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RESEARCH

Alpine skinks persist 12 months post-translocation with no initial evidence of weka predation

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Abstract: Many of Aotearoa | New Zealand's lizards are threatened, and translocation to offshore islands where introduced mammalian pests are absent is one option to increase species' security. However, the high densities of native avian predators of lizards that occur on some offshore islands are a potential barrier to translocation success. This threat is amplified for obligate alpine lizards, as few offshore islands have an alpine zone. Off the coast of Fiordland, Secretary Island has alpine habitat and is largely mammal free, with only a suppressed population of stoats (*Mustela erminea*) present. It has been identified as a potential translocation site for the critically endangered Sinbad skink (*Oligosoma pikitanga*), but the resident weka (*Gallirallus australis*) population poses a potential threat. Mahogany skinks (*Oligosoma* aff. *pluvialis* "mahogany") co-occur with Sinbad skinks, but are less endangered (classified as At Risk – Declining), and were identified as a surrogate species to first attempt to translocate to Secretary Island as a proof-of-concept. In January 2023 and February 2024, a total of 40 mahogany skinks were translocated from Sinbad Gully to Secretary Island. We used trail cameras, visual observations, and tracking tunnels to monitor the mahogany skink population at their release site for a total of 177 days. We investigated whether the resident weka preyed on the translocated skinks, measured skink dispersal from the release site, and compared temporal activity of weka and skinks. Weka were not witnessed preying upon skinks. Skinks persisted at the release site for at least one year, and some dispersed at least 25 metres away. Skink detections significantly increased with temperature. In relation to time of day, daylight type, or temperature, peak activity levels of skink and weka did not overlap. These results imply that we can be cautiously optimistic about habitat viability and any future translocation of Sinbad skinks to Secretary Island.

Keywords: translocation, lizard, avian, predator, prey, threatened species, offshore island, conservation

Introduction

Aotearoa | New Zealand (hereafter Aotearoa) boasts a rich diversity of herpetofauna, almost all of which is endemic. Unfortunately, 96% of Aotearoa's reptile species are considered At Risk or Threatened under the New Zealand Threat Classification System (NZTCS; Hitchmough et al. 2021). The two largest threats to Aotearoa's native lizards are habitat destruction and introduced mammalian predators, particularly mustelids (three *Mustela* species), rats (three *Rattus* species) and mice (*Mus musculus;* Hitchmough et al. 2016, 2021). One of the most prevalent tools used to increase lizard species' security is translocation to relatively safe sites like pest-free islands (Hitchmough et al. 2016, 2021). These islands serve as sanctuaries for many threatened native species, but occasionally there are complications when species negatively affect others via predation or competition.

There have been over 50 translocations of lizards in Aotearoa for conservation purposes, but they have all been to low altitude sites (Sherley et al. 2010; Miller et al. 2014; Romijn & Hartley 2016). Concerningly, over 25% of Aotearoa's native lizard species exist in the alpine zone, which adds an additional pressure of rising thermoclines, and in turn increases the likelihood of them requiring translocations in the future (Christie 2014; O'Donnell et al. 2017; Knox et al. 2019; Hitchmough et al. 2021; Macinnis-Ng et al. 2021; Keegan et al. 2022). However, translocations carry risks and uncertainties, many of which are not fully understood (Morris et al. 2021). For example, the habitat into which a species is released may differ from its origin in a variety of ways, such as resource availability, microhabitats, and predator presence. The capability of the translocated species to persist may depend on its behavioural and physiological plasticity (Silver & Marsh 2003; Kenison & Williams 2018; Wilson et al. 2022). However, as research relating to translocations continues to grow, so too does our understanding of the factors that influence translocation success (Miller et al. 2014; Seddon et al. 2014; Morris et al. 2021; Wren et al. 2023). This increased knowledge is exceptionally important in the case of groups such as invertebrates and reptiles, which are

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under-represented in the peer-reviewed scientific literature on animal translocations both within Aotearoa (Parker et al. 2023) and on a global scale (Evans et al. 2023).

Many taxa are more vulnerable to competition with, and predation by, other species during the establishment phase immediately following a translocation (Armstrong & Seddon 2008; Parlato & Armstrong 2013), including Aotearoa's herpetofauna (DOC Lizard Technical Advisory Group 2018). In Aotearoa, introduced predators, if present, are the biggest threat to a translocated lizard population (e.g. Norbury et al. 2014; Towns et al. 2016). However, native predators such as larger-bodied lizards, tuatara (*Sphenodon punctatus*), sacred kingfisher (kōtare, *Todiramphus sanctus*), kiwi (*Apteryx* spp.), pūkeko (*Porphyrio porphyrio*) and weka (*Gallirallus australis*) can also pose risks (van Winkel & Ji 2012; DOC Lizard Technical Advisory Group 2018). The intensity of such predation varies among species. For example, the sacred kingfisher is known to specialise in hunting lizards in certain locations, whereas kiwi likely only prey upon lizards opportunistically (Hayes 1991; Hare et al. 2016; Nelson et al. 2016; Savoca et al. 2018). Predation risk to lizards may be exacerbated in restoration sites and on offshore islands, where the absence of other native or introduced predators can allow native lizard predators to reach high population densities.

Aotearoa's lizards have co-evolved with their reptilian and avian predators for around 23–55 million years (Nielsen et al. 2011; King 2019). Their typical defense mechanisms against predators include a freeze response, cryptic colouration, cryptic basking, fleeing, hiding under the cover of other objects, and caudal autotomy (Hare et al. 2016). An additional defense mechanism is temporal avoidance, low overlap of foraging or basking periods with their potential predators, which could be intentional or intrinsic (Sih et al. 2010). Introduced mammals commonly hunt using olfactory and visual cues (King & Forsyth 2021), against which these defense mechanisms may be less effective.

One of the most controversial of Aotearoa's native predators to manage is the weka. Historically, weka would have occupied a mesopredator role, but most of the native apex predators, such as Eyles' harrier (*Circus eylesi*) and Haast's eagle (*Aquila moorei*), are now extinct. Weka are threatened by mammalian predation pressure, habitat loss, and starvation through droughts, which has led to their range restricting considerably (Carpenter et al. 2021). They are listed as Vulnerable by the International Union for the Conservation of Nature (IUCN), and the NZTCS status ranges from Threatened (three subspecies) to Not Threatened (one subspecies; Birdlife International 2018; Robertson et al. 2021). Weka are omnivores whose diet primarily consists of seeds and fruit, but also includes invertebrates, herpetofauna, birds and their eggs (Carpenter et al. 2021). This presents a conservation conundrum when it comes to ecological restoration or conservation management, as they are a threatened species that may prey on other threatened species (Miskelly & Beauchamp 2004; Carpenter et al. 2021).

The impact of weka predation on lizard populations remains largely unknown. On the Open Bay Islands, a weka was witnessed persistently attempting to prey on a skink (*Oligosoma taumakae*; Lettink et al. 2010), and weka are often believed to be a key threat to small lizard populations on islands with high weka densities. The only experimental study that has been conducted to assess the impact of weka on lizard populations used fences to exclude weka following a rat eradication on Kāpiti Island and found no effect on the recovery of three lizard species (Miskelly & Beauchamp 2004). In a separate report from the Chetwode Islands (Te Kakaho), skink detections increased after weka eradication, but it was unknown if this reflected population density changes, behaviour, or habitat differences (Rufaut & Clearwater 1997). Even less is known about the possible effects of weka on translocated lizards. On Rotoroa Island and Ulva Island, studies that monitored three translocations of three different skink species released either within or outside of weka exclosures suggested that weka may have an impact on translocated skink populations; however, all of the studies were inconclusive and found no evidence of weka predation despite high weka abundance (Goodman et al. 2006; Sharpe 2011; Wood 2016; Manning 2023). Regardless of the research thus far, among both conservation managers and scientists it is generally agreed upon that weka are more likely to have an impact on prey species if the prey population is already limited (e.g. in population size and/or extent). This means that small populations of translocated lizards may be particularly susceptible to weka predation if released at a location with an established weka population (Carpenter et al. 2021).

Here, we assess the potential impact of weka on the outcome of an alpine skink translocation within Fiordland National Park (Te Rua-o-te-Moko). Sinbad skinks (*Oligosoma pikitanga*) are one of the most critically endangered lizards in Aotearoa and are only known from one population, so are being considered for translocation to an insurance site (Bell & Patterson 2008; Hitchmough et al. 2019, 2021). A translocation of Sinbad skinks was deemed too high-risk by the Department of Conservation (DOC) because of its small population size, and thus mahogany skinks (*Oligosoma* aff. *pluvialis* "mahogany"; also referred to as Te Wāhipounamu skinks) were chosen as a surrogate species to be translocated first as a proof-of-concept, and for their own conservation benefit. Mahogany skinks co-exist with Sinbad skinks in the same alpine cirque basin and face the same threats, but are also found elsewhere in northern Fiordland, so are less threatened and considered At Risk – Declining under the NZTCS (Hitchmough et al. 2021).

In January 2023 and February 2024, two groups of mahogany skinks were translocated from Sinbad Gully to the alpine zone of Secretary Island (Kā Tū-waewae-o-Tū). Secretary Island was chosen as the release site because it is one of very few offshore islands with an alpine zone and is free of rodents, which can cause population-level impacts on lizards through predation (e.g. Newman 1994; Towns & Ferreira 2001; Hoare et al. 2007; Norbury et al. 2014). However, one of the primary concerns regarding Secretary Island as a release site is the presence of other predators of lizards, specifically weka and stoats (although it is free of all other mammals). Stoats are controlled to low densities on Secretary Island by an extensive network of traps (McMurtrie et al. 2011; Veale et al. 2012; Kameyama 2024). Weka are uncontrolled and occur at high densities, and thus the potential impacts of weka on translocated lizards are of more concern than that of stoats.

In addition to the threat of predators, there are other uncertainties that could affect the success of the mahogany skink translocation, such as the difference in climates (e.g. resulting from a change from c. 1400 m a.s.l. to c. 950 m a.s.l.) and microhabitat components (e.g. differences in plant species, rock complexity, and crevice availability). Additionally, it is likely that this translocation has released the mahogany skink into a new area outside of its historic range, albeit in the same region. Alpine conditions are harsh, with wide-ranging temperatures and often extreme weather conditions, and while this could increase the susceptibility of skinks to translocation failure, there is no existing research on this topic.

The overarching aim of this research was to understand whether weka posed a threat to translocated skinks in the alpine zone of Secretary Island and whether this threat could cause the population to fail to establish. As far as we know, this is the first conservation translocation of alpine lizards in the world, and it provided a valuable research opportunity as the need for alpine lizard translocations will likely increase as the climate warms. We also know little about predation impacts on alpine lizards by both native and introduced predators. Specifically, we addressed the following questions: (1) Do weka attempt to prey on the translocated mahogany skinks? (2) Do weka and mahogany skinks overlap in their temporal activity patterns? (3) Do any other species inhabiting the site attempt to prey on the skinks (e.g. stoats, kārearea New Zealand falcon *Falco novaeseelandiae*, or kea *Nestor notabilis*)? (4) If sightings of skinks at the release site decline over time, can detection patterns be used to infer potential causes (i.e. mortality or dispersal associated with predation, adverse weather events, or a combination of factors)?

Methods

Study species

The mahogany skink (*Oligosoma* aff. *pluvialis* "mahogany") is a small (61–74 mm snout-vent-length) lizard that was originally considered part of the *O. inconspicuum* species-complex of southern Aotearoa, but has recently been described as a distinct species (Hitchmough et al. 2021; Jewell 2022). The newly described species has been given the name 'Te Wāhipounamu skink', which refers to the United Nations Educational, Scientific and Cultural (UNESCO) World Heritage Area of South West New Zealand where this species is distributed. While Te Wāhipounamu skinks can be found in many mountainous areas of this region, the common name of mahogany skink refers to the specific population of *O.* aff. *pluvialis* "mahogany" that is found only around the Llawrenny Peaks (Te Puhituia) in Fiordland (Jewell 2022). They have long limbs, an acute snout shape, and relatively high lamellae counts, all of which could be adaptations to the extreme environments that they inhabit (Jewell 2022; Fig. 1). For consistency's sake, the common name of mahogany skink is used throughout this article.

Translocations

Two separate DOC-led mahogany skink translocations took place during this study (31 January 2023 and 29 February 2024). In total 40 skinks were translocated from Sinbad Gully over the two years (22 in 2023 and 18 in 2024) and released onto an alpine ridgeline (c. 950 m a.s.l.) of All Round Peak on Secretary Island. The two translocations included 18 juveniles or sub-adults, eight mature males, and 14 mature females (nine of which were pregnant). Both releases occurred within three metres of each other. The numbers of individual skinks translocated on both occasions were lower than the target number of at least 80 individuals per translocation; however, they were a function of what was possible due to weather and logistical constraints.

Skink source site

The Sinbad Gully alpine cirque is an amphitheatre-like shallow hanging valley that is the result of glacial and subsequent freeze-thaw erosion of the granitic rock (Fig. 1). It sits above Sinbad Gully and below the Llawrenny Peaks in Fiordland National Park (1200–1600 m a.s.l.). The rock cliffs that encompass it are 150–320 m high, and the environment at the top and bottom

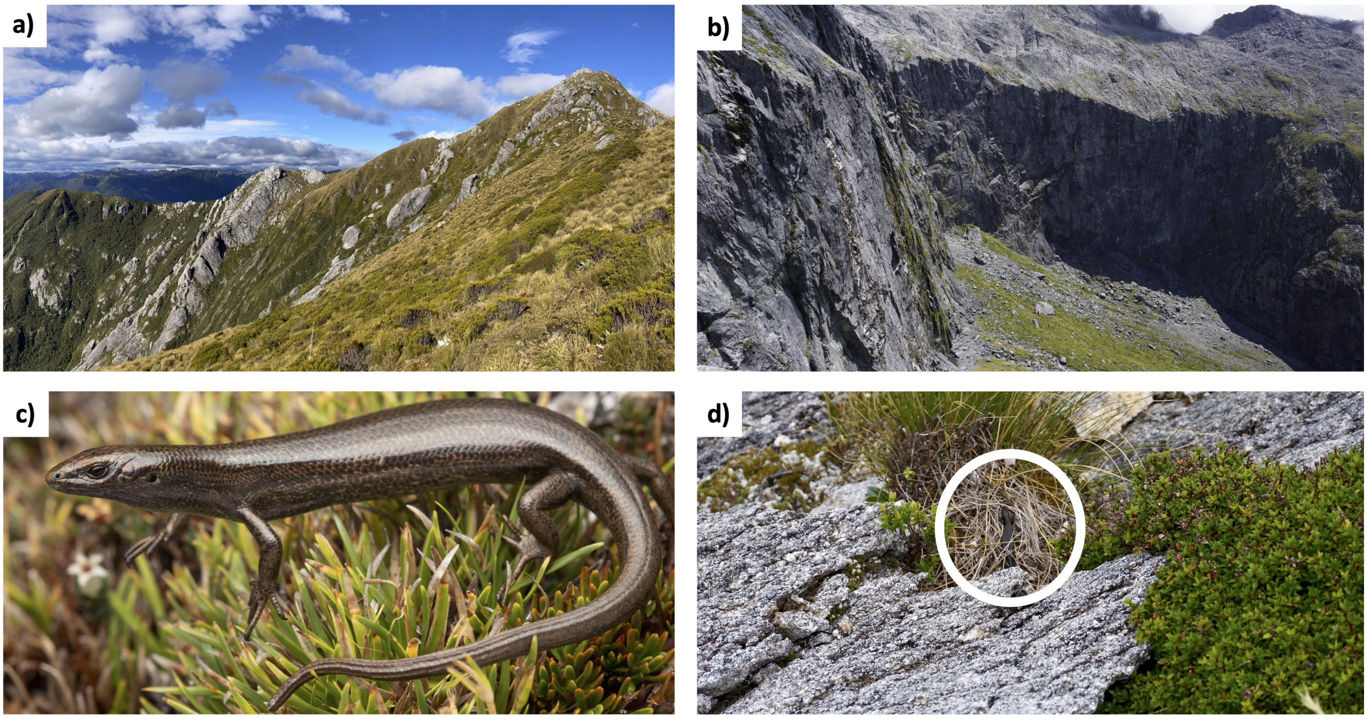

Figure 1. Photos of (a) the sub-alpine/alpine habitat on Secretary Island; (b) the alpine cirque basin in Sinbad Gully; (c) a translocated mahogany skink (*Oligosoma* aff. *pluvialis* "mahogany"; photo credit: Samuel Purdie); (d) a basking mahogany skink on Secretary Island (skink is circled with white ellipse).

of the cliffs ranges from alpine to subalpine respectively. It is north/northwest facing, and ledges and crevices on the cliff faces support subalpine grasses, ferns, and shrubs, while the rest is largely devoid of vegetation. Introduced mammalian predators known to be present in the cirque basin are mice (J. Reardon unpubl. data), rats (C. Gunton unpubl. data), and possums (Bell et al. 2007; Jewell & Morris 2007), and it is likely stoats are present as well as they are confirmed to be lower in the Sinbad Gully valley (J. Monks unpubl. data).

Skink release site

Secretary Island is an 8140 ha inshore island that lies between Doubtful Sound (Patea) and Thompson Sound (Te Awa-o-Tū) on the coast of Fiordland National Park. The island is free of all introduced mammalian predators and browsers except for stoats (McMurtrie et al. 2011; Veale et al. 2015). It is a steep, mountainous island, spanning from sea level to its highest point of 1196 metres a.s.l., comprised mostly of mixed beech-podocarp forest, but also features several isolated subalpine and alpine ecosystems. The mahogany skinks were released on a northwest aspect of a ridgeline (c. 950 m a.s.l.) within the alpine zone surrounding All Round Peak (1130 m a.s.l.; Fig. 1). In addition to a variety of snow tussocks and sedges (e.g. *Chionochloa flavescens*, *Carex acicularis*), the dominant plant species in the subalpine/alpine area were *Olearia colensoi* (tūpare or leatherwood) and *Halocarpus biformis* (pink pine or yellow pine). The rest of the release site area was composed primarily of granite, ranging from large boulders to patches of gravel. Beside cascade geckos (*Mokopirirakau* "Cascades"), there are no other lizards known to occur in the alpine zone of Secretary Island.

Field methods: trail cameras and visual observations

Trail cameras (model Reconyx HC600; Reconyx Inc.) were used to monitor the release site for skinks, their potential predators, and any interactions between them over three study periods (hereafter referred to as camera periods). The dates and purposes of each camera period can be found in Table 1. In camera periods 1 and 3, eight trail cameras were used and were placed in the same positions. In camera period 2, five trail cameras were used, three were in the same location as the other camera periods, and the other two were within two metres of their original location.

The trail cameras were mounted on tripods that were attached to rocks using lacing wire. The trail camera locations and field of views were chosen based on where lizards were seen around the release site and where the trail cameras were considered most likely to capture a weka if one travelled through the area (Fig. 2). For these same reasons, six of the trail cameras had wider fields of view (approximately 3–5 m^2), and two of the trail cameras had narrower field of views (approximately 1–3 m^2). The trail cameras were spread out to capture an approximate total area of 30 m^2 around the exact location the skinks were released, but the spread of their placement was not centred on the release site due to a sheer cliff on one side (Fig. 2). They were spaced approximately 2–8 m apart from one another. From 10–14 February 2023 (the beginning of the first camera period), trail cameras captured one five-second video if the motion detection sensor was triggered. From 15 February until the end of camera period 1 (6 April 2024), and for all of camera periods 2 and 3, the motion detection setting was changed to capture five photos at one second intervals to ensure more efficient battery use

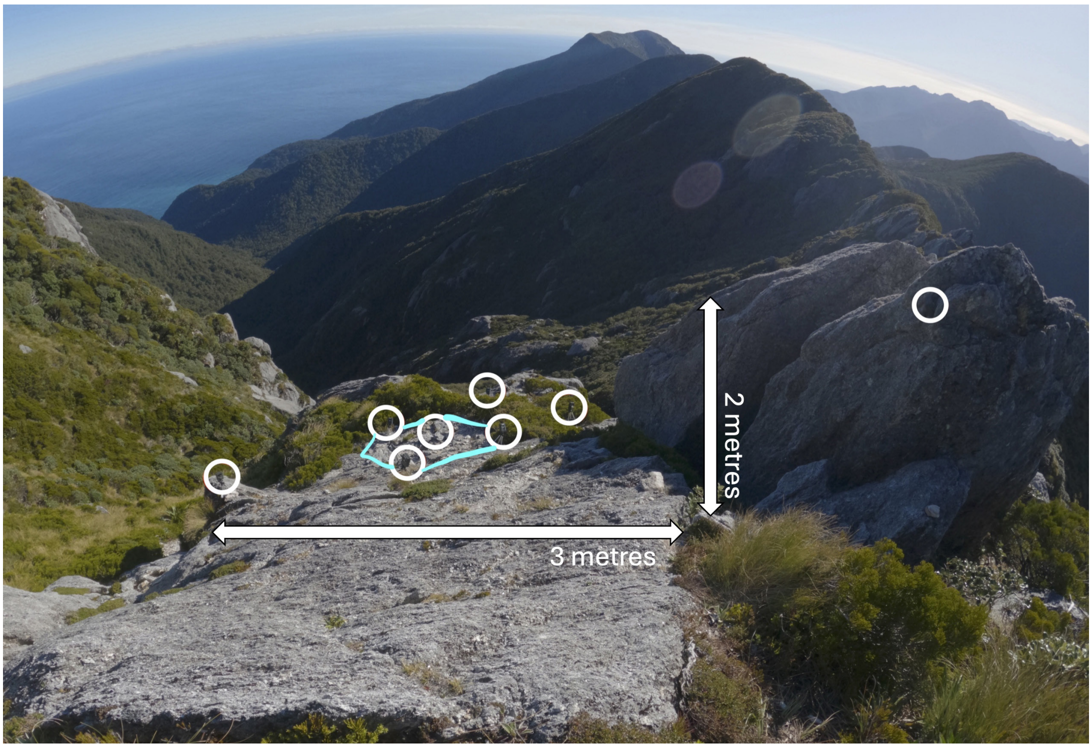

Figure 2. A photo of the release site area on Secretary Island and the eight trail camera locations (white circles) that were used in camera periods 1 and 3. The blue shape shows the exact release site where all mahogany skinks (*Oligosoma* aff. *pluvialis* "mahogany") were released within three metres of each other. In camera period 2, five trail cameras were used, three of which were in the same location as three of the cameras in this photo, but two were placed in slightly different locations in an attempt to maximise the same coverage of the release site. The photo was taken with a fisheye lens (camera model GoPro HERO9) and is facing northwest. Scaling is approximate.

and memory capacity. Motion detection was active day and night for the duration of each period. In addition to motion detection, all trail cameras captured one photo every five minutes between 6:00 and 20:00 local time (hereafter referred to as timelapse photos). Any visual observations of skink or weka behaviour that were noticed when field workers were present at the release site were also recorded.

Field methods: Tracking tunnel grid

In March 2024, a grid of tracking tunnels (n = 85 tunnels at 4 m spacing) centred on the release site area was set up to detect skinks that might be far enough from the release site to not be captured by the trail cameras (Fig. 3). The purpose of this was to look for further evidence of skink survival and possible evidence of skink dispersal. The grid shape was modified to avoid dangerous terrain such as sheer cliffs (Fig. 3). The tracking tunnels were designed specifically for lizards and were made from 500 × 65 mm lengths of PVC piping, which could fit a standard tracking tunnel card (500 × 100 mm) inside. Tunnels were baited with tinned pear enclosed in perforated resealable plastic bags to prolong the life of the bait. The edges of the cards were secured to the ends of the tunnels using duct tape. The tunnels were secured in place by either weighing them down with rocks or wedging them under shrubs. The tracking tunnels were put in place from 13–15 March and then checked and re-baited from 2–4 April (Table 1; Fig. 3). They were then deployed again until 6 April, after which they were permanently removed from the area (Table 1; Fig. 3).

Trail camera photo processing

At the end of the camera periods, all photos and videos were manually processed using Timelapse2 (Greenberg & Godin 2015), a software programme that streamlines the extraction of data from images. We recorded counts of skinks, weka, stoats, and any other species seen (e.g. kea, rock wren pīwauwau *Xenicus gilviventris*, ground wētā *Hemiandrus* spp.) in all photos and videos. We also described the type of daylight in each photo as either dark; in shade (it is daylight, but the release site area is in shade because the sun is behind a ridgeline or boulder); overcast and/or cloud blocking direct sunlight from hitting release site; inside cloud or fog; partial sunlight (it is daylight but over 66% of the release site is still in shade); or full sunlight (it is daylight and less than 33% of the release site is in shade). If rainfall was visible, it was also recorded. The following metadata were also extracted from the imagery and included in the dataset for analysis: date, local time, and ambient temperature. It should be noted that temperature recordings of trail cameras are not always accurate (e.g. Geller 2012; Larbi & Green 2018). Any photo

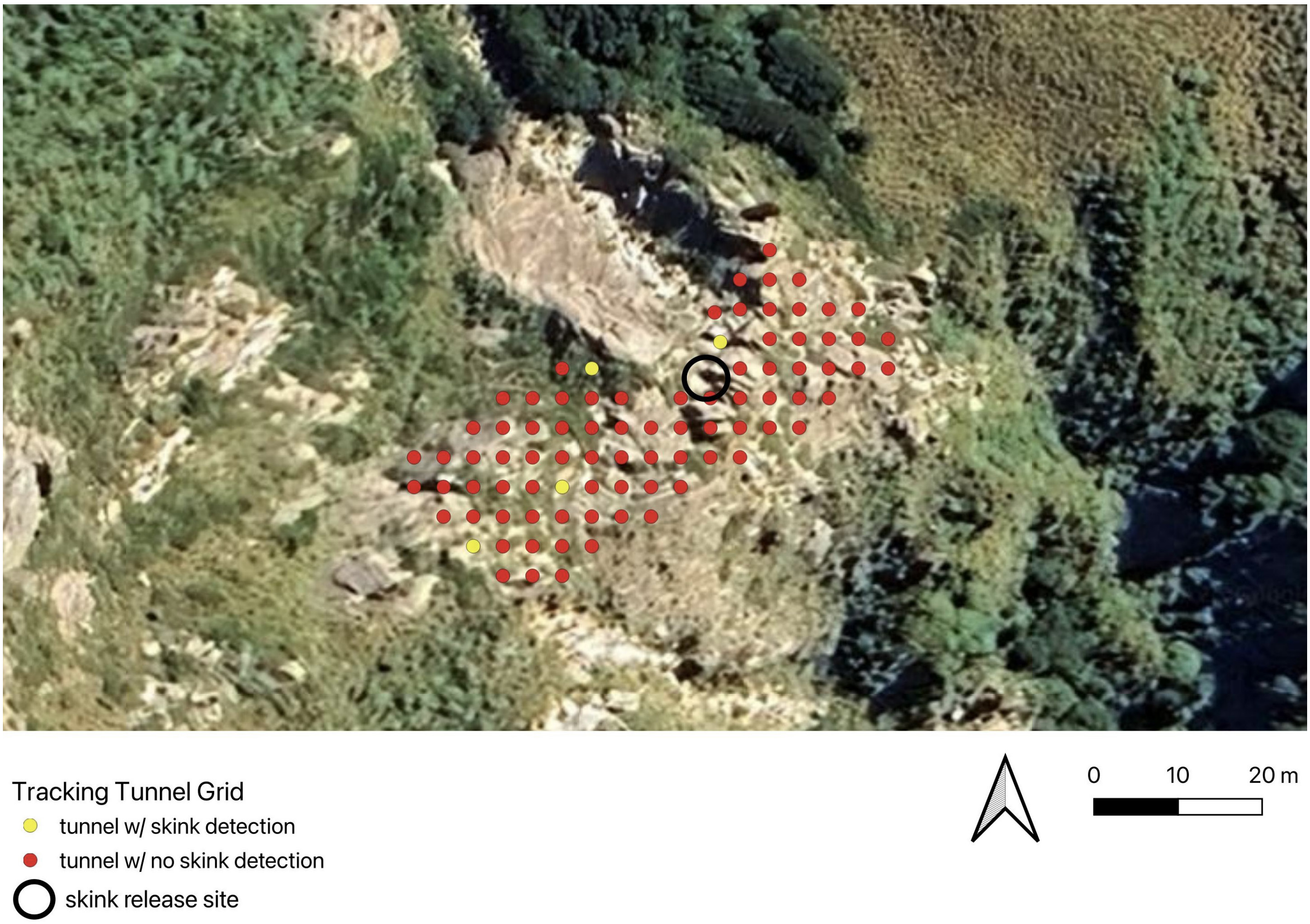

Figure 3. The tracking tunnel grid that was in place around the mahogany skink (*Oligosoma* aff. *pluvialis* “mahogany”) release site area on Secretary Island between 13 March and 6 April 2024. There were 85 tracking tunnels in total, spaced 4 m apart. Maps data: Google, ©2023 Airbus.

Table 1. The four different trail camera and tracking tunnel study periods of translocated mahogany skinks (*Oligosoma* aff. *pluvialis* "mahogany") on Secretary Island. Translocations occurred on 31 January 2023 and 29 February 2024. The tracking tunnels were checked and re-baited from 2–4 April 2024.

Monitoring method	Start date(s)	End date(s)	Total number of days deployed	Purpose
Trail camera	10–13 February 2023	7 April 2023	54–57	Monitor for skinks released in first translocation, potential predators, and any interactions between them
Trail camera	24 November 2023	11–28 February 2024	80–97	Monitor for skinks released in first translocation that had survived winter season, potential predators, and any interactions between them
Trail camera	15 March 2024	6 April 2024	23	Monitor for skinks released in both translocations, potential predators, and any interactions between them
Tracking tunnels	13–15 March 2024	6 April 2024	21–23	Monitor skink survival and potential evidence of skink dispersal

in which the field of view was obstructed (e.g. by thick fog) was flagged and excluded from data analysis.

Data processing

While collating skink photos, all captures were checked for among-camera duplication (e.g. simultaneous captures of the same individual by two trail cameras), and duplicates were omitted. If motion-triggered captures produced multiple photos of skinks within five seconds, these were consolidated into a single data point to avoid inflating skink presence counts. Thus, skinks photographed on the same trail camera at intervals of five minutes or more were considered temporally independent detections because we do not yet know enough about mahogany skink ecology to be confident about their basking or behavioural patterns, i.e. whether or not they consistently bask for five or more minutes at time. Photos of other species were similarly filtered, but weka detections within 15 minutes of a previous sighting were excluded (this occurred only once) because we are more confident that a weka seen within this timeframe would be the same individual that has remained in the release site area. After filtering, weka detections were limited (n = 21), preventing statistical analysis of factors associated with their detections. However, we visually compared weka and skink detections by temperature, local time, and daylight type (see Results). Skink and weka detections were counted from both timelapse and motion detection photos to compare their activity levels. Where multiple individuals appeared in a single photo, detection counts refer to the number of individuals rather than photographic events. Hereafter, detections can be interpreted as the total number of individuals per photographic or video event.

To examine changes in skink detection following the two translocations, statistical summaries of each day were created including the following factors: days since translocation, average temperature, and proportion of cloud cover (calculated as the fraction of photos classified as "inside cloud/fog" or "overcast," excluding those labelled "dark" or "shade"). Only timelapse photos were used in calculating the average temperature and proportion of cloud cover. A new response variable, "minimum number of skinks per day", was created to represent the total count of individual skinks across all trail cameras. Each skink seen on a different camera was treated as unique, while repeat sightings on the same camera were not recounted, i.e. there could be a maximum of eight skinks per day (from eight cameras) unless there were two skinks seen in the same photo. As the average home range size of mahogany skinks is unknown, it is possible that the same individual was captured on multiple cameras. However, treating skinks seen on different cameras as unique individuals ensured a consistent approach, which allowed trends in the minimum number of skinks detected per day to be analysed.

Statistical analysis of factors influencing skink detections

To investigate possible factors influencing skink detections, we prepared an additional dataset of skink presences (1) and absences (0) as a binomial response variable. After accounting for among-camera duplication and temporal independence (described above), data from both field seasons were merged into a single dataset. However, because of the vast number of absences in the raw dataset, which can bias model estimates, we truncated the data by creating a new dataset that had all skink presences and an equal number of absences, which were randomly selected from the raw dataset using the "dplyr" package in R Studio (Wickham et al. 2023; Posit Team 2024). Before conducting the random sampling from the raw dataset, all photos that were categorised as "dark" were omitted as it did not make biological sense to include them when considering diurnal skink activity, as well as any photos categorised as "motion detection" events that were not triggered by a skink. Lastly, we checked the random sample of absences to confirm it contained a similar distribution of possible response variables to the original dataset, so that it was an accurate representation of the two summer seasons' weather and daylight conditions.

Using this new dataset, we created a generalised linear mixed model (GLMM) with a binomial error structure and a logit link to assess the factors influencing skink detection via trail camera captures. The continuous fixed effects were temperature and solar time. Solar time was considered more appropriate for analysis than local time because the camera periods spanned over five different months, meaning the length of day and the peak position of the sun varied greatly. Using solar time, in which noon is always exactly when the sun culminates, therefore seemed the most biologically relevant form of time to consider when looking for an effect on the activity levels of a heliothermic, diurnal skink (Nouvellet et al. 2012). Local time was converted to solar time using the "solartime" package in R (Wutzler 2021). Solar time and temperature were also rescaled and centred to allow direct comparison of effects. "Daylight type" was included as a categorical fixed effect with three levels ("full or partial sun;" "cloud;" and "shade"). "Cloud" included photos that were described as either "overcast/cloud blocking direct sun" or "inside cloud/fog." The five possible categorical levels were combined into three to increase the statistical power of the model by increasing the degrees of freedom and reducing complexity. Trail camera and date were included as random effects. We checked the model for collinearity by calculating the variance inflation factor using the "car" package (Fox & Weisberg 2019), as well as inspecting residual plots. All analysis was completed in R version 4.4.1 (R Core Team 2024).

Results

Overall species detection and no evidence of predation on trail cameras

Once trail camera photos that were flagged for errors (e.g. trail camera had fallen over; human triggered motion sensor) were removed, the final dataset for both field seasons had a total of one motion detection video, 3637 motion detection photos, and 194 202 timelapse photos. After filtering and reducing the photos to count how many total detections, rather than photos, there were of skinks, weka, stoats, or kea in the release site over both field seasons, there were 357 skink detections, 21 weka detections, three stoat detections, and four kea detections (Table 2). Other animals that triggered the motion sensors included ground wētā, New Zealand pipits (pīhoihoi *Anthus novaseelandiae*), and tomtits (ngirungiru *Petroica macrocephala*) (Table 2). Weather conditions varied among the three camera periods, particularly in terms of cloudiness and rainfall, further details of which can be found in Table 3.

Table 2. Total number of detections of each species via timelapse photos or motion detection events over all three trail camera periods on Secretary Island. Detections refer to the total number of individuals per photographic or video event and are corrected for multiple captures (e.g. two cameras simultaneously capturing same individual).

Species	Total number of detections
Mahogany skink (*Oligosoma* aff. *pluvialis* "mahogany")	357
Weka (*Gallirallus australis*)	21
Stoat (*Mustela erminea*)	3
Kea (*Nestor notabilis*)	4
Tomtit (*Petroica macrocephala*)	10
Rock wren (*Xenicus gilviventris*)	2
New Zealand pipit (*Anthus novaeseelandiae*)	2
Ground wētā (*Hemiandrus* spp.)	16

Throughout all camera periods, there was no evidence of weka, stoats, or any other potential predators preying on skinks nor interacting with them. While weka sometimes appeared to be foraging (e.g. ripping moss or pushing foliage around), on most occasions they appeared to be travelling through the release site area. Stoats were seen at the release site on two occasions, once during the day at 22°C (two stoats) and once at night (one stoat). The four kea sightings were from only two different events, both at dawn. One photo event captured a kea flipping a small rock off a ledge, but it is unlikely that this was an attempt to find a skink. Although not captured by a trail camera, a kārearea was seen flying in the general area of the release site on two occasions during camera period 1, but was not seen flying towards or landing on the release site. A stoat was also seen via visual observation, during broad daylight running over a large boulder, but about 300 m away from the release site.

Evidence of skink survival and dispersal on trail cameras and tracking tunnels

Skinks were detected on two different trail cameras on 11 different days between 3 December 2023 and 29 January 2024 (camera period 2), i.e. 10–12 months following the first translocation but one month before the second translocation. This demonstrates that at least some skinks were still alive and present at the immediate release site area 12 months after the initial translocation. In terms of skink survival and dispersal further away from the release site, four tracking tunnels had skink prints in them following the period from 13–15 March to 2–4 April 2024 (camera period 3; Fig. 3). Between checking and re-baiting the tunnels during 2–4 April and shutting them down on 6 April, one tunnel had skink prints in it, which was one of the same tunnels as the previous period. None of the tunnels that had skink prints were directly next to each other and instead were 10–20 m apart, so it is likely that all four tunnels represent four different individual skinks (Fig. 3). The furthest tunnel from the release site with skink prints was

Table 3. The three trail camera periods on Secretary Island and their respective dates, total number of days, minimum temperature, maximum temperature, average temperature, percentage of cloudy photos, and percentage of days with rain. The averages and percentages of all three camera periods combined are provided in the last row. Temperatures were recorded by the trail cameras at the time of any photo taken. Minimum, maximum, and average temperatures were calculated using timelapse photos only. Percentage of cloudy photos was calculated once all photos categorised as "dark" or "shade" were omitted from the dataset, i.e. only photos during daylight hours were included, and using only timelapse photos.

Camera period	Date range	Total no. of days	Minimum temperature	Maximum temperature	Average temperature	Percentage of cloudy photos	Percentage of days with rain
Camera period 1	10/02/2023–07/04/2023	57	−3°C	38°C	12°C	60%	56%
Camera period 2	24/11/2023–28/02/2024	97	−2°C	37°C	11°C	75%	73%
Camera period 3	15/03/2024–06/04/2024	23	0°C	36°C	8°C	80%	58%
All periods	See above	177	−3°C	38°C	11°C	60%	65%

approximately 25 m away (Fig. 3). Three of the four tunnels with skink prints were on the edge of the tunnel grid (Fig. 3).

Relationships between environmental variables and skink detections

Mahogany skink detections via trail cameras increased with temperature (estimate = 5.12; c^2 = 53.68; p < 0.001; Fig. 4), whereas solar time did not significantly affect skink detections (estimate = 0.48; c^2 = 1.18; p = 0.277). Daylight type also did not significantly affect skink detections (estimate = 0.45; c^2 = 5.18; p = 0.396). Pseudo-R^2 values were calculated to assess the model's goodness of fit. The marginal pseudo-R^2 of 0.32 and conditional pseudo-R^2 of 0.87 both imply that a substantial amount of variation in skink presence was explained by the included random effects (trail camera and date) compared to the fixed effects (temperature, solar time, and daylight type), but that fixed effects still explained a reasonable amount of the variation.

Comparison of weka and skink activity

Weka and skink detections are reported in local time, rounded to the nearest hour for simplicity and visualisation, as comparisons between local and solar time showed no difference in temporal activity patterns. Photos of mahogany skinks were captured between 09:35 and 19:50 local time. Skink detection levels increased in frequency throughout the day, with peak levels of skink detection occurring around 18:00 local time (Fig. 5). Photos of weka were captured between 05:50 and 20:00 local time (Fig. 5), demonstrating substantial overlap in activity periods. However, peak levels of weka detection occurred around 9:00–10:00 local time, with another smaller peak around 19:00 local time. The minimum and maximum temperatures recorded by trail cameras at the time of skink detection were 10°C and 35°C respectively (mean temperature = 21°C; Fig. 6). The minimum and maximum temperatures recorded by trail cameras at the time of weka detection were −1°C and 26°C respectively (mean temperature = 9°C; Fig. 6). Most skink photos were captured in full or partial sun (*n* = 176) or under cloud cover (*n* = 161), with substantially fewer captured in shade (*n* = 20), and none captured in darkness (Fig. 7). The majority of weka were captured in either cloud or shade (both *n* = 8) with fewer in full or partial sun (*n* = 4) and one in darkness (Fig. 7).

Skink counts following both translocations

Trail cameras were active for 52 full days following the 2023 translocation (15 to 66 days post-translocation) and for 21 full days following the 2024 translocation (16 to 36 days post-translocation). The maximum number of mahogany skinks counted per day following the 2023 translocation was six (Fig. 8). The maximum number of skinks counted following the 2024 translocation was four (15 days post-translocation; Fig. 8). In the period following the 2023 translocation, there was a decreasing trend in skinks counted per day (30 days post-translocation; Fig. 8). However, decreased skink detections were typically correlated with lower average daily temperatures and increased daily proportions of cloud cover. In the period following the 2024 translocation, there was no discernible trend in the minimum skinks counted per day, however this period was 21 days long, which may not be long enough to allow a trend, or lack thereof, to emerge.

Visual observations of skink behaviour at the release site

Mahogany skinks at the release site were cryptic in their

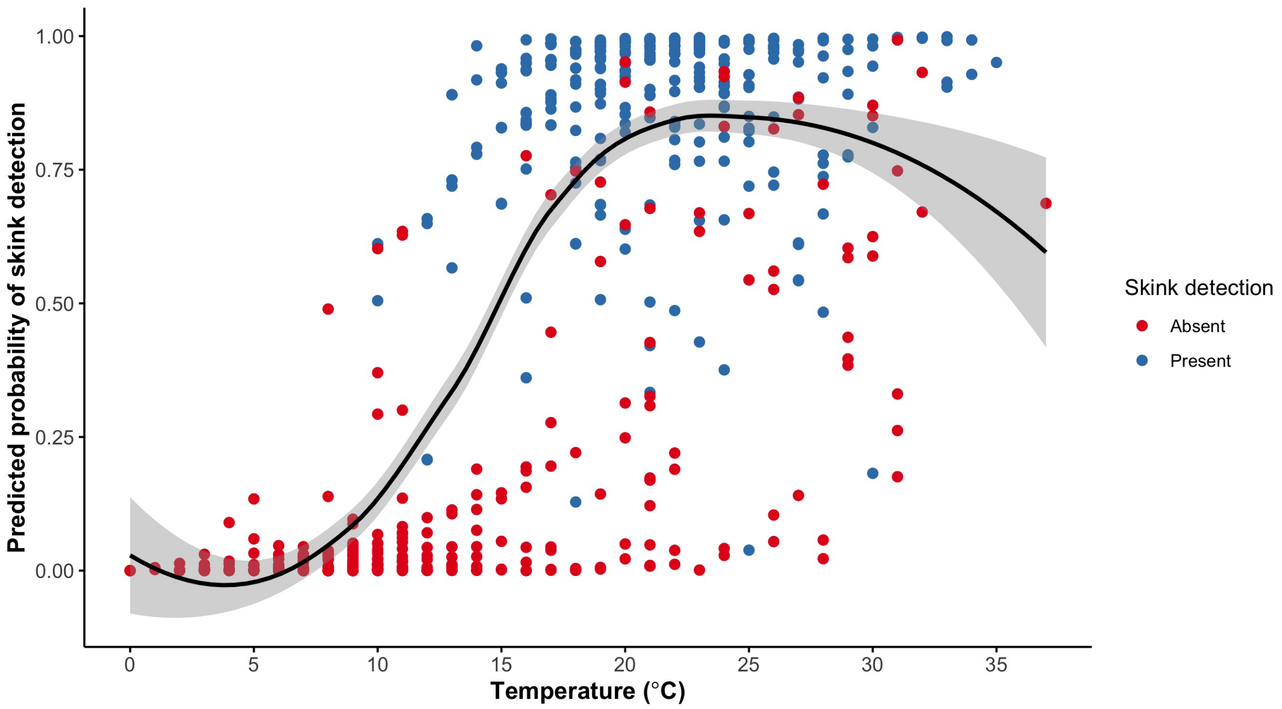

Figure 4. Predicted probabilities (fitted line) and actual observations (points) of mahogany skink (*Oligosoma* aff. *pluvialis* "mahogany") detections on Secretary Island based on temperature. The fitted line was derived from the GLMM that included temperature, daylight type, and solar time as the predictor variables and skink presence (1) vs. absence (0) as the binomial response variable. The grey shaded area represents the 95% confidence interval around the fitted line. Trail camera and date were also included in the model as random effects. Temperature was a significant predictor of skink detections.

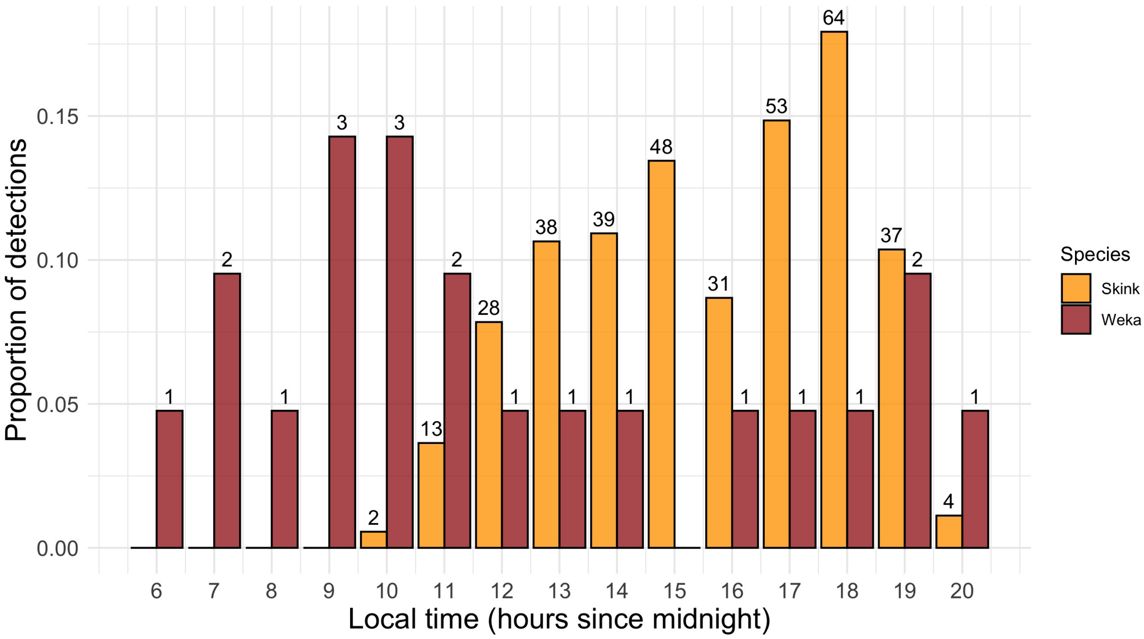

Figure 5. Proportions of total weka (*Gallirallus australis*) and mahogany skink (*Oligosoma* aff. *pluvialis* "mahogany") detections at different local times (hours since midnight) throughout the three camera periods on Secretary Island. Times were rounded to the nearest hour for visualisation purposes. Numbers on top of individual bars are the number of detections at the corresponding local time. Detections refer to the total number of individuals per photographic or video event and are corrected for multiple captures (e.g. two cameras simultaneously capturing same individual).

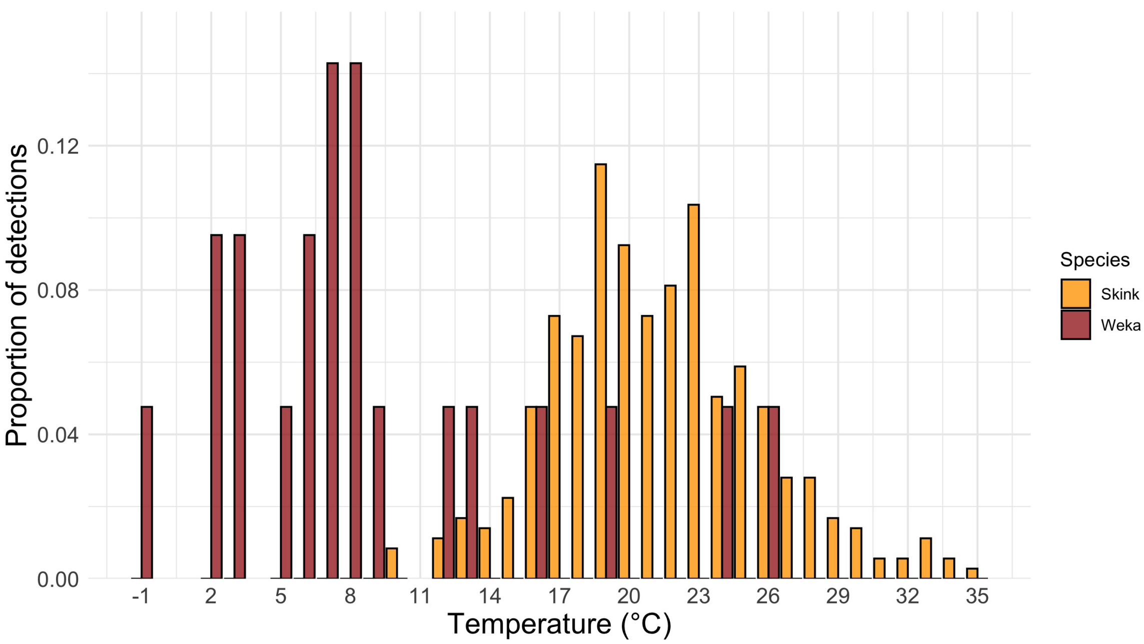

Figure 6. Proportions of total weka (*Gallirallus australis*) and mahogany skink (*Oligosoma* aff. *pluvialis* "mahogany") detections at different temperatures throughout the three camera periods on Secretary Island. Temperatures were recorded by the trail cameras at the time of photographic capture. The total sample size was 21 weka detections and 357 skink detections. Detections refer to the total number of individuals per photographic or video event and are corrected for multiple captures (e.g. two cameras simultaneously capturing same individual).

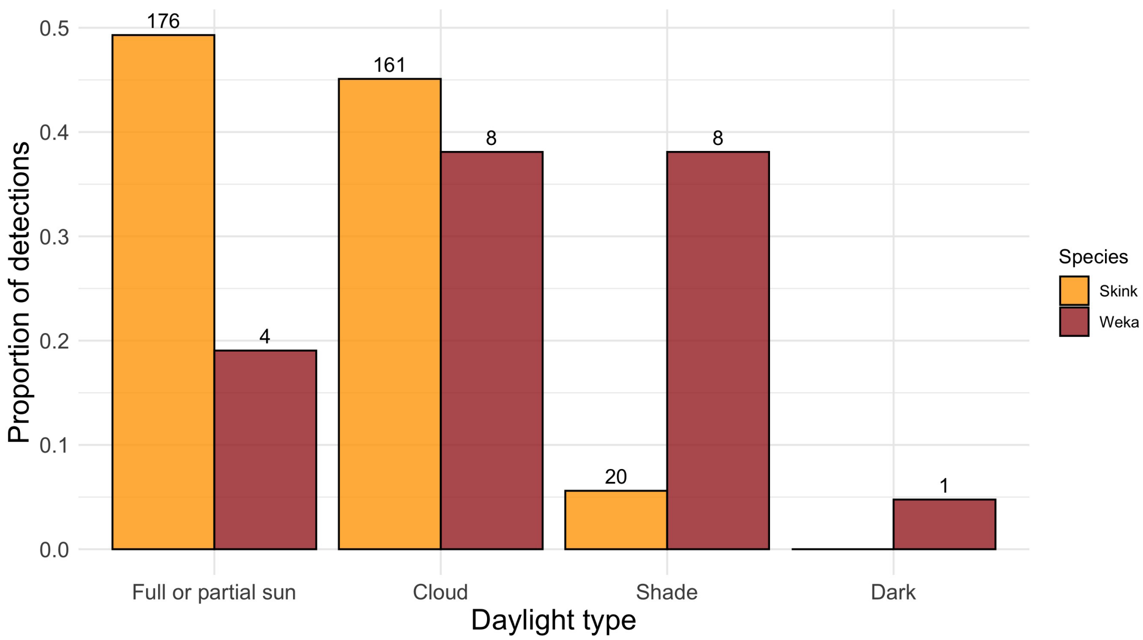

Figure 7. Proportions of total weka (*Gallirallus australis*) and mahogany skink (*Oligosoma* aff. *pluvialis* "mahogany") detections at different daylight types throughout the three camera periods on Secretary Island. Full or partial sun = 33–100% of the release site is being hit by direct sunlight; Cloud = overcast / cloud blocking direct sun from hitting release site / inside cloud or fog; Shade = it is daylight but 66–100% of the release site is in shade; Dark = it is before sunrise or after sunset and the trail camera utilises its flash to expose the field of view. Numbers on top of individual bars are the number of detections during the corresponding daylight type. Detections refer to the total number of individuals per photographic or video event and are corrected for multiple captures (e.g. two cameras simultaneously capturing same individual).

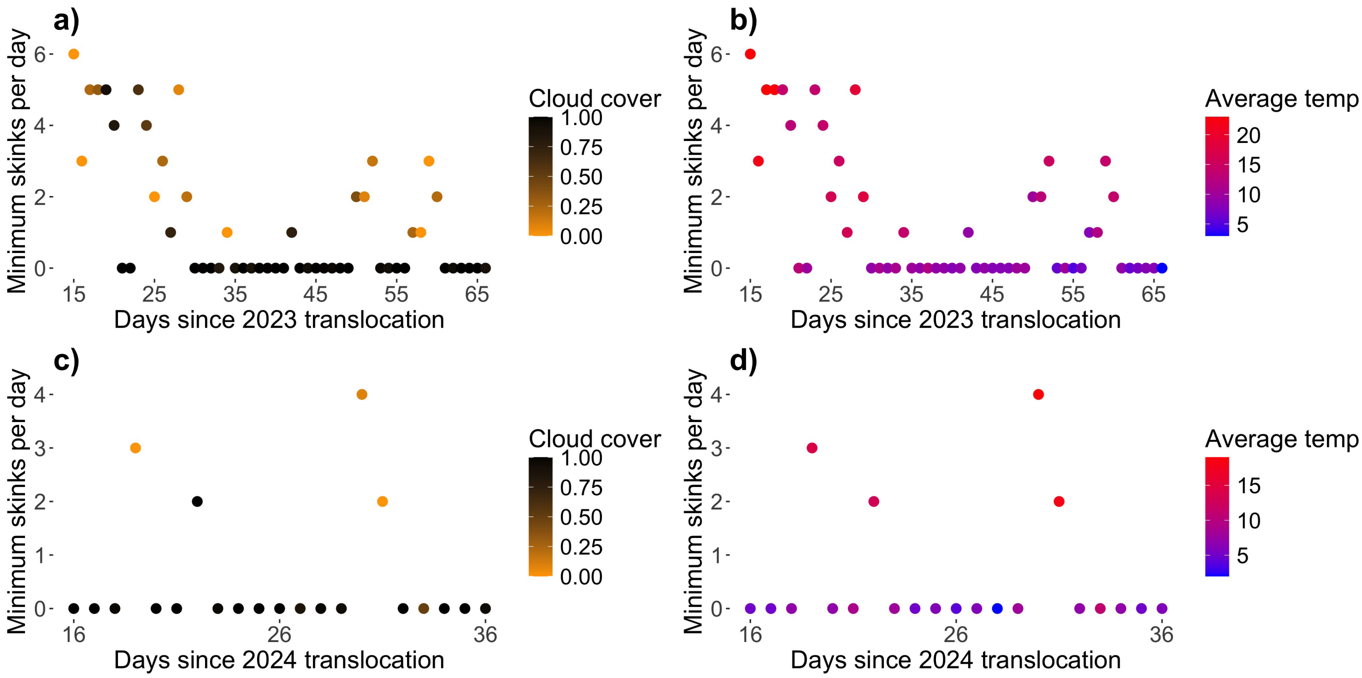

Figure 8. The minimum number of mahogany skinks (*Oligosoma* aff. *pluvialis* "mahogany") counted per day on Secretary Island relative to (a) cloud cover and (b) average daily temperature following the 2023 translocation; (c) cloud cover and (d) average daily temperature following the 2024 translocation. The proportions of cloud cover were calculated by dividing the total number of timelapse photos that were described as "overcast/cloud blocking direct sun from hitting the release site" or "inside cloud/fog" by the total number of photos taken per day (excluding any photos described as "dark" or "shade").

behaviour, and, if basking in the direct sunlight, were never seen more than a few centimetres away from a shrub or rock crevice. If spotted a metre or more away from shrubbery or crevices, they were moving quickly and only briefly stopping to assess their surroundings. On hot afternoons, they were occasionally seen basking partially concealed within the pink pine shrubs, which, paired with their very dark colouration, hid them well. In contrast, shortly after the first translocation, and when the sun first hit the release site in the morning, skinks could be spotted basking on the top of the pink pine shrubs directly next to where they were released. However, after those initial few weeks, they were not observed doing so at that location again. Mahogany skinks at the release site were also frequently observed emerging to bask on rock that was likely still warm when the sun was behind cloud, the release site was inside fog, or the sun had just gone behind the ridgeline.

Discussion

No evidence of weka preying on mahogany skinks was observed in the release site area, and there was evidence of skinks surviving at least 12 months following the first translocation. Weka and mahogany skinks were typically active at the release site during different times of day and at different temperatures. The relatively few detections of stoats and kea suggests that these potential skink predators may be of limited concern at this release site.

Weka as a threat to mahogany skinks on Secretary Island

The lack of observed lizard predation by weka on Secretary Island could be due to several factors. Likely due to the absence of rodents, Secretary Island has high invertebrate and flora diversity and abundance (Mark 1963; Wardle 1963; Murphy et al. 2016; Bertoia et al. 2024). Abundant and accessible food resources may influence the feeding behaviour of weka and decrease their likelihood of focussing on a novel and seldom encountered prey source. Potential predation by weka could be further mitigated by the ecology of the mahogany skinks, particularly their cryptic behaviour. The habitat complexity within the release site, combined with the behaviour of the skinks, may reduce the likelihood of skinks catching the attention of weka passing through or foraging in the area. On some islands like the Open Bay Islands (Lettink et al. 2010), Kāpiti Island (Gollin et al. 2021), and the Chetwode Islands (Towns et al. 2002), weka have been assumed to be having an impact on lizard populations. However, these islands contain different ecosystems compared with Secretary Island and notably have or have had high lizard densities, with weka present due to relatively recent human introduction. Some of these ecosystems have also experienced habitat loss or degradation, along with the presence of both introduced mammalian predators and other native avian predators, which increases the difficulty of disentangling any direct effects of weka from other factors.

On mammal-free Tiritiri Matangi Island, sacred kingfishers were significant predators of skinks, with 88% of pellets containing skink remains, all identified as moko skinks despite three other skink species being present (van Winkel & Ji 2012). The moko skink represents a remnant population on the island, whereas the translocated shore skink population, released in 2006, increased in size over at least seven years (van Winkel & Ji 2012; Baling et al. 2013). Van Winkel and Ji's (2012) findings may support the notion that skink behaviour and habitat influence susceptibility to native avian predation, both generally and following translocation. Although both moko and shore skinks are diurnal and heliothermic, shore skinks are coastal specialists, flee disturbance more readily, and had greater access to natural refugia at the Tiritiri Matangi release site (van Winkel et al. 2018). In contrast, moko skinks occupy more open habitats and may be less reactive to threats. Additionally, Tiritiri Matangi provides more natural refugia for shore skinks at the release site compared to nearby Motuora Island, where released shore skinks declined in population, despite similar predation pressure and storm impacts (van Winkel & Ji). These results highlight the importance of the release-site microhabitat in lizard translocations, not only for resource availability and thermoregulation, but also protection from severe weather and predation, both relevant on Secretary Island.

It is also possible that predation events or other interactions between weka and skinks occurred but were not detected. Where an animal appears in a trail camera's field of view, and how large that animal is, can affect whether or not it effectively triggers the motion detection, as well as ambient temperatures and infrared sensor sensitivity (Wellington et al. 2014; Urbanek et al. 2019). While the specific model of trail camera that we used (Reconyx H600) has been found to be superior in detecting smaller-bodied animals compared to at least one other model, and the detection of stoats, weka, and small animals such as rock wren at the release site provide us with confidence in its detection abilities in this environment, trigger failures are inevitable, especially over such long study periods (Wellington et al. 2014). Additionally, an interaction between weka and skinks may have happened outside of a trail camera's field of view entirely, or in the new areas that the skinks have dispersed into.

Comparing skink and weka activity levels

It is possible that skink density was so low that weka failed to encounter them and thus did not learn to target them. Since the translocations reported in this study, the population was supplemented by translocation of another 45 skinks (creating a total founder population of 85 individuals) in February 2025. The only way to rule out the possibility of density-dependent predation is to continue to monitor the release site area. If a larger skink population caused the frequency of skink-weka interactions to increase, it is possible that the release site area could become part of the foraging strategy of nearby weka if they viewed skinks as a valuable prey source (Dukas 2002; Garay et al. 2018). Nevertheless, whether or not potential predators and their prey are active at the same times of day or in similar weather conditions is also important, as overlapping activity patterns can increase the chances of interaction and therefore possible predation.

Weka and skinks differed in their peak activity levels. Weka activity occurred at all times of day, but appeared primarily crepuscular as observed elsewhere in Aotearoa (Bramley 1994; Lamb et al. 2021; Figure 5), and spanned lower temperatures (−1 to 26°C; mean 9°C; Fig. 6). Skink activity peaked in the late afternoon, consistent with other alpine skinks in Aotearoa (Bertoia et al. 2023) and internationally (Melville & Swain 1997; Fig. 5), and occurred at higher temperatures (10°C to 35°C; mean 21°C; Fig. 6). Strong and direct midday sun may be too hot for skinks to bask in, so this late afternoon activity could reflect thigmothermy, where skinks gain warmth from the environment after direct sunlight has passed. Similar behaviour was observed in an alpine skink *Carinascincus microlepidotus* in Tasmania, which basked on warm rocks up to an hour after sunset, and Bertoia et al. (2023) proposed the same explanation for the behaviour of an alpine population of McCann's skinks (*Oligosoma maccanni*). Although daylight type did not significantly influence skink detections, relatively high detections occurred when clouds blocked direct sunlight (Fig. 7). It is also important to note that the trail cameras were positioned to capture skinks when travelling through or basking in the more open portions of the release site habitat, so it is possible that skinks may have been cryptically basking unnoticed within the pink pine. Even so, from what we know thus far, the differing activity patterns between weka and skinks may help limit interactions between them.

Possible factors affecting skink detections over time

In the 57 days following the first mahogany skink translocation, the minimum number of skinks counted per day declined over time. This pattern likely reflects both weather effects on skink detections and dispersal. During camera period 1, severe weather between days 30 and 50 after the translocation saw only one skink detected in 20 days. This period included heavy rain, flooding at the release site, and average daily temperatures of 15°C or lower, with only one day of less than 100% cloud cover (Fig. 8). After this period, skink counts dropped to three or fewer per day, with detections limited to three trail cameras compared to six before the bad weather. Some skinks may have perished, but it is more likely they dispersed to more suitable microhabitats, given tracking tunnel detections up to 25 metres away (Fig. 3). Furthermore, skinks detected on the edge of the tracking tunnel grid suggest others may have moved beyond the monitored area.

The detection of skinks between December 2023 and January 2024 showed that at least some skinks from the first translocation (released on 31 January 2023) had survived one year on Secretary Island, indicating that the habitat they have been released in is of suitable quality (Germano & Bishop 2009). Their survival suggests that there are adequate food sources for them and deep enough retreats to survive sub-freezing winter temperatures. However, there remains little known about the ecology and resource requirements of mahogany skinks. Long-term research into their habitat requirements, life history, and ecology paired with further monitoring of the Secretary Island population is required to conclude if the translocation has been successful (Miller et al. 2014).

Sinbad skinks, mahogany skinks, and their future on Secretary Island

Only a single population of Sinbad skinks is known to exist. This highly localised population faces the threat of predation from mammalian predators and is vulnerable to stochastic events such as earthquakes (Bell et al. 2007; Bell & Patterson 2008; O'Donnell et al. 2017). Climate change is also increasing the elevational range of mammalian predators in Aotearoa, putting further pressure on the native species of the alpine zone (Christie 2014; O'Donnell et al. 2017; Macinnis-Ng et al. 2021; Keegan et al. 2022). Critically, the habitat that Sinbad and mahogany skinks occupy is largely vertical and not viable for sustained application of high intensity rodent control as is currently being deployed and tested for other similar species such as awakōpaka skinks (*Oligosoma awakopaka*) in the Homer Basin of Fiordland. If the translocation of mahogany skinks at the Secretary Island release site is successful, Sinbad skinks could be translocated to the same release site with increased confidence in the future. As the two species are already sympatric in their alpine cirque basin and are often found occupying the same microhabitat patches, there is no major concern regarding their potential co-existence in a different location.

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Conflicts of interest: The authors declare no conflicts of interest.

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Ethics: Only passive monitoring of skinks was conducted, therefore we did not require an ethics permit for this study. The translocation of mahogany skinks to Secretary Island was led and implemented by the Department of Conservation.

Data availability: The data and code are not publicly available for this paper.

Author contributions: All authors were involved in the conceptualisation of the research and in developing methods. Investigation and analysis was undertaken by CG who also wrote the original manuscript draft, and all authors contributed to review and editing.

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