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SHORT COMMUNICATION

Use of constructed rock piles by lizards in a grassland habitat in Otago, New Zealand

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Abstract: The main drivers of lizard population declines in Aotearoa New Zealand are habitat loss and introduced predators. Therefore, habitat enhancement could be useful for mitigating declines, but there is little information on how Aotearoa-endemic lizards respond to these interventions. We examined whether novel habitats created by ten c. 375 m^3 constructed rock piles would be used by McCann's skinks (*Oligosoma maccani*), southern grass skinks (*O.* aff. *polychroma* Clade 5), and kōrero geckos (*Woodworthia* "Otago/Southland large"). The rock piles and their immediate edges were surveyed 22 times between four months and 2.4 years post-construction, resulting in 228 sightings of McCann's skinks on all ten piles, 20 sightings of southern grass skinks on six piles, and two sightings of kōrero geckos on two piles. Estimated abundance of McCann's skinks increased over time, and neonates were observed. These observations indicate that rock pile construction could create habitats for McCann's skinks, but further inference is limited. We recommend that future mitigation programs quantify how habitat construction affects lizard populations and suggest methods for achieving this.

Keywords: artificial refuges, gecko, habitat enhancement, mitigation, skink

Introduction

Aotearoa New Zealand's endemic lizards are in an imperilled state, with 94% of the 124 described and putative species being classified as nationally Threatened or At Risk (Hitchmough et al. 2021). The main drivers of lizard population declines and extirpations in Aotearoa are habitat loss and introduced predators (Towns & Daugherty 1994). Therefore, enhancing habitat quality could be useful for their conservation. Globally, numerous attempts at enhancing reptile habitats have been undertaken for conservation or ecological effects mitigation, particularly in Europe, North America, and Australia (Herbert 2020). While reptile species readily use enhanced habitats, fewer studies demonstrate any benefits for reptile populations (Herbert 2020). Furthermore, few studies have documented the responses of Aotearoa reptiles to habitat enhancement (Hoare et al. 2007; Lettink et al. 2010; Knox et al. 2012; Lennon 2019; Herbert 2020). Therefore, further case studies of reptile responses to habitat enhancement attempts are sorely needed to inform conservation and ecological consulting practice both in Aotearoa and internationally.

All endemic lizard species within Aotearoa are afforded absolute protection under the Wildlife Act 1953 and it is an offence to disturb or kill native lizards without government permission. Additionally, under the Resource Management Act 1991, organisations undertaking specific resource management activities that may adversely impact the habitats of indigenous species must avoid, remedy, or mitigate these effects. However, the outcomes of ecological effects mitigation efforts for Aotearoa-endemic lizards often go undocumented, are inconclusive, or are only monitored for a short period of time (Lennon 2019).

In 2013, the international gold production company OceanaGold Ltd sought resource consent to develop a new 62-hectare open pit and 105-hectare waste rock piles in eastern Otago. This project was termed the Coronation Project and aimed to extend mining activities at the OceanaGold owned and operated Macraes Flat gold mine. An assessment of the ecological effects of this project indicated that three endemic lizard species (McCann's skinks *Oligosoma maccani*, southern grass skinks *O.* aff. *polychroma* Clade 5, and kōrero geckos *Woodworthia* "Otago/Southland large") would be adversely impacted. Southern grass skinks and kōrero geckos are classified as At Risk, whereas McCann's skinks are considered Not Threatened (Hitchmough et al. 2021).

Mitigation for the loss of resident lizards and their habitats within the project area was required as a condition of resource consent granted for the Coronation Project by the Waitaki District Council (201.2013.360) and the Dunedin City Council (LUC-2013-25), and by a Wildlife Act Authority (39247-FAU)

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granted by the Department of Conservation. As part of the lizard mitigation package, OceanaGold was required to build new rock piles to provide lizard habitat in the area adjacent to the Coronation Project site. Construction of refugia using artificial rocks or rubble has successfully provided habitat for reptile species in Australia and England, but were untested in Aotearoa before 2019 (Showler et al. 2005; Croak et al. 2010, 2013; Lennon 2019; Herbert 2020). Because of this lack of knowledge, the rock piles and their immediate edges were monitored for 2.4 years post-construction to determine: (1) which lizard species used the newly created habitats and (2) the temporal trend of each species' abundance within these habitats.

Methods

The study site was located on private land near the township of Macraes Flat, eastern Otago, in the South Island of Aotearoa (45°25′ S, 170°28′ E). Macraes Flat lies in a cool-to-cold semi-arid environment at 400–600 m above sea level (Reardon et al. 2012; Singers & Rogers 2014). The present-day vegetation consists of a mosaic of agricultural pasture, indigenous tussockland dominated by *Chionochloa rubra* and *C. rigida*, and mixed indigenous shrubland dominated by mānuka (*Leptospermum scoparium* agg.; Reardon et al. 2012). Outcrops of Haast schist are prevalent throughout the landscape (Reardon et al. 2012). The Macraes Flat area contains a biodiverse lizard community consisting of eight described and putative species, with the most common species being McCann's skinks, southern grass skinks, and kōrero geckos.

McCann's skinks and southern grass skinks are heliothermic and terrestrial lizards with body lengths of up to 80 mm. They mature at 2–3 years, reproduce annually, and give birth to 2–6 young (van Winkel et al. 2018). Kōrero geckos reach up to 90 mm in body length and are terrestrial; although nocturnal, they may sun-bask close to the entrance of daytime refugia (Gibson et al. 2015; van Winkel et al. 2018). Kōrero geckos mature at 3–4 years and females produce 1–2 young biennially at Macraes Flat (Rock & Cree 2003; Penniket 2012; van Winkel et al. 2018). All three species use rocky habitats within scrub and tussock grassland areas, but McCann's skinks and kōrero geckos are more strongly saxicolous than southern grass skinks in Otago (Patterson 1992; van Winkel et al. 2018).

Ten rock piles measuring approximately 25 × 5 × 3 m (length × width × height) were constructed in October 2014 in tussock-grassland habitat adjacent to the stage 5 area of the Coronation Project gold mine (Fig. 1). All piles were 5–10 m apart and created using a bulldozer to stack locally excavated rock (Haast schist pieces ranging in length and width from 2–50 cm). However, Pile 1 comprised a mixture of soil and schist. By March 2016, 677 *Melicytus alpinus*, 136 *Coprosma propinqua*, and 243 *C. dumosa* seeds had been scattered over these rock piles to assist colonisation by indigenous shrubs.

Immediately following rock pile construction, four 2 L pitfall traps were installed per pile (40 pitfall traps in total). All pitfalls had four 3-mm drainage holes drilled in the bottom and were set so that the lip was either flush with or lower than the surrounding substrate surface. Half of these pitfalls were dug into the ground on the immediate edges of rock piles, and the remaining half were placed within holes excavated in the rock piles approximately 1.5 m above the ground level (Fig. 1e). Each trap was covered by a double layer of Onduline (dimensions: 50 × 40 cm). These monitoring 'stations' were left in place for four months to allow lizards to become habituated to using the Onduline refuges.

The rock piles were surveyed for lizards in February 2015 (four months post-construction) and in March 2016 and 2017 (1.4 years and 2.4 years post-construction, respectively). Lizards were recorded as using habitats created by rock pile construction if they were observed directly on a pile or within 0.5 m of its edge. Prior knowledge of the study species, or closely related species, indicated that movements of 5–20 m are possible within 2–3 week periods (Whitaker 1982; Bannock 1998; Lettink et al. 2010). It was therefore likely that lizards moved on and off the piles within and between each monitoring period. We assumed that within-period immigration and emigration were random processes with the same mean probability of occurrence and did not affect within-period net abundance.

On the first day of monitoring, the pitfall traps were opened and baited with canned pear. Small rocks and a wet sponge were placed at the bottom of the traps to provide shelter and humidity for trapped lizards. The first lizard survey was conducted approximately 12 hours after the initial opening session. Thereafter, each rock pile was surveyed twice daily up to a total of nine repeated surveys each year (Table 1). Surveying was suspended for four days in 2015 during a period of poor weather. The pitfall traps were closed during this time and re-opened once surveying resumed. Survey of each rock pile consisted of a single experienced observer checking the four traps, waiting for c. 15 minutes for disturbed lizards to re-emerge, then carrying out a ten-minute visual encounter search (VES) of the pile surface and the ground within 0.5 m from the pile edge to observe additional lizards. Visual encounter searches consisted of a surveyor circumnavigating each rock pile once while keeping an approximately 2 m distance from the edge to avoid disturbing lizards. Short-range binoculars were used to assist with VES. Every lizard encountered within a monitoring station was captured and held in a cloth bag while the VES was conducted to ensure that individuals were only counted once, then released at the point of capture. The species and life stage (neonate, juvenile, or adult) of observed lizards were recorded. The temperature at the start and end of each survey was measured with a handheld Kestrel 2500 anemometer held c. 1.4 m above ground in shade and averaged.

Poisson N-mixture models (Royle 2004) were applied in PRESENCE version 2.12.31 (Hines 2006) to the repeated counts of McCann's skinks to estimate their abundance. Each year's data were modelled separately because N-mixture models assume population closure within the sampling period. Four candidate models were constructed per season: the null model $\lambda(.),r(.)$, a model where temperature affected detection probability $\lambda(.),r(temp)$, a model where time of day (morning / afternoon) affected detection probability $\lambda(.),r(TOD)$, and a model where detection probability was affected by both temperature and time of day $\lambda(.),r(temp+TOD)$. Model averaging was used to derive estimates of average abundance per rock pile (λ) and individual detection probability (r) (Burnham & Anderson 2002). Wald confidence intervals for model-averaged estimates were calculated in R version 4.2.1 (R Core Team 2022) as:

$$95\%\ CI = \hat{\lambda} \pm z(\alpha/2) \times \sqrt{\hat{\lambda}/n} \qquad (1)$$

with $z(\alpha/2) = 1.96$ and $n = 10$ rock piles. Southern grass skinks and kōrero geckos were encountered too infrequently to be able to estimate abundance, therefore only summary count and rock pile occupancy data are provided for these species.

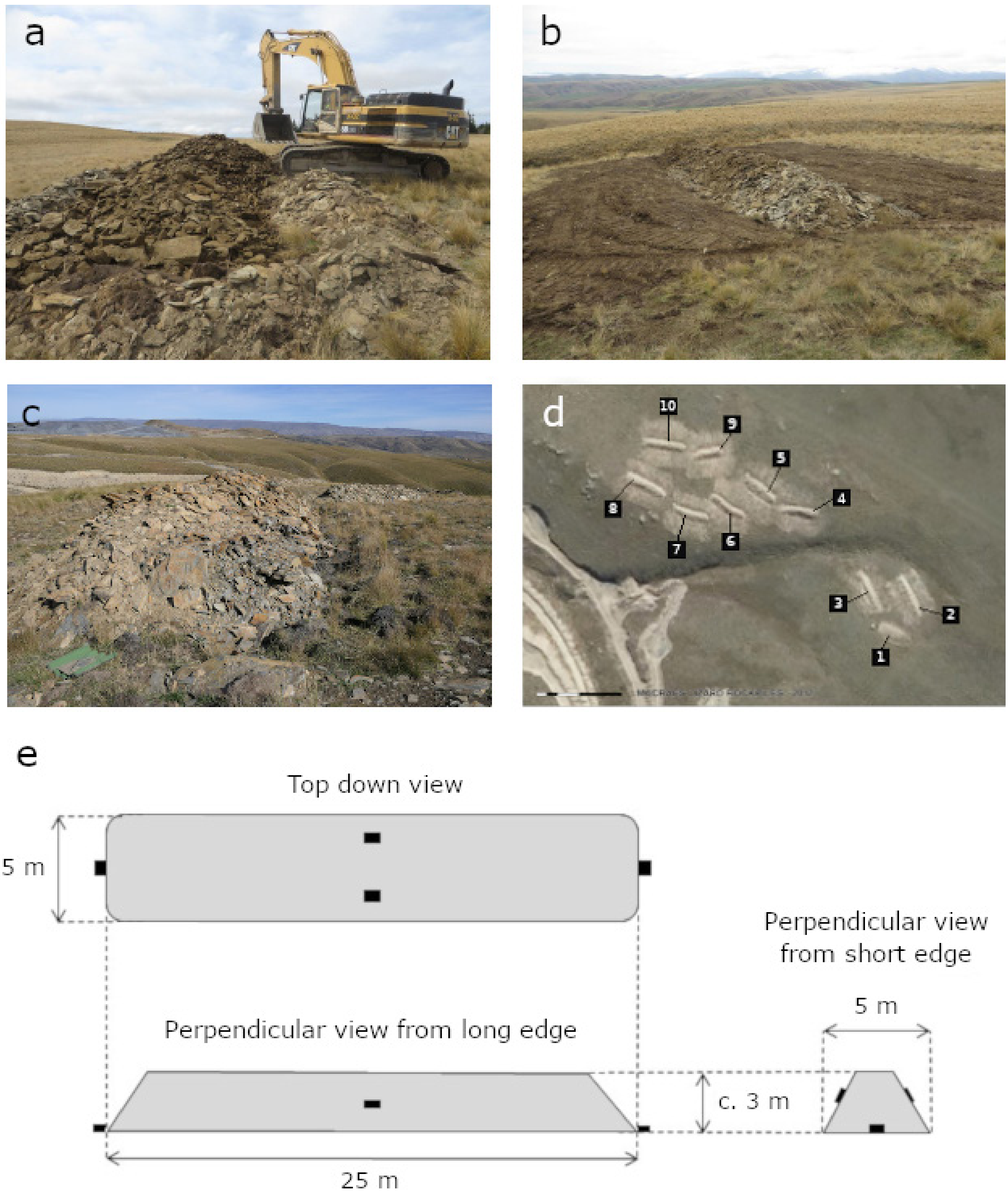

Figure 1. Photographs and diagram of the constructed rock piles adjacent to the Coronation Project at Macraes Flat. (a) Rock pile construction using a bulldozer in October 2014. (b) Pile 2 immediately following construction. (c) Piles 4 (front left) and 5 (right, behind Pile 4) in March 2017 showing natural revegetation in the immediately surrounding area. One of the Onduline artificial cover objects used to monitor lizards is visible in the foreground. (d) Aerial photograph of the rock piles taken in 2017. Divisions on the scale bar are 5 m, 10 m, and 20 m (L-R). (e) Schematic showing the dimensions and approximate shape of each rock pile. The black rectangles indicate the placement of the four pitfall-and-Onduline lizard traps per pile.

Table 1. Number of observations and annual catch-per-unit effort (CPUE) of lizard species at the constructed rock piles. An asterisk (*) indicates that a shed skin of this species was found. Survey period is the time elapsed post-construction. Abbreviations: N_{surv} = number of surveys, VES = visual encounter survey.

Year (time since construction)	N_{surv}	Method	Life stage	McCann's skink	Southern grass skink	Kōrero gecko
2015 (4 months)	6	All	All	29 (CPUE = 4.8)	2 (CPUE = 0.3)	0 (CPUE = 0)
		Onduline	All	1	0	0
			Adult	1	0	0
		Pitfall	All	5	0	0
			Adult	5	0	0
		VES	All	23	2	0
			Adult	20	2	0
			Juvenile	1	0	0
			Neonate	2	0	0
2016 (1.4 years)	7	All	All	44 (CPUE = 6.3)	4 (CPUE = 0.6)	0* (CPUE = 0)
		Onduline	All	9	1	0*
			Adult	9	1	0*
		Pitfall	All	14	2	0
			Adult	14	2	0
		VES	All	21	1	0
			Adult	17	1	0
			Neonate	4	0	0
2017 (2.4 years)	9	All	All	155 (CPUE = 17.2)	14 (CPUE = 1.6)	2 (CPUE = 0.2)
		Onduline	All	15	0	1
			Adult	15	0	1
		Pitfall	All	35	4	1
			Adult	32	4	1
			Neonate	3	0	0
		VES	All	105	10	0
			Adult	87	10	0
			Neonate	18	0	0
Total		All	All	228	20	2

Results

An absence of *Melicytus* and *Coprosma* shrub species on the rock piles was noted, suggesting that seeding the piles with these species was unsuccessful. However, parts of the piles that contained soil, and the areas surrounding the piles, had been colonised by grasses (mostly browntop, *Agrostis capillaris*) and sedges by 2017 (Figs. 1c, 1d). Natural revegetation was particularly noticeable on Pile 1, which had been constructed with a mixture of rocks and soil.

Two hundred and fifty observations were made of lizards in the 2.4 years following rock pile construction (Table 1). Of these, 164 (65%) were recorded during VES, 61 (24%) in pitfall traps, and 27 (11%) in Onduline ACOs. The number of observations and catch-per-unit-effort values of kōrero geckos, southern grass skinks, and McCann's skinks encountered within rock pile core or edge habitats increased over time (Table 1). McCann's skinks were encountered at all rock piles by March 2017 (Fig. 2). In contrast, southern grass skinks and kōrero geckos were only encountered at 60% and 20% of the piles by March 2017 respectively (Fig. 2). Neonate McCann's skinks were encountered within rock pile habitats during each monitoring period, whereas no juvenile or neonate southern grass skinks were encountered (Table 1). A pregnant female gecko was encountered on Pile 1 in 2017.

The most-parameterised Poisson N-mixture candidate models adequately fitted the repeated McCann's skink count data (2015: $\chi^2_{13} = 12.02$, $p = 0.53$; 2016: $\chi^2_{14} = 16.70$, $p = 0.27$; 2017: $\chi^2_{22} = 15.17$, $p = 0.86$). In all years, the null model had the lowest Akaike information criterion value (Appendix S1 in Supplementary Materials). The estimated abundance of McCann's skinks across all piles increased significantly between February 2015 and March 2017 (Fig. 3).

Discussion

Use of the core and edge habitats created by rock pile construction varied among the three study species. Of these species, McCann's skinks appeared to use the piles most readily, as indicated by: (1) the presence of neonates, (2) presence of this species at all ten piles, and (3) a significant increase in estimated abundance across the rock piles within 2.4 years following construction. These outcomes suggest that that this technique may be capable of creating habitat for McCann's skinks. In contrast, fewer southern grass skinks

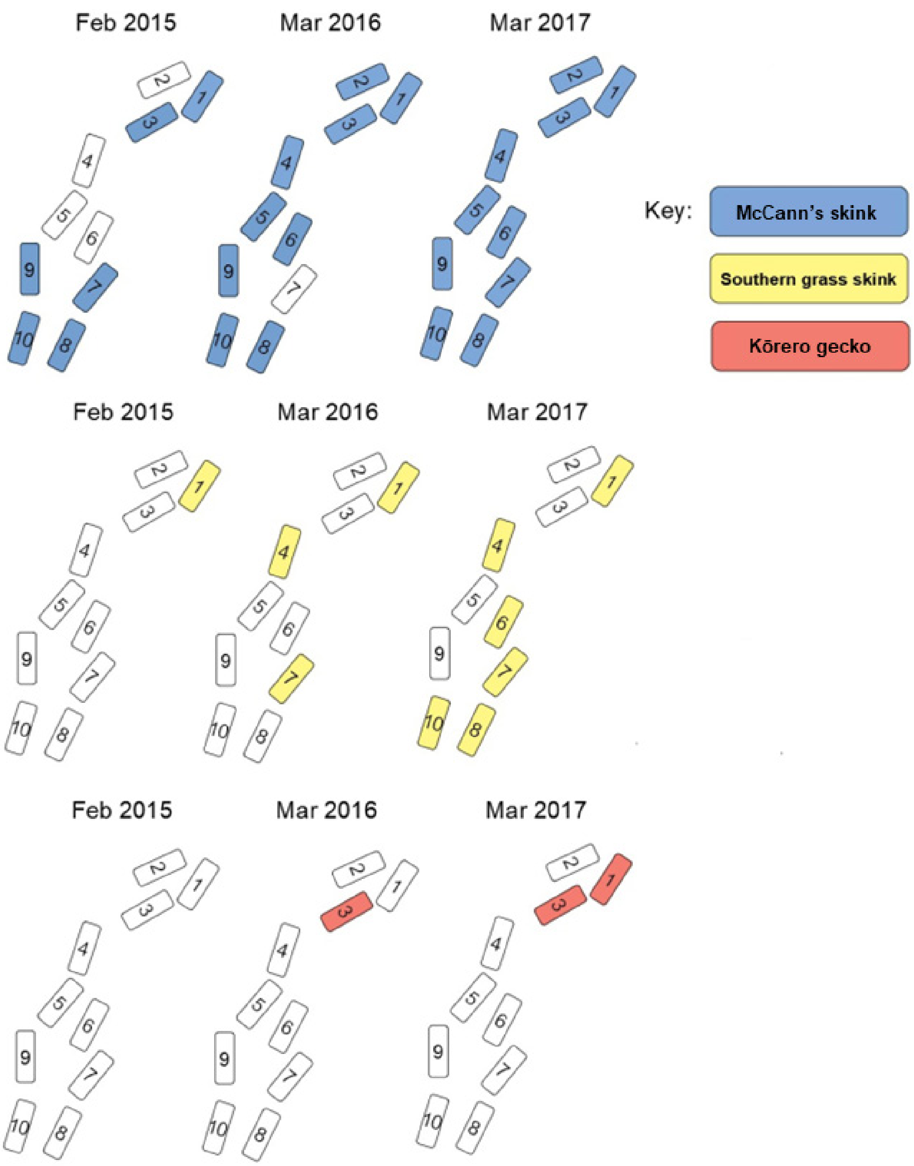

Figure 2. Observed use of the Coronation Project rock piles by McCann's skinks (top), southern grass skinks (middle), and kōrero geckos (bottom) within 2.4 years following construction in October 2014. Coloured rock piles indicate observed presence of each species. The presence of kōrero geckos on Pile 3 in March 2016 was indicated by a shed skin of this species.

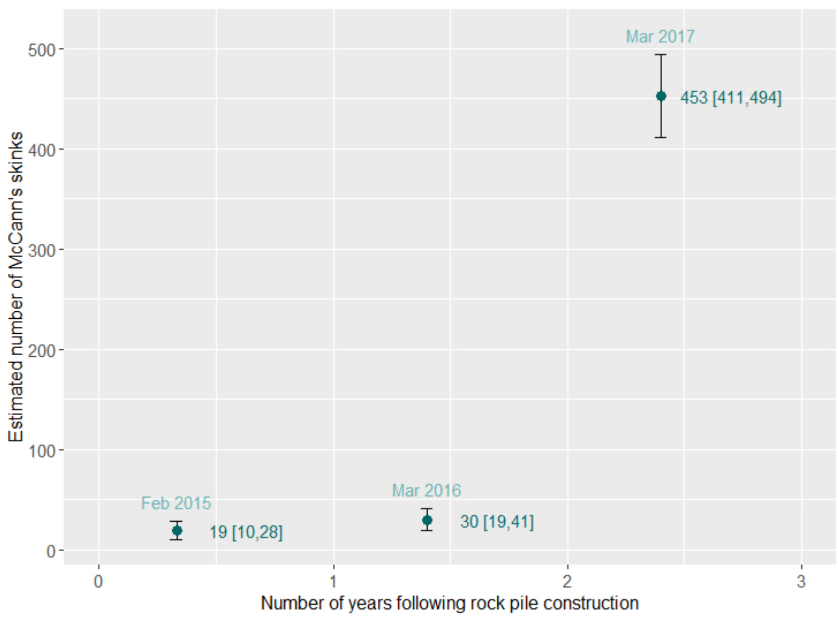

Figure 3. Estimated number of McCann's skinks using the Coronation Project rock piles in the 4 months to 2.4 years following construction in October 2014. Error bars are 95% Wald confidence intervals. The estimates and confidence intervals are displayed next to each point.

were encountered and there was no evidence of breeding. The differing responses of these two skink species may be a function of differing local abundances, or due to interspecific competition for bare rock microhabitats. Other studies in the Macraes Flat area suggest the relative abundances of McCann's skinks and southern grass skinks varies locally, rather than one species being consistently more abundant (Reardon & Norbury 2004; Jones et al. 2013). Where these two species are sympatric, McCann's skinks tend to be the most abundant species on bare rock, whereas southern grass skinks are restricted to vegetation and rock-vegetation interfaces (Patterson 1992). The impact of rock pile construction on kōrero geckos was unclear in this study, given that only two individuals were detected. The low encounter rates may reflect low local abundance or be due to kōrero geckos having lower intrinsic population growth rates than McCann's and southern grass skinks (Rock & Cree 2003; Penniket 2012; van Winkel et al. 2018).

Further inference about the biological outcomes of rock pile construction on the study species was prohibited by the design of the monitoring programme. Lizards were not surveyed before rock pile construction. Therefore, the observed variation in species responses may merely reflect density-dependence in the number of individuals available to encounter and start using newly created habitat. Furthermore, without concurrent lizard monitoring at spatially independent control sites, it is unclear whether the construction of the rock piles caused the increase in abundance of McCann's skinks or simply reflected local population increase rates. Nor is it known how rock pile construction ultimately affected lizard populations. For example, the increase in abundance of McCann's skinks within rock pile habitat may have arisen solely from immigration from surrounding areas. Such source-sink dynamics have been recorded in other reptile species, with consequences for metapopulation health ranging from benign to detrimental (Driscoll et al. 2012; Carter et al. 2017). Ideally, future studies investigating the effects of rock pile construction on lizards will follow a before-after-control-impact (BACI; Stewart-Oaten et al. 1986) design to strengthen the level of inference that can be made about the biological effects of habitat enhancement.

Despite the limitations of the monitoring programme, the relevant condition of the Wildlife Act Authority could be considered fulfilled by the observed outcomes of the lizard monitoring programme. This was because the estimated abundance of McCann's skinks had significantly increased in magnitude by $\geq 10\%$ in the period between 4 months and 2.4 years following construction and there was no evidence of a temporal decline in abundance of any lizard species present on the constructed rock piles. This outcome reflects the finding by Lennon (2019) that while mitigation translocations of lizards in Aotearoa usually fulfil legal requirements, they do not necessarily result in meaningful conservation outcomes. We strongly recommend that consents granted for future habitat enhancement attempts require a monitoring programme that can determine effects on lizard populations instead of only documenting habitat use. Whether examining the outcome of a mitigation- or conservation-driven habitat manipulation, we envisage that a sufficient monitoring programme will be required to use a BACI design and have a post-construction monitoring period exceeding three years if the responses of kōrero geckos or southern grass skinks are being studied. Ideally, the length of the post-monitoring period should be determined by the intrinsic population increase rates of the species being studied.

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Additional Information and Declarations

Conflicts of interest: Trent Bell, Carey Knox, and Sarah Herbert carried out this piece of work as employees (all) and Directors (TB and SH) of EcoGecko Consultants Ltd. EcoGecko Consultants were contracted by OceanaGold (New Zealand Ltd) from 2013 to 2019 to provide expert advice on, and to carry out aspects of, the lizard mitigation programme for the Coronation Project. Debbie Clarke is a current employee of OceanaGold. This manuscript was written up without funding, but its release for publication was subject to approval from OceanaGold (New Zealand Ltd).

Funding: This project was funded by OceanaGold (New Zealand Ltd).

Ethics: The mitigation actions and fieldwork for this study were carried out under Wildlife Act Authority 39247-FAU issued by the New Zealand Department of Conservation.

Data and code availability: The data and code associated with this article are openly available at https://github.com/ms-sherbert/Otago-lizard-rocks

Author contributions: TPB conceptualised the project, the methods for which were developed by SMH and investigations undertaken by CK and TPB. DC administered the project. SMH, TPB, and CK wrote and reviewed the manuscript.

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Supplementary material

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

Appendix S1. List of candidate models and model selection statistics for each monitoring season

The New Zealand Journal of Ecology provides supporting information supplied by the authors where this may assist readers. Such materials are peer-reviewed and copy-edited but any issues relating to this information (other than missing files) should be addressed to the authors.