz/) and 50 tracking tunnels (rodent tracking tunnels cut in half to create two equal-sized lizard tracking tunnels: purchased from: http://gotchatraps.co.nz/) were set up at QL-A in November 2015 with each device installed ≤1 m apart to allow for a direct comparison. We baited tracking tunnels with canned pear and strawberry essence in small perforated plastic bags which were stapled to the centre of the tracking cards. These were checked in January 2016 (three times and then relocated to an area which appeared to have more geckos) and once in April 2016 (Appendix S1) before being removed from the site.

Results

Distribution, abundance, and demography

Orange-spotted geckos were found at six of the 11 sites surveyed (Table 1). Three of these sites represented new population discoveries (QL-C, CO-A and CO-E) with the remainder being identified and/or surveyed previously. Survey results are reported in Tables 1 and 2.

At the site with the most gecko sightings (QL-A) 95 individual orange-spotted geckos (distinguished from each other by photo-identification; Knox et al. 2013; Fig. 1) were recorded over four trips (Tables 1 & 2). Adults were defined as ≥70 mm SVL based on the smallest female confirmed to be gravid via palpation (Table 2; Fig 2).

Detection methods

Across the six sites where orange-spotted geckos were located, the vast majority (129 geckos) were found by rock lifting during 218 person hours of searching. Geckos were found under rocks in a range of weather conditions (dry weather with temperatures between 13°C and 22°C). Some warmth from the sun on the rocks appeared to increase catch per unit effort (CPUE). When rain fell CPUE appeared to decrease (e.g. only one was found from 10 person hours (PH) across two days with persistent rain at QL-A), suggesting that the geckos may have retreated away from surface rocks to beneath boulders that were too heavy to lift.

Night-time temperatures during our surveys were generally low (7–8°C) and suboptimal for emergence of geckos. One

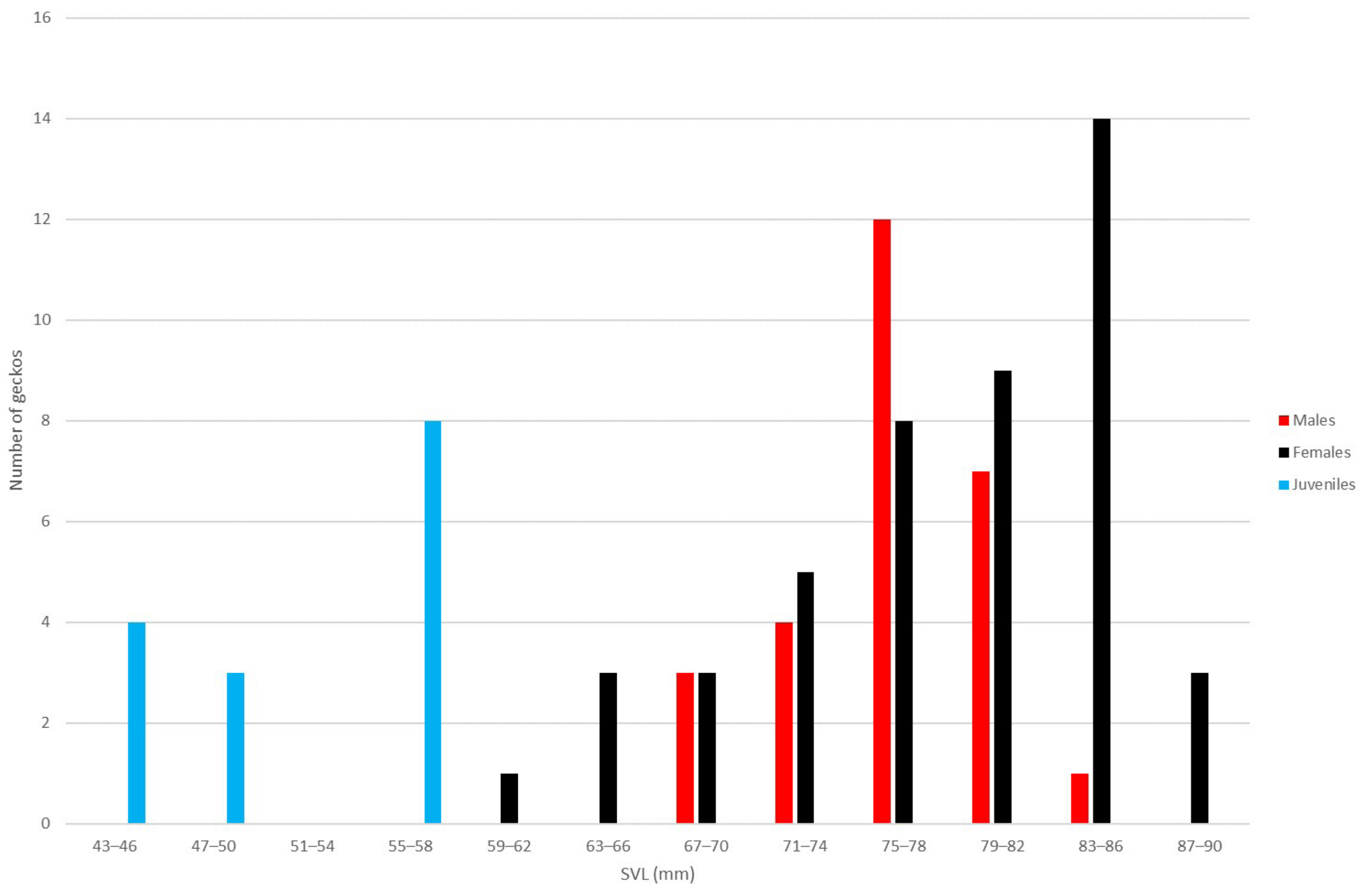

Figure 2. Distribution of Orange-spotted gecko (*Mokopirirakau* "Roys Peak") SVLs recorded at Queenstown-Lakes A in 2015/16. Juveniles defined as ≤58 mm SVL.

gecko was located emergent from 2 nights of spotlighting at QL-A in 7–8°C air temperatures (15 PH, five observers). Two geckos were located on an 11°C night at CO-E (2 PH, one observer).

No orange-spotted geckos, shed skins, or droppings were recorded in the Onduline retreats at QL-A in January 2016, April 2016, or February 2017. However, the tracking tunnels recorded orange-spotted gecko footprints in five out of 45 tracking tunnels in April 2016 (Fig. 3).

Reproductive frequency

Females differed greatly in their reproductive status between individuals at each of the four sites where multiple females were examined. Most pregnant geckos (32 of 35) were carrying two embryos. The largest sample size to assess (n = 35) was found at QL-A in January 2016 (Fig. 4). Thirteen females at QL-A were assessed as early-mid pregnant, 14 as late pregnant, and eight were not carrying embryos. One female was recaptured between successive summers and was assessed to be early-mid pregnant in January 2016 and early vitellogenic with loose flanks in February 2017. Our observations suggest that orange-spotted geckos are not on an annual reproductive cycle and are likely to take 2 or more years to produce successive progeny.

Habitat characteristics

All of the sites surveyed were between 1100–1800 m a.s.l. The main habitats used by orange-spotted geckos were scree slopes, rock jumbles, and boulder fields, composed of schist rock. Occasional individuals were found in creviced rock bluffs. Most geckos were detected during the day beneath loose slabs of schist rock or boulders. However, geckos emergent at night and detected by spotlighting were utilising vegetation, including a large, dense patch of *Dracophyllum pronum*, about 1.5 m away from rocky cover at site CO-E. All sightings were associated with rocky habitats between 1100 and 1620 m a.s.l. The six populations found encompassed a range of aspects, but three of the six sites were N- or NE-facing. Orange-spotted geckos appeared to be absent from areas with frequent erosion, and where scree or large boulders were sparse.

Figure 3. Orange-spotted gecko (*Mokopirirakau* “Roys Peak”) footprints obtained on a tracking tunnel card at Queenstown-Lakes A in April 2016. Top left: tracking tunnel. Bottom left: gecko footprints.

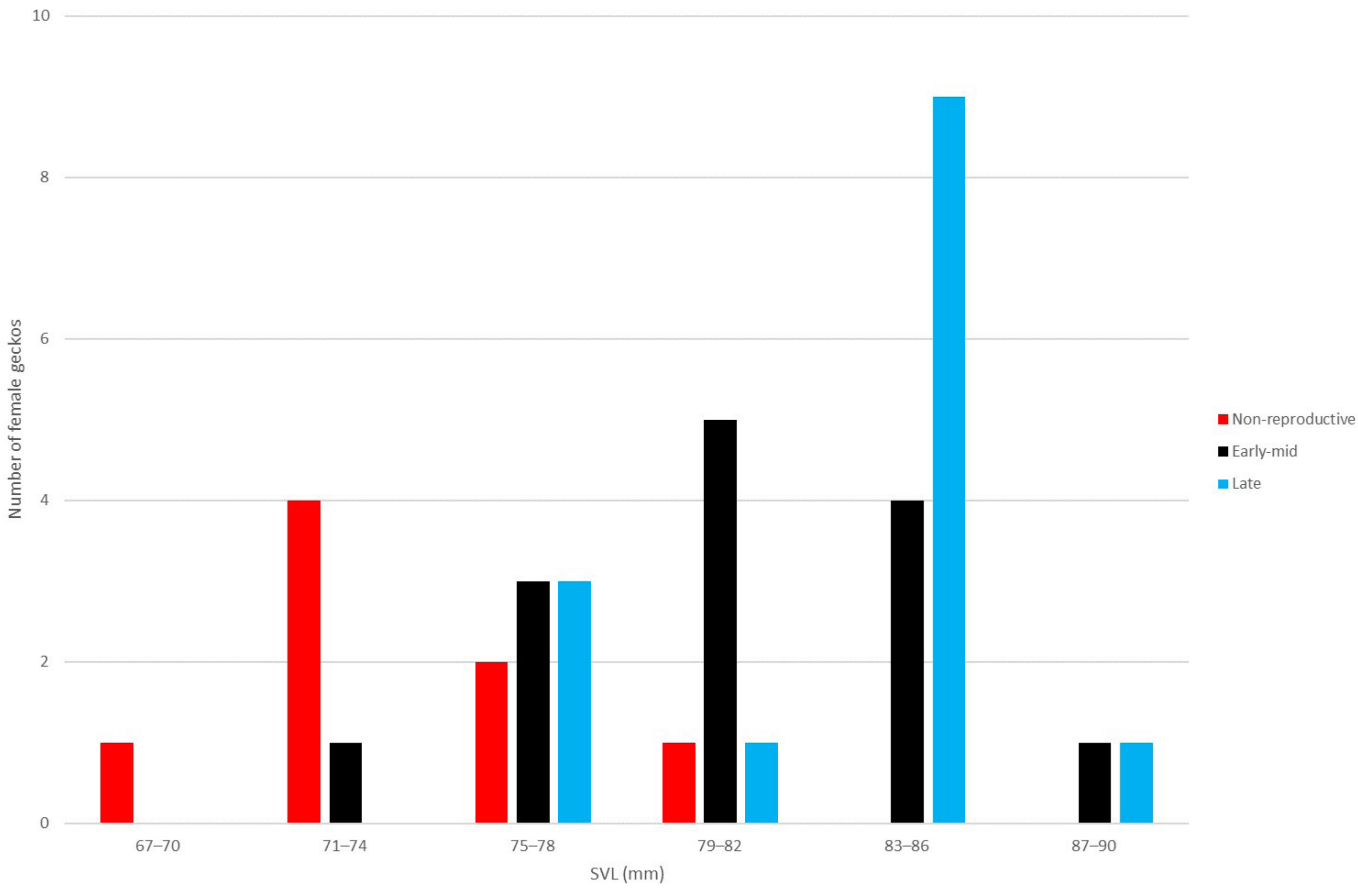

Figure 4. Data on the reproductive status of mature female orange-spotted geckos (*Mokopirirakau* "Roys Peak") recorded at Queenstown-Lakes A in January 2016 between 1360–1600 m a.s.l. All pregnant geckos were carrying two embryos except for one which had a single embryo.

Observations at CO-C provide insight into habitat segregation between orange-spotted geckos and geckos from the *Woodworthia* gecko complex. Most orange-spotted geckos were detected around the periphery of a boulder field positioned either between rocks or on stony soil. In contrast, korero geckos and Kawarau geckos (*Woodworthia* "Cromwell") were found among schist tors beside the boulder field but appeared to be largely absent from the boulder field itself.

Opportunistic observations of introduced predators

At the QL-A site, evidence of stoats (*Mustela erminea*; one sighted and two tracks in the tracking tunnels), possums (*Trichosurus vulpecula*; droppings throughout), and hedgehogs (*Erinaceus europaeus*; one sighted and hedgehogs tracked on 21% of the tracking papers) was found in the orange-spotted geckos' habitat.

Discussion

The largest known population of orange-spotted geckos is at QL-A, where they cover at least 20 ha. Distributional limits have not been accurately determined at the other five known sites; however, based on the extent of boulder field and scree and/or known sightings of orange-spotted geckos, all are thought to be less than 5 ha in size. Over two summers, 95 individual geckos were identified at QL-A, compared with only 37 individuals located at the other sites combined. Although a population estimate at QL-A is not possible at this point in time, we think it is likely that the population numbers >400 individuals. This estimate is based on the number of geckos located, lack of recaptures between summers (only 1 of the 17 geckos found in February 2017 was a recapture from the 79 photographed the previous summer), and the limitations of the search methods (surveys did not cover all potential habitat, geckos are difficult to locate among deep screes, and many large rocks and boulders too heavy to lift are present). All known sites require further survey to better understand distribution and abundance of orange-spotted geckos, especially those sites that are still only known from 1–3 individuals (Table 1).

Surveys to date indicate that the main habitats used by orange-spotted geckos are scree slopes, rock jumbles, and boulder fields. These habitats may be crucial for overwintering in the alpine zone. Mature native or exotic forests could provide habitat where present (although mature forests are now limited in extent in Central Otago; Walker et al. 2003). Moderate abundance in deep scree or boulder field habitats could reflect the opportunity for geckos to forage underneath or between rocks sheltered below ground level in a greater range of weather/temperature conditions than may be the case for animals in crevices or under singular rocks. A sunny aspect may be beneficial at high altitudes, as the geckos must obtain sufficient energy for foraging and reproduction.

Geckos appear to be absent from sites where disturbance and/or erosion is too frequent, scree slopes are too shallow or fine, or if large boulders are too sparse. Considering these factors, many rocky habitats in the alpine zone may be unsuitable for orange-spotted geckos. The reason for the apparent absence of orange-spotted geckos at sites where they were not detected was beyond the scope of our work and requires further study; however, some possibilities include differences in the predator assemblage (O'Donnell et al. 2017), temperature range or climate, rock size, frequency of erosion, snow loading, aspect, or the degree of habitat fragmentation.

Many rocky boulder field and scree habitats throughout Otago have been thoroughly searched without orange-spotted geckos being found. Unlike the mountains of Fiordland or the West Coast of the South Island, the mountains of Otago are more accessible, and have received relatively high search effort from entomologists, herpetologists, the giant skink surveys of the 1980s (Whitaker & Loh 1995) and tenure review. This search effort indicates that orange-spotted gecko populations are indeed of rare and discontinuous occurrence in the alpine zones of Central Otago. There is a historical lack of incidental collections from Otago, with 1998 being the first report, suggesting that orange-spotted geckos are likely to have been rare for a long time. If there are any remaining undiscovered sites it seems likely that they will be in mountain ranges with an abundance of scree or boulder field habitat. Thus, a consideration of rock-type and geology can help narrow down sites to survey. Many of Otago's mountain ranges lack these habitats and instead have more rock tor or bluff habitat e.g. Rock and Pillar Range, Old Man Range, and Pisa Range.

In addition to the rocky alpine habitats where orange-spotted geckos are found today, it is possible that, historically, they occupied shrublands and mature forests below the alpine zone. Orange-spotted geckos may have become restricted to high altitudes since human colonisation, due to habitat loss and predation by introduced mammals, but this hypothesis requires further investigation. Seven of the other eight species in the genus *Mokopirirakau* have been found in forested habitats, and some are known from both forest and alpine boulder fields or scree (e.g. cascade gecko, *Mokopirirakau* "Cascades", and Takitimu gecko; Jewell 2006, 2008; Bell & Patterson 2008). However, the genus also contains the black-eyed gecko (*Mokopirirakau kahutarae*), which is thought to be an alpine specialist and is largely restricted to deeply creviced alpine bluffs from 1200–2200 m a.s.l. in the Nelson and Marlborough area (Whitaker et al. 1999; Jewell 2006). Historically forest may have helped connect alpine populations of orange-spotted geckos, but today these populations have become isolated to individual mountains, or, at best, individual mountain ranges. This isolation may result in reduced genetic diversity, and associated consequences, including increased extinction risk (Frankham 2005; O'Grady et al. 2006; Miller et al. 2009). Genetic analyses could examine levels of genetic diversity or inbreeding and whether populations have been recently isolated, or whether there is a long history of fragmentation.

About 75% of New Zealand alpine endemic lizards are considered threatened or at risk (Hitchmough et al. 2016), but there are few data on the impacts of introduced predators (O'Donnell et al. 2017). At lower altitudes, the impacts of a wide range of mammalian predators have been implicated in declines of several lizard species (Newman 1994; Towns & Daugherty 1994; Hoare et al. 2007; Spitzen - van der Sluijs et al. 2009; Tocher 2009; Jones et al. 2013). The most convincing evidence implicating introduced predators as a strong impact on lizard population viability comes from studies where lizard numbers increased following predator control or eradication (Newman 1994; Lettink et al. 2010; Reardon et al. 2012; Monks et al. 2014). Stoats, possums and mice are present on the sheer rock walls >1100 m a.s.l. occupied by Sinbad skinks (*Oligosoma pikitanga*), cryptic skinks (*Oligosoma inconspicuum*), and cascade geckos in Sinbad Gully, Fiordland (Bell & Patterson 2008), indicating that introduced mammals can potentially access even the steepest and harshest of alpine habitats. Furthermore, in a recent dietary analysis of stoats in alpine habitat on the Haast Range in South Westland, a cascade gecko was recovered from the gut of a freshly-trapped stoat (O'Donnell et al. 2017).

It is logical to assume that, at least occasionally, orange-spotted geckos will be preyed upon by mammals such as stoats, possums, mice, and/or hedgehogs, but the degree to which these predators impact the viability of alpine gecko populations remains uncertain and needs further research. Given the orange-spotted geckos slow life history traits, (only producing young every 2 or more years and probably over 4 years to reach maturity) predation by introduced mammals (if frequent enough) may be a significant threat. In addition, climate change could enable more species of mammalian predators, or higher densities of predators, to infiltrate the alpine zone from lower slopes (Christie 2014).

Orange-spotted geckos can be found at QL-A in a range of weather conditions, making the site amenable to long-term monitoring. All except one of the geckos was found by rock-lifting, but weather conditions were not suitable for spotlighting (<9°C). Spotlighting on this scree slope would probably be successful on warm, cloudy nights. However, with the majority of nights being cold in the alpine zone, it may be difficult to align a trip with warm enough weather for night-time emergence of geckos. This may limit the practicality of spotlighting as a repeatable monitoring technique, but it may prove worth attempting on any nights where the air temperature remains above 10°C. In addition, whether day searching or night spotlighting is preferred may depend on habitat type. In cases where geckos cannot be easily found under by lifting rocks, spotlighting for emergent geckos at night may be preferable. For example, Whitaker et al. (1999) found that spotlighting was an effective method for locating black-eyed geckos in creviced bluffs.

No orange-spotted geckos, shed skins, or droppings were recorded in the Onduline retreats. Onduline retreats may not work well because of the abundance of suitable rocks (or natural retreats) on the scree slope at QL-A. Therefore, traps or devices that use an attractant (as opposed to provision of shelter and thermal advantage) may work better. This seemed to be the case with the tracking tunnels showing some potential as a monitoring technique (5/45 cards had orange-spotted gecko tracks in April 2016). Gees-minnow traps (Vogt 1947; Greenberg et al. 1994; Gebauer 2009; Bell 2010) are also likely to work, but these need to be checked every 24 hours (whereas tracking tunnels can be left unchecked for several days, or even weeks, meaning that a better detection rate can probably be obtained by spacing checks further out than what is possible with Gees-minnow traps). Rock-lifting often appears to be the most effective means of locating these geckos, but has the disadvantage of disturbing the habitat, especially if care is not taken (e.g. if rocks are not put back exactly how they were before being lifted) or the rocks in an area are disturbed multiple times.

Future priorities for alpine *Mokopirirakau* include undertaking more monitoring or detection technique trials to look at how best to monitor populations and identify trends, gaining a greater understanding of the reproductive cycles at sites at different elevations and evaluating whether predators and other factors threaten population viability and need managing. Genetic analyses could examine levels of genetic diversity and whether populations have been recently isolated, or otherwise. Surveys over larger areas are needed to discover new populations and learn more about the distribution and abundance of geckos at known sites. Such efforts will help to inform any future reassessments of threat status.

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References

Bell TP 2010. A novel technique for monitoring of highly cryptic lizard species in forests. Herpetological Conservation and Biology 4: 145–425.

Bell TP, Patterson GB 2008. A rare alpine skink *Oligosoma pikitanga* n. sp. (Reptilia: Scincidae) from Llawrenny Peaks, Fiordland, New Zealand. Zootaxa 1882: 57–68.

Chamberlain DE, Negro M, Caprio E, Rolando A 2013. Assessing the sensitivity of alpine birds to potential future changes in habitat and climate to inform management strategies. Biological Conservation 167: 127–135.

Christie J 2014. Adapting to a changing climate: a proposed framework for the conservation of terrestrial native biodiversity in New Zealand. Wellington, New Zealand. Department of Conservation. 23 p.

Cree A, Guillette L 1995. Biennial reproduction with a fourteen-month pregnancy in the gecko *Hoplodactylus maculatus* from southern New Zealand. Journal of Herpetology 29: 163–173.

Dirnböck T, Essl F, Rabitsch W 2011. Disproportional risk for habitat loss of high-altitude endemic species under climate change. Global Change Biology 17: 990–996.

Dragon S, Carey C, Martin K, Baumann R 1999. Effect of high altitude and in vivo adenosine/(β)-adrenergic receptor blockade on ATP and 2, 3BPG concentrations in red blood cells of avian embryos. Journal of Experimental Biology 202: 2787–2795.

Frankham R 2005. Genetics and extinction. Biological Conservation 126: 131–140.

Franzén M, Molander M 2012. How threatened are alpine environments? A cross taxonomic study. Biodiversity and Conservation 21: 517–526.

Gebauer K 2009. Trapping and identification techniques for small-scaled skinks (*Oligosoma microlepis*). Research & Development Series 318. Wellington, Department of Conservation. 24 p.

Greenberg CH, Neary DG, Harris LD 1994. A comparison of hereptofaunal sampling effectiveness of pitfall, single-ended, and double-ended funnel traps used with drift fences. Journal of Herpetology 28: 319–324.

Hitchmough R, Barr B, Lettink M, Monks J, Reardon J, Tocher M, van Winkel D, Rolfe J 2016. Conservation status of New Zealand reptiles, 2015. Wellington, Department of Conservation. 14 p.

Hoare JM, Adams LK, Bull LS, Towns DR 2007. Attempting to manage complex predator–prey interactions fails to avert imminent extinction of a threatened New Zealand skink population. Journal of Wildlife Management 71: 1576–1584.

Jarvie S, Monks JM 2014. Step on it: can footprints from tracking tunnels be used to identify lizard species? New Zealand Journal of Zoology 41: 210–217.

Jewell T 2006. Central Otago lizards. CD book. Cromwell, Central Otago, New Zealand, Jewell Publications. 125 p.

Jewell T 2008. A photographic guide to reptiles and amphibians of New Zealand. New Holland, Auckland. 144 p.

Jones C, Norbury G, Bell T 2013. Impacts of introduced European hedgehogs on endemic skinks and weta in tussock grassland. Wildlife Research 40: 36–44.

Knox CD, Cree A, Seddon PJ 2013. Accurate identification of individual geckos (*Naultinus gemmeus*) through dorsal pattern differentiation. New Zealand Journal of Ecology 37: 60–66.

Laiolo P, Dondero F, Ciliento E, Rolando A 2004. Consequences of pastoral abandonment for the structure and diversity of the alpine avifauna. Journal of Applied Ecology 41: 294–304.

Lettink M 2007. Adding to nature: can artificial retreats be used to monitor and restore lizard populations? Unpublished PhD thesis, University of Otago, Dunedin.

Lettink M, Cree A 2007. Relative use of three types of artificial retreats by terrestrial lizards in grazed coastal shrubland, New Zealand. Applied Herpetology 4: 227–243.

Lettink M, Norbury G, Cree A, Seddon PJ, Duncan RP, Schwarz CJ 2010. Removal of introduced predators, but not artificial refuge supplementation, increases skink survival in coastal duneland. Biological Conservation 143: 72–77.

MacDonald MA, Bolton M 2008. Predation on wader nests in Europe. Ibis 150: 54–73.

Mark A, Dickinson K 1997. New Zealand alpine ecosystems. In: Wielgolaski FE, Goodall DW eds. Polar and alpine tundra. Ecosystems of the world. Amsterdam, Elsevier. Pp. 311–346.

Mark AF, Dickinson KJ, Hofstede RG 2000. Alpine vegetation, plant distribution, life forms, and environments in a perhumid New Zealand region: oceanic and tropical high mountain affinities. Arctic, Antarctic, and Alpine Research 32: 240–254.

Miller KA, Nelson NJ, Smith HG, Moore JA 2009. How do reproductive skew and founder group size affect genetic diversity in reintroduced populations? Molecular Ecology 18: 3792–3802.

Monks JM, Monks A, Towns DR 2014. Correlated recovery of

five lizard populations following eradication of invasive mammals. Biological Invasions 16: 167–175.
Nielsen SV, Bauer AM, Jackman TR, Hitchmough RA, Daugherty CH 2011. New Zealand geckos (Diplodactylidae): cryptic diversity in a post-Gondwanan lineage with trans-Tasman affinities. Molecular Phylogenetics and Evolution 59: 1–22.
Newman DG 1994. Effects of a mouse, *Mus musculus*, eradication programme and habitat change on lizard populations of Mana Island, New Zealand, with special reference to McGregor's skink, *Cyclodina macgregori*. New Zealand Journal of Zoology 27: 443–456.
O'Donnell CFG, Weston KA, Monks JM 2017. Impacts of introduced mammalian predators on New Zealand's alpine fauna. New Zealand Journal of Ecology 41: 1–22.
O'Grady JJ, Brook BW, Reed DH, Ballou JD, Tonkyn DW, Frankham R 2006. Realistic levels of inbreeding depression strongly affect extinction risk in wild populations. Biological Conservation 133: 42–51.
Patthey P, Wirthner S, Signorell N, Arlettaz R 2008. Impact of outdoor winter sports on the abundance of a key indicator species of alpine ecosystems. Journal of Applied Ecology 45: 1704–1711.
Ramløv H, Wharton DA, Wilson PW 1996. Recrystallization in a freezing tolerant Antarctic nematode, *Panagrolaimus davidi*, and an alpine weta, *Hemideina maori* (Orthoptera; Stenopelmatidae). Cryobiology 33: 607–613.
Reardon JT, Whitmore N, Holmes KM, Judd LM, Hutcheon AD, Norbury G, Mackenzie DI 2012. Predator control allows critically endangered lizards to recover on mainland New Zealand. New Zealand Journal of Ecology 36: 141–150.
Rolando A, Caprio E, Rinaldi E, Ellena I 2007. The impact of high-altitude ski-runs on alpine grassland bird communities. Journal of Applied Ecology 44: 210–219.
Sandercock BK, Martin K, Hannon SJ 2005. Life history strategies in extreme environments: comparative demography of arctic and alpine ptarmigan. Ecology 86: 2176–2186.
Scridel D 2014. Ecology and conservation of birds in upland and alpine habitats: a report on the BOU's Annual Conference held at the University of Leicester, 1–3 April 2014. Ibis 156: 896–900.

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Siyam SM 2006. Reptile monitoring: development of an effective, passive monitoring technique. Unpublished MSc thesis, University of Auckland, Auckland, New Zealand. 264 p.
Spitzen - van der Sluijs AM, Spitzen J, Houston D, Stumpel AHP 2009. Skink predation by hedgehogs at Macraes Flat, Otago, New Zealand. New Zealand Journal of Ecology 33: 205–207.
Tocher MD 2009. Life history traits contribute to decline of critically endangered lizards at Macraes Flat, Otago. New Zealand Journal of Ecology 33: 125–137.
Tocher MD, Marshall LJ 2001. Surveys for *Hoplodactylus* aff. *granulatus*, Roys Peak and Mount Alpha, Wanaka. Conservation Advisory Science Notes 344. Wellington, Department of Conservation. 27 p.
Towns DR, Daugherty CH 1994. Patterns of range contractions and extinctions in the New Zealand herpetofauna following human colonisation. New Zealand Journal of Zoology 21: 325–339.
Vogt W 1947. A practical lizard trap. Copeia 2: 115.
Wallis GP, Trewick SA 2009. New Zealand phylogeography: evolution on a small continent. Molecular Ecology 18: 3548–3580.
Walker S, Lee WG, Rogers GM 2003. The woody vegetation of Central Otago, New Zealand: its present and past distribution and future restoration needs. Science for Conservation 226. Wellington, Department of Conservation. 99 p.
Whitaker AH, Loh G 1995. Otago skink and grand skink recovery plan (*Leiolopisma otagense* and *L. grande*). Threatened species recovery plan No 14. Wellington, Department of Conservation. 40 p.
Whitaker T, Shaw T, Hitchmough R 1999. Black-eyed geckos (*Hoplodactylus kahutarae*) on Mt Arthur, Kahurangi National Park. Conservation Advisory Science Notes No. 230. Wellington, Department of Conservation. 17 p.
Wilson JL, Cree A 2003. Extended gestation with late-autumn births in a cool-climate viviparous gecko from southern New Zealand (Reptilia: *Naultinus gemmeus*). Austral Ecology 28: 339–348.
Worthy T 1987. Osteological observations on the larger species of the skink *Cyclodina* and the subfossil occurrence of these and the gecko *Hoplodactylus duvaucelii* in the North Island, New Zealand. New Zealand Journal of Zoology 14: 219–229.

Supplementary material

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

Appendix S1. Data from orange-spotted gecko (*Mokopirirakau* "Roys Peak") surveys at Queenstown-Lakes A.

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