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RESEARCH

Effect of pitfall trap design on internal trap temperature and the implications for live-trapped lizards

Matthew K. Turner[1]*, Dave Kelly[1] and Marieke Lettink[2]

[1]School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand
[2]Fauna Finders, 20 Days Road, Lyttelton, Christchurch 8082, New Zealand
*Author for correspondence (Email: matty_turner@hotmail.co.nz)

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Abstract: The capture of animals in live traps poses inherent risks of heat stress and mortality to trapped individuals. Despite a long history of pitfall trap use in New Zealand for monitoring small lizards, the design of traps and their covers often varies; however, the effects that this has on the internal temperature of the traps is unknown. Poor trap design may increase the risk of stress and mortality if internal temperatures exceed thermal limits. We tested the influence of three aspects of trap design (cover material, cover colour, and internal trap size) on the maximum and mean internal trap temperatures at Kaitorete Spit, New Zealand. Temperatures were recorded with dataloggers across 24 days during midsummer (December 2020 to January 2021). Internal temperatures reached a maximum of 38.2 °C (on a day with a maximum air temperature around 31 °C). Those trap temperatures are above predicted harmful thermal limits of some New Zealand gecko species and levels that induce avoidance behaviour in some skinks. Maximum temperatures were lower under plywood covers than those made of plastic or Onduline, brown covers than black, and in 4 L traps rather than 1 L. The best trap design had thermal maxima 3.9 °C lower than the worst design, averaging 4.9 °C above air maximum temperatures in the best design compared with 8.6 °C above for the worst. As climate change increases temperatures in some areas, the risk of heat stress and mortality rises for lizards constrained in pitfall traps. We recommend the use of plywood covers and larger internal trap sizes to reduce this risk.

Keywords: gecko, heat stress, lizard, pitfall trap, skink, temperature, thermal limit, trap design

Introduction

Pitfall trapping is a sampling method frequently used for small terrestrial reptiles, mammals, and invertebrates in biodiversity surveys (Raxworthy & Nussbaum 1994; Paoletti et al. 2018; Stokeld et al. 2018) and in conservation and management (Towns & Ferreira 2001; Schofield et al. 2012). Pitfall traps consist of a container recessed into the ground, with the top of the container level with the surface. The target species fall in and are unable to climb out (for live trapping) or fall into a killing solution (typically for invertebrates). Traps are often used in conjunction with drift fences, which aid in guiding animals into the traps, thereby increasing catch rates (Ellis 2013; Muller et al. 2017). Although pitfall trapping is used globally, trap design (container and cover materials, colours and sizes) varies, influencing internal trap temperature and capture rates (Hobbs & James 1999; Thompson & Thompson 2009).

Various types of containers have been used, including metal tins (Towns & Elliot 1996; Lettink & Monks 2019) and plastic buckets (Hobbs et al. 1994; Enge 2001; Read & Moseby 2001). Trap size can vary greatly depending on the size of the target species and terrain, from 750 mL (Walker et al. 2014; Wilson et al. 2017) to 100 L (Ribeiro-Júnior et al. 2011). Pitfall traps are sometimes covered with vegetation, shade cloth, or lids of varying materials, providing protection from potential larger predators (since the target species is constrained inside the trap) and reducing the amount of sunlight, heat, precipitation, and debris reaching the inner trap.

In New Zealand, containers used for live-trapping lizards range from 750 mL to 10 L (Neilson et al. 2006; Wilson et al. 2017), as the targeted species are generally small with most having snout-vent lengths (SVLs) of less than 100 mm. Ten-litre container sizes have been used for larger species including the chevron skink, *Oligosoma homalonotum* (SVL ≤ 146 mm; van Winkel et al. 2018). Covering traps is essential to prevent or reduce lizard mortality from predation, and desiccation (Lettink & Seddon 2007). Plywood and plastic are frequently used as cover materials; however, the identification of Onduline (a lightweight corrugated roofing material made of organic materials and bitumen), as an effective artificial refuge material for lizards due its favourable structural and thermal properties (Lettink & Cree 2007; Thierry et al. 2009), has since led to its use as a trap cover by some herpetologists in New Zealand (e.g. Lennon 2019). However, this is not standard practice and a study on the thermal profile of Onduline as artificial refuges has shown they can reach temperatures exceeding 58 °C (Thierry et al. 2009), thereby potentially increasing the risk of heat stress to trapped lizards. Also, Onduline is corrugated,

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creating comparatively large gaps which might allow entry by rodents (potential lizard predators).

The live trapping of animals has inherent risks; however, the frequency of deaths and their direct causes are rarely reported in trapping studies (Woolley et al. 2021). Increased stress and mortality can be induced by factors including exposure to extreme temperatures (Read & Kearney 2016), predation (Ferguson et al. 2008; Waudby et al. 2019), desiccation (Jenkins et al. 2003), and drowning (Enge 2001). The minimisation of risks associated with trapping is important for animal welfare and is considered when applying for permits to work with wildlife and by Animal Ethics Committees. Therefore, it is important to use a trap design that minimises the risk of stress and mortality to the target species.

Pitfall trap container and cover material and size can influence temperatures within the trap, potentially affecting an animal's welfare. Metal traps exposed to direct sunlight may heat rapidly to temperatures harmful to trapped animals. Dark coloured plastic traps are warmer than lighter ones when exposed to high levels of sunlight for long periods, which can lead to increases in animal mortality and damage to the traps (Fisher et al. 2008). Despite this, dark plastic containers are often more effective in capturing small vertebrates (Crawford & Kurta 2000), probably due to resembling a naturally dark refuge. The depth of the trap can also influence the temperature of the refuge. Deeper traps are used in desert habitats as soil temperatures generally decrease with depth (Fisher et al. 2008).

Temperature is an important factor influencing the activity of reptile species, with capture rates of reptiles generally increasing with rising ambient temperature, up to certain thermal limits (Read & Moseby 2001). For example, observations of the New Zealand skink species *Oligosoma grande* and *O. otagense* were rare at air temperatures under 7 °C but significantly greater as temperatures increased (Coddington & Cree 1997). Trapping takes place across different seasons and weather conditions for species management and research (Fitzgerald et al. 1999). This could potentially include trapping during periods where the ambient temperature may be below or above an animal's preferred temperature.

Many reptiles and amphibians have a low thermal safety margin, which is the difference between the maximum heat tolerance of a species and the temperatures that it experiences regularly, and therefore must rely on behavioural actions to regulate body temperature and avoid heat stress (Sunday et al. 2014). Such actions include seeking shade and burrowing. Trapped individuals exposed to harmful temperatures cannot move to cooler areas, thus increasing the likelihood of heat stress and desiccation. Trap mortality of herpetofauna in pitfall traps, including the skink *Ctenotus schomburgkii* and the frog *Neobatrachus sudelli* in Australia, has been found to be positively related to increased exposure to solar radiation (Read & Kearney 2016). Similarly, Dodd (1995) reported 4.7% of trap mortality in the toad *Gastrophome carollnensis*, was predominantly attributed to desiccation during a hot summer.

The thermal tolerance of lizards affects the risks associated with trapping. Unfortunately, the thermal tolerances of New Zealand's lizard fauna are largely unknown, with a few exceptions. Laboratory tests of lethal temperatures in summer acclimatised *Oligosoma maccanni* or *O. polychroma* (previously described as a single species named *Leiolopisma zelandica*) showed skinks could tolerate temperatures of 35 °C, however under these conditions they exhibited "attempted escape" behaviours suggesting potential heat stress (Morris 1974). At 40 °C skinks were found to be inactive or exhibited escape behaviours, surviving for approximately 15–20 minutes (Morris 1974).

A sublethal measure of the upper thermal limit of an animal is its voluntary thermal maximum (temperature that induces avoidance behaviour; Camacho & Rusch 2017) and critical thermal maximum (temperature at which the lizard is no longer able to turn itself upright after being inverted or body spasms begin to occur; Hare & Cree 2016). Known voluntary thermal maxima of the New Zealand gecko *Woodworthia* "Otago/Southland large" and skink *O. maccanni* are 30.7 °C (Chukwuka et al. 2020) and 34.7–36.4 °C (Virens & Cree 2019) respectively. The predicted critical thermal maximum of *W.* "Otago/Southland large" was 35–37 °C (Hare & Cree 2016), lower than that of *O. maccanni*, of 40.2–41.8 °C (Virens & Cree 2019). The thermal tolerance of different species may differ with varying latitude and altitude (Sunday et al. 2014). For instance, critical maximum body temperatures of skinks in arid regions of Australia vary between 37 and 46 °C (Greer 1980). Pregnancy was found to influence the critical thermal maximum of *O. maccanni*, where pregnant females had reductions in their critical thermal maxima of 1.4 and 2.0 °C compared with males and postpartum females respectively, suggesting at higher temperatures, the ability of pregnant skinks to keep up with oxygen demands is reduced (Virens & Cree 2019).

The variation in pitfall trap design used throughout New Zealand could influence risk of heat stress and mortality to trapped lizards. Lizards can remain in traps for up to 24 hours (live traps must be checked every 24 h under the NZ Animal Welfare Act 1999), leaving them vulnerable to potential heat related stress or mortality. Pitfall trapping is generally carried out during warmer months when lizards are more active. But to date, no study in New Zealand has tested the influence of different cover materials on the internal temperature of pitfall traps. We tested combinations of three cover materials, two colours of covers and two trap container sizes (all frequently used for pitfall trapping in New Zealand) in duneland on Kaitorete Spit during midsummer (December 2020–January 2021). Our aim was to test the influence of these three components of trap design on the internal temperature of the traps.

Methods

Kaitorete Spit is a 30 km long sand and gravel barrier which separates Lake Ellesmere/ Te Waihora from the Pacific Ocean, to the southwest of Banks Peninsula, Canterbury. The settlement of Birdlings Flat is located at the eastern end of the spit. The southern part of Kaitorete spit is covered by coastal dunelands, much of which is managed by the Department of Conservation as it contains multiple threatened endemic species including the sand-binding sedge pīngao (*Desmoschoenus spiralis*) and the katipō spider (*Latrodectus katipo*). Kaitorete Spit supports four of Bank Peninsula's lizard species: the Nationally Vulnerable Canterbury spotted skink (*O. lineoocellatum*), the southern grass skink (*O.* aff. *polychroma* Clade 5) and Waitaha gecko (*Woodworthia* cf. *brunnea*) which both have a threat classification of At Risk - Declining, and the McCann's skink (*O. maccanni*), classified as Not Threatened under the New Zealand Threat Classification System (Townsend et al. 2008, Hitchmough et al. 2021).

The study was conducted on Department of Conservation land at Kaitorete Spit, an 11 km strip of duneland along the southern face of the spit. The pitfall traps were placed 6 km west of Birdlings Flat in the dune flats. This site was selected because of the relatively arid and warm climate (e.g. ambient air temperatures of 40 °C have been recorded at a weather station at Birdlings Flat; ML unpubl. data).

Twelve pitfall trap designs were used, being all possible combinations of three trap cover materials, two cover colours and two trap container sizes. Cover materials were 220 mm diameter plastic bucket lids (supplied with the 4 L buckets), 270 × 270 × 6 mm plywood sheet, and a 310 × 310 mm piece of Onduline. Covers were painted black (to match the colour of the purchased Onduline) or brown (matching the natural colour of the plywood). The paint colours used were Resene "All Black", applied to plywood and plastic, and Resene "Brown Sugar" applied to Onduline and plastic. White (the natural colour of the plastic lids) was not included in the trial as it is highly visible and might increase the likelihood of traps being vandalised. Two sizes of pitfall trap containers were used: 1.1 L (127 mm diameter × 119 mm depth) and 4 L (211 mm diameter × 192 mm depth) round white plastic pails. Pails were dug into the ground with the lip flush with the surface. Small holes were drilled into the bottom of the pails to allow water to drain out. Leaf litter and damp sponges are commonly placed in pitfall traps to provide shelter for lizards and reduce desiccation (Drummond et al. 2015), however, in this study these were not used as they would likely require re-wetting every second day and as such may influence the internal trap temperature. Plywood and plastic covers had four wooden spacers glued to their undersides, leaving a 10 mm gap for lizards to enter the trap. Onduline covers have corrugations (approximately 30 to 35 mm) which allows lizards to enter traps. Covers were secured over the traps using metal pegs placed into the ground. Sticks were placed in each trap to allow any animals that had entered the traps to escape, as the objective was to measure internal trap temperatures but not actually trap lizards. The twelve pitfall traps were arranged in two rows of six traps spaced 0.5 m apart along and between rows, and the six cover types were rotated systematically among traps (Fig. 1). Each lid design was used sequentially on each of six different containers of the same size totalling 72 observations across the two container sizes.

Internal trap temperatures were recorded using a HOBO U23 Pro v2 Temperature/Relative Humidity datalogger mounted inside each pitfall trap using PVC pipe holders, with sensors suspended 10 mm from the bottom, where trapped lizards would be held during pitfall trapping. Before being placed within the pitfall traps, the dataloggers were all tested in the same environment to verify logger accuracy. The dataloggers recorded temperatures every ten minutes, and from this the daily maximum and minimum temperature was extracted for that trap for each day (for some days, recorded over less than 24 h, see below). Dataloggers were set on 7 December 2020 and 8 January 2021 to record internal trap temperatures for 24 days from 8 to 19 December 2020 and 9 to 20 January 2021 during midsummer (recording was suspended over the Christmas period). Temperatures were recorded for

Figure 1. Layout of the pitfall traps on Kaitorete Spit. Cover order from left to right: plywood, Onduline, plastic. Cover colours: black and brown. Bottom row: 1.1 L traps, top row: 4 L traps.

each particular trap/lid combination for four days. Loggers were all started at 1800 hours, and after four days, the loggers were stopped and downloaded at approximately 1500 hours, the covers were rotated, and the loggers restarted at 1800 hours. This meant the fourth day only had data for 21 hours, but the maxima would normally occur around noon and the minima overnight, so missing the late afternoon period would not be expected to alter the results. We subsequently tested that assumption (see below). Covers were rotated to adjacent pitfall traps of the same size until each container's temperature had been recorded with each cover type. As there was no measurement of ambient air temperatures on site, we compared trap temperatures to the nearest NIWA meteorological station (Broadfield in Lincoln), 26 km north of our study site. As daily maximum and minimum temperatures were recorded by the dataloggers for the 24 hours to midnight, but by NIWA at 800 hours, the Lincoln recorded daily maxima were shifted one day earlier (they would typically have occurred the previous afternoon). This shift greatly increased the correlation between datalogger and Lincoln daily maximum temperatures.

All statistical analyses were performed using the program R (Version 4.0.2) and used the glmmTMB statistical package. Trap daily mean temperatures, and daily maximum temperatures were tested. The daily mean internal trap temperature and daily mean at Lincoln were calculated as the average of the daily maximum and daily minimum temperatures. A large amount of day-to-day variation in maximum ambient temperature was observed during the recording periods. To account for this, we compared traps using the difference between each trap's temperature and both the daily maximum temperature across all 12 traps (local temperature deviations), and the Lincoln meteorological air temperature (Lincoln temperature deviations). We tested both, as the Lincoln deviations allow comparison of trap temperatures to standard meteorological conditions, which would be widely available near to the sites of other proposed trapping programmes. The temperature deviation data were analysed using generalised linear mixed models (GLMM) with Gaussian error distributions. We ran models testing four response variables: (1) deviations from local daily maximum temperatures (°C), (2) deviations from local daily mean temperatures, (3) deviations from Lincoln daily maximum temperatures, and (4) deviations from Lincoln daily mean temperatures. The predictor variables were cover material (Onduline, plywood, or plastic), cover colour (black or brown) and trap size (1.1 L or 4 L). Trap ID was included in each GLMM as a random variable to account for the repeated sampling from the same traps over time and variation caused by potential differences in temperature at particular pitfall traps.

On the last day of each 4-day recording period, temperatures were recorded only until about 1500 hr (partial day). Also, if a trap was changed to a cover differing in temperature, the internal temperatures might take a few days to equilibrate. To test if there was variation caused by whether the temperatures were recorded from a full or partial day (duration) or the number of days since the cover was changed and the temperature logger was reset (days since reset; between 1–4 days), GLMMs were applied. This analysis showed that neither full vs partial days, or days since reset, had any significant effect on either local maximum or local mean temperature deviations (in all cases $P > 0.90$). Therefore, for further analyses, duration and days since reset were not included in the analyses.

Results

For all trap variants, the highest maximum temperatures were recorded on 19 December 2020, which also had the highest daily maximum air temperature at Lincoln of 31.1 °C (Fig. 2). Internal trap temperatures on this day exceeded 35 °C for up to 3 hours. Trap daily maximum temperatures changed in

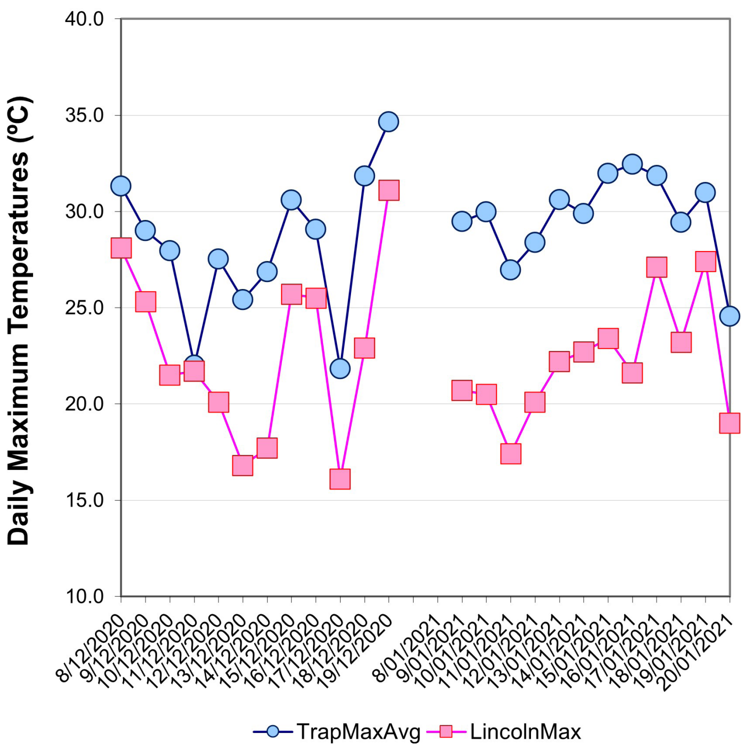

Figure 2. Mean daily maximum temperatures in pitfall traps at Kaitorete spit (blue circles: average of the pitfall trap daily maxima) and at Lincoln (red squares: daily maximum ambient air temperatures) over 8–19 December 2020 and 9–20 January 2021.

parallel with Lincoln maximum air temperatures but were generally warmer by between 4 and 10 °C (mean 6.5 °C). Daily maximum internal trap temperatures in individual traps ranged between 22.2–38.2 °C and the daily mean internal trap temperatures ranged between 18.2–28.8 °C. The analysis of daily maximum temperature deviations showed similar trends whether analysed relative to Lincoln daily maximum air temperatures (Fig. 3a–c) or relative to the daily maxima at the study site averaged across all traps (Fig. 3d–f). The main difference was that analysis relative to Lincoln air temperatures had larger variance since this included additional variation between the Kaitorete and Lincoln sites. This meant that the P values of various effects were less significant for Lincoln temperature deviations than for local temperature deviations (Table 1). There were also similar conclusions based on analyses using deviations of daily maximum, vs daily average temperatures (Table 1); we focus on daily maxima as these are more relevant to heat stress.

During the monitoring period, all four analyses (daily maximum and daily mean temperatures, compared to either local mean or Lincoln temperatures) found that traps with plastic covers were significantly warmer than those with Onduline and plywood covers (Table 1; Fig. 3). Plastic covers had an average maximum temperature of 30.1 °C, compared with Onduline (28.4 °C) and plywood (28.4 °C). Onduline and plywood cover temperatures did not differ significantly, except when testing local deviations in daily means (Table 1). For trap size, in all analyses 1.1 L containers were warmer than 4 L containers (average daily maxima 29.8 °C and 28.2 °C respectively). Traps with black covers were significantly warmer than those with brown covers only in the more sensitive analyses using deviations from local averages, although the deviations from Lincoln temperatures were close to significant. Average daily maxima were 29.3 °C for black covers and 28.6 °C for brown covers.

The 1.1 L trap with a black plastic cover reached the highest temperatures, with an average daily maxima 2.2 °C above the site average. The coldest trap type was 4 L containers with a brown plywood cover, 1.7 °C below the site average. Relative to Lincoln daily maximum air temperatures, maxima in small traps with black plastic lids averaged 8.6 °C warmer, whereas large traps with brown plywood lids averaged only 4.9 °C warmer (Fig. 4). On some occasions, individual trap daily maxima in the hottest trap types were > 10 °C above Lincoln daily air temperature maxima.

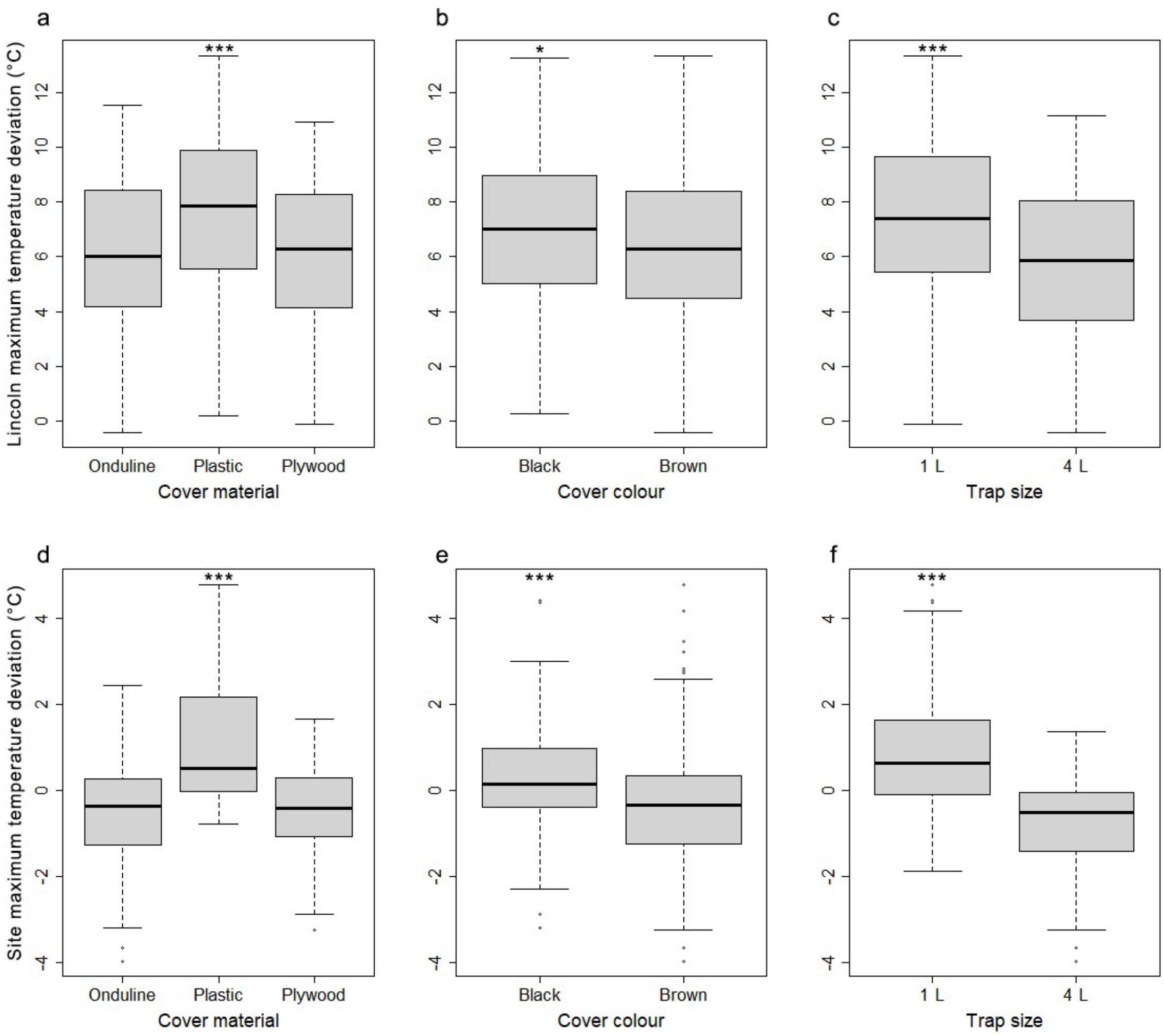

Figure 3. Relationship between pitfall trap features (cover material, cover colour, and trap size) and trap daily maximum temperature deviations from (a–c) Lincoln air temperatures and (d–f) local site average across all traps (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

Table 1. Generalised linear mixed models for different pitfall trap types used to predict temperature deviations during summer monitoring periods on Kaitorete Spit. Predictors using either daily maximum or daily average temperatures, relative to Lincoln or to site average across all traps. Trap ID was included in each model to allow for the data structure. Intercept is for Onduline cover material, black cover colour and 1.1 L trap size.

	Estimate	Std. Error	Z value	*P*
Maximum Lincoln				
Intercept	7.14	0.361	19.778	< 0.001
Cover material (plastic)	1.579	0.395	3.994	< 0.001
Cover material (plywood)	−0.013	0.395	−0.032	0.974
Colour (brown)	−0.632	0.323	−1.957	0.05
Trap size (4 L)	−1.63	0.323	−5.048	< 0.001
Average Lincoln				
Intercept	5.999	0.195	30.743	< 0.001
Cover material (plastic)	0.704	0.214	3.293	0.001
Cover material (plywood)	0.172	0.214	0.807	0.42
Colour (brown)	−0.326	0.175	−1.867	0.062
Trap size (4 L)	−0.49	0.175	−2.808	0.005
Maximum Site				
Intercept	0.609	0.176	3.461	0.001
Cover material (plastic)	1.579	0.115	13.743	< 0.001
Cover material (plywood)	−0.013	0.115	−0.112	0.911
Colour (brown)	−0.632	0.094	−6.734	< 0.001
Trap size (4 L)	−1.63	0.221	−7.389	< 0.001
Average Site				
Intercept	0.116	0.073	1.590	0.112
Cover material (plastic)	0.704	0.066	10.659	< 0.001
Cover material (plywood)	0.172	0.066	2.610	0.009
Colour (brown)	−0.326	0.054	−6.043	< 0.001
Trap size (4 L)	−0.49	0.079	−6.194	< 0.001

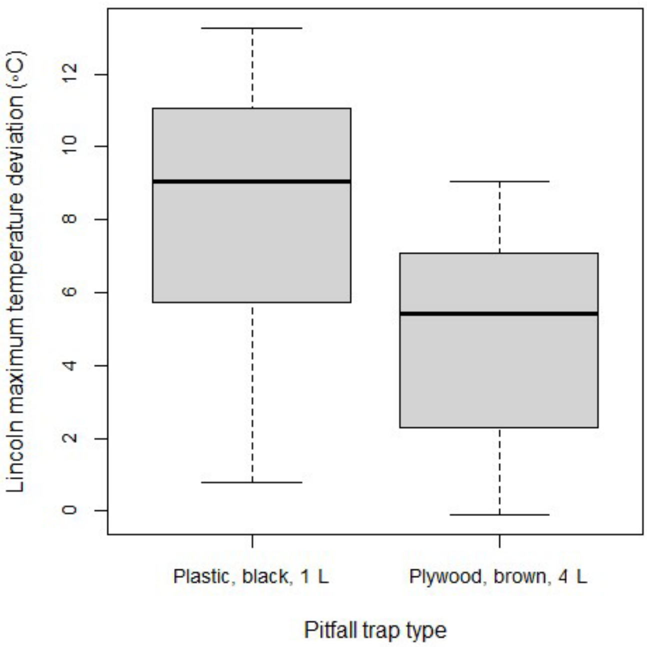

Figure 4. Pitfall trap daily maximum temperatures (relative to Lincoln air temperature) for the hottest type (black plastic lid, 1.1 L size) and coldest type (brown plywood lid, 4 L size) at Kaitorete Spit in December 2020–January 2021.

Discussion

Pitfall trapping during hot weather can leave trapped animals exposed to prolonged periods of elevated temperatures, which may ultimately lead to mortality. One method of reducing the internal temperatures and subsequently the risk of heat-induced mortality is by altering the design of the pitfall traps. In this study, different aspects of pitfall trap design used in New Zealand (cover material, cover colour and trap size) were found to all influence trap internal temperatures. We found that the warmest and coolest pitfall trap designs varied by 3.9 °C in average daily maximum internal temperatures. In summer, 4 L traps with brown plywood covers were the coolest trap type; for the mean internal temperature, 4 L traps with brown Onduline covers were coolest. Daily mean temperatures did not reach temperatures that would be of concern to New Zealand lizards.

Of greater concern is whether maximum internal trap temperatures exceed the thermal limits of New Zealand lizards. Internal temperatures of the pitfall traps at Kaitorete Spit over 24 days in mid-summer did not exceed the known critical thermal maximum temperature and likely lethal limit for New Zealand skink species (Virens & Cree 2019). However, temperatures in the traps reached over 35 °C for up to 3 hours on one day. These temperatures would likely exceed the predicted lower range (35 °C) of the critical thermal maximum temperature of *W*. "Otago/Southland large" (Hare & Cree 2016), thus potentially being harmful to trapped geckos of this species. Moreover, pitfall trap maximum temperatures were usually markedly higher than air maximum temperatures. On the day when internal trap temperatures reached 35–38 °C, the nearest weather station to Kaitorete Spit (26 km north of the site at Lincoln) recorded maximum air temperatures of only 31.1 °C, so internal trap maxima were 4–7 °C above standard meteorological maximum air temperature at a nearby station. Summer air temperatures in Canterbury frequently exceed 30 °C. At the Christchurch Botanic Gardens during January and February over the years 2000–2020, 82 days (just under two days month^{-1}) had maxima ≥ 30 °C, which might give trap temperatures over 40 °C.

Even during our (relatively mild) sampling period, trap temperatures frequently exceeded the known voluntary thermal maxima of *O. maccanni* and *W.* "Otago/Southland large" (Virens & Cree 2019; Chukwuka et al. 2020). On two occasions, the daily maximum internal temperatures reached and surpassed the voluntary thermal maxima range of *O. maccanni* (34.7–36.4 °C; Virens & Cree 2019), with the highest trap temperature being 38.2 °C. During 17 of the 24 recording days, at least one trap exceeded the mean voluntary thermal maxima of *W.* "Otago/Southland large" (30.65 °C; Chukwuka et al. 2020). All trap variants exceeded these temperatures during the monitoring period for at least six hours. Once temperatures exceed the voluntary thermal maxima, risk of mortality increases exponentially (Camacho & Rusch 2017).

While there are published data for the thermal maxima of *O. maccanni* and *W.* "Otago/Southland large" from Eastern-Central Otago that could be compared to the pitfall trap temperatures at Kaitorete Spit, the thermal maxima for most New Zealand lizards remain unknown. It is likely that thermal maxima would vary with species across latitude and altitude (Tocher 1992; Sunday et al. 2014) as thermal limits are determined by local adaptations and plasticity (Clusella-Trullas & Chown 2014). For instance, *W.* cf. *brunnea* on the Port Hills, Christchurch, were observed readily occupying artificial refuges with internal temperatures above the known mean voluntary thermal maxima of W. "Otago/Southland large" (Turner 2021).

Deeper 4 L (192 mm) containers reduced the internal temperature experienced at the bottom of the traps. This is consistent with a previous study which determined that increasing trap depth reduced its internal temperature and the likelihood of animals experiencing heat related stress (Read et al. 2018). The larger traps reach deeper in the substrates, putting the lower part of the trap in contact with lower soil layers, which are usually cooler than the top layers of soil. Hence, larger traps would provide a safer thermal environment for lizards.

Plastic bucket lids were the least effective material at reducing internal trap temperatures. These observations agree with field results from Hobbs and James (1999), that plastic lids propped against drift fences over traps were ineffective at reducing the internal temperature during the hottest periods of the day. Elevated internal temperatures could be due to the plastic reaching greater underside temperatures compared with the plywood cover materials, thus having a greater capacity to radiate heat into the base of the trap.

Onduline covers had the largest range in maximum and mean internal temperatures. Thierry et al.'s (2009) study on the thermal profile of Onduline as an artificial refuge material suggests it has a low thermal inertia, heating and cooling rapidly. Temperature readings from Onduline refuges (stacks of Onduline with small spacers between sheets, placed on the ground surface as shelters for lizards) varied greatly, reaching 58 °C during summer and −6 °C in winter (Thierry et al. 2009). This study found similar findings during the experiment where an Onduline-covered trap recorded the second highest maximum temperature of 37.1 °C. Thus, the potential to reach harmful temperatures on a clear sunny day may make its use as a cover material less desirable.

Although we found that trap design can alter trap daily maximum internal temperature by up to 3.9 °C, external factors such as ambient temperature, wind and sunshine also strongly influence its temperature. The cooling effect that a breeze provides would be expected to decrease the boundary layer effect where still air near the ground can heat up well above ambient, allowing the ground surface to reach high temperatures on calm sunny days. However, a previous study by Thompson and Thompson (2009) found wind caused no evident drop in pitfall trap temperatures during the two hottest days recorded during the study period. This may be due to traps either being uncovered or having bucket lids suspended 300 mm over them, which allowed sunlight to reach the bottom of the traps during different times of the day.

The substrate (and its water content) may also influence its internal temperature. For example, this study site was on sand dunes. Sand is usually well drained, and dry soil has less heat capacity (it takes less heat to warm a certain soil volume by 1 °C), so traps warm up more rapidly. In comparison, if the substrate has a higher water content, the soil around the trap would warm up more slowly. Therefore, in dry or well-drained sites potential maximum internal temperatures will be higher than in sites where the substrate is normally wet, even under similar ambient temperatures.

Ideally sampling methods should be designed to minimise risks to the health and wellbeing of trapped animals. In dry dunelands in New Zealand, internal temperatures of all pitfall traps tested could exceed thermal levels for heat stress, particularly in nocturnal geckos which have lower thermal maxima. We found that by selecting specific pitfall trap design elements, internal temperatures can be reduced, decreasing the potential the risk to trapped lizards. By using plywood as a cover material and larger container sizes, maximum summer temperatures were reduced by 3.9 °C compared with the warmest trap variant. Therefore, the use of plywood covers and larger buckets is recommended for lizard pitfall trapping in New Zealand in warmer regions and warmer times of year.

While pitfall trap design is effective for reducing internal temperature, more frequent checking of traps (e.g. twice daily) can also help to minimise risk of mortality when trapping in hot weather. Checking traps in the morning can reduce nocturnal lizard exposure to high daytime temperatures and checking late in the day can reduce diurnal lizard exposure to nocturnal predators (Thompson & Thompson 2009). Additionally, leaf litter and damp sponges placed at the bottom of traps would likely further reduce potential risks to lizards by providing a more humid environment and temporary cooling effect from the re-wetting of the sponge.

While the use of larger container sizes can reduce internal temperatures, larger traps would be heavier and more difficult to transport to field sites. Larger containers would require greater time, cost and effort to install compared to smaller sized traps. Smaller containers may be ineffective in locations with larger bodied species present which could escape the smaller trap sizes (≤ 1 L). Onduline covers were easier to transport as sheets stack together compared to the plywood covers with spacers, however, in this study, Onduline was the heaviest cover material. Additionally, the size and weight of Onduline covers may be restricted to what size is available for purchase. Plywood was cheaper than Onduline at approximately $2–3 per cover compared to Onduline covers which cost about $6 per cover.

Predation is another risk to animals constrained in live traps (Ferguson et al. 2008). Towns and Elliot (1996) reported mouse (*Mus musculus*) predation may have resulted in up to 7% mortality in skinks captured in pitfall traps at Pukerua Bay, Wellington. Onduline and plastic covers may increase this risk. Gaps larger than 10 mm between the cover and the trap may enable predators including rats and small mustelids to enter traps (mice cannot be excluded from traps as they are able to access gaps < 10 mm). For instance, camera monitoring of pitfall traps in New Zealand showed that Norway rats (*Rattus norvegicus*) and ship rats (*R. rattus*) readily entered traps baited with pear with plastic covers placed 20 mm above traps (Woolley et al. 2021). Onduline poses the greatest risk of predation due to its corrugated profile, which means that gaps of around 35 mm are inevitable, likely allowing access to traps by rats and small mustelids. Plastic may become distorted in shape over time, potentially increasing the size of the gap. Therefore, the best balance of thermal safety and low predation risk comes from using plywood covers.

Increased daily temperatures in response to climate change will be of great concern in future pitfall trapping for lizards globally, particularly during the warmer months when trapping typically occurs due to increased lizard activity. Presently, the internal daily maximum temperatures of each of the trap variants tested in this study exceeded temperatures of over 30 °C. Future predicted warming conditions will bring elevated maximum temperatures and more days when the maximum temperature exceeds 25 °C (Ministry for the Environment 2018), increasing the risks to trapped lizards. Trapping should be suspended during periods of very hot weather or scheduled to cooler weather when possible. Using larger trap sizes with plywood covers, along with suspending trapping during periods of very hot weather, is recommended to help keep potential trap temperatures within acceptable ranges.

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Additional information and declarations

Author contributions: All authors conceptualised the project; MT and DK developed the methods and worked on the analysis and writing the original draft. MT undertook the investigation under the supervision of DK. ML and DK reviewed and edited the final manuscript.

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References

Camacho A, Rusch TW 2017. Methods and pitfalls of measuring thermal preference and tolerance in lizards. Journal of Thermal Biology 68: 63–72.

Chukwuka CO, Monks JM, Cree A 2020. Heat and water loss versus shelter: a dilemma in thermoregulatory decision making for a retreat-dwelling nocturnal gecko. Journal of Experimental Biology 223(20): jeb231241.

Clusella-Trullas S, Chown SL 2014. Lizard thermal trait variation at multiple scales: a review. Journal of Comparative Physiology B 184: 5–21.

Crawford E, Kurta A 2000. Color of pitfall affects trapping success for anurans and shrews. Herpetological Review 31(4): 222–224.

Coddington EJ, Cree A 1997. Population numbers, response to weather, movements and management of the threatened New Zealand skinks *Oligosoma grande* and *O. otagense* in tussock grassland.Pacific Conservation Biology3(4): 379–391.

Dodd CK 1995. The ecology of a sandhills population of the eastern narrow-mouthed toad, *Gastrophryne carolinensis*, during a drought. Bulletin of the Florida Museum of Natural History 38: 11–41.

Drummond AJ, Newcomb RD, Buckley TR, Xie D, Dopheide A, Potter BC, Heled J, Ross HA, Tooman L, Grosser S, Park D 2015. Evaluating a multigene environmental DNA approach for biodiversity assessment. GigaScience 4: 13742–13015.

Ellis M 2013. Impacts of pit size, drift fence material and fence configuration on capture rates of small reptiles and mammals in the New South Wales rangelands. Australian Zoologist 36(4): 404–412.

Enge KM 2001. The pitfalls of pitfall traps. Journal of Herpetology 35(3): 467–478.

Ferguson AW, Weckerly FW, Baccus JT, Forstner MR. 2008. Evaluation of predator attendance at pitfall traps in Texas. The Southwestern Naturalist 53(4): 450–457.

Fisher R, Stokes D, Rochester C, Brehme C, Hathaway S, Case T 2008. Herpetological monitoring using a pitfall trapping design in southern California. US Geological Survey Techniques and Methods 2: A5.

Fitzgerald LA, Cruz FB, Perotti G 1999. Phenology of a lizard assemblage in the dry Chaco of Argentina. Journal of Herpetology 33(4): 526–535.

Greer AE 1980. Critical thermal maximum temperatures in Australian scincid lizards: their ecological and evolutionary significance. Australian Journal of Zoology 28: 91–102.

Hare KM, Cree A 2016. Thermal and metabolic physiology of New Zealand lizards. In: Chapple DG ed. New Zealand Lizards. Berlin, Springer. Pp. 239–267.

Hitchmough R, Barr BP, Knox C, Lettink M, Monks JM, Patterson GB, Reardon JT, van Winkel D, Rolfe J, Michel P 2021. Conservation status of New Zealand reptiles, 2021. Wellington, Department of Conversation. 15 p.

Hobbs TJ, James CD 1999. Influence of shade covers on pitfall trap temperatures and capture success of reptiles and small mammals in arid Australia. Wildlife Research 26(3): 341–349.

Hobbs TJ, Morton SR, Masters P, Jones KR 1994. Influence of pit-trap design on sampling of reptiles in arid spinifex grasslands. Wildlife Research 21(5): 483–489.

Jenkins CL, McGarigal K, Gamble LR 2003. Comparative effectiveness of two trapping techniques for surveying the

abundance and diversity of reptiles and amphibians along drift fence arrays. Herpetological Review 34(1): 39–42.
Lennon O 2019. Mitigation translocation for conservation of New Zealand skinks. Unpublished MSc thesis. Victoria University of Wellington. Wellington, New Zealand.
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(3): 227–243.
Lettink M, Monks JM 2019. Ecology of scree skinks (*Oligosoma waimatense*) in O Tu Wharekai Wetland, mid-Canterbury high country, New Zealand. New Zealand Journal of Ecology 43: 3354.
Lettink M, Seddon PJ 2007. Influence of microhabitat factors on capture rates of lizards in a coastal New Zealand environment. Journal of Herpetology 41(2): 187–197.
Ministry for the Environment 2018. Climate change projections for New Zealand: atmosphere projections based on simulations from the IPCC fifth assessment. 2nd ed. Wellington, Ministry for the Environment. 131 p.
Morris RW 1974. Some aspects of the thermophysiology of the skink *Leiolopisma zelandica*. Unpublished PhD thesis, University of Canterbury, Christchurch, New Zealand.
Muller JA, Veech JA, Roach J 2017. Using drift fence arrays to compare terrestrial herpetofauna diversity in three habitats at Tishomingo National Wildlife Refuge, Oklahoma. Southeastern Naturalist 16(2): 182–194.
Neilson K, Curran JM, Towns DR, Jamieson H 2006. Habitat use by chevron skinks (*Oligosoma homalonotum*) (Sauria: Scincidae) on Great Barrier Island, New Zealand. New Zealand Journal of Ecology 30(3): 345–356.
Paoletti A, Darras K, Jayanto H, Grass I, Kusrini M, Tscharntke T 2018. Amphibian and reptile communities of upland and riparian sites across Indonesian oil palm, rubber and forest. Global Ecology and Conservation 16: e00492.
Raxworthy CJ, Nussbaum RA 1994. A rainforest survey of amphibians, reptiles and small mammals at Montagne d'Ambre, Madagascar. Biological Conservation 69(1): 65–73.
Read JL, Kearney MR 2016. Too hot to handle? Balancing increased trapability with capture mortality in hot weather pitfall trapping. Austral Ecology 41(8): 918–926.
Read JL, Moseby KE 2001. Factors affecting pitfall capture rates of small ground vertebrates in arid South Australia. I. The influence of weather and moon phase on capture rates of reptiles. Wildlife Research 28: 53–60.
Read JL, Pedler RD, Kearney MR 2018. Too much hot air? Informing ethical trapping in hot, dry environments. Wildlife Research 45: 16–30.
Ribeiro-Júnior MA, Rossi RV, Miranda CL, Ávila-Pires TC 2011. Influence of pitfall trap size and design on herpetofauna and small mammal studies in a Neotropical Forest. Zoologia (Curitiba) 28: 80–91.
Schofield JA, Fenner AL, Pelgrim K, Bull CM 2012. Male-biased movement in pygmy bluetongue lizards: implications for conservation. Wildlife Research 39(8): 677–684.
Stokeld D, Fisher A, Gentles T, Hill BM, Woinarski JC, Young S, Gillespie GR 2018. Rapid increase of Australian tropical savanna reptile abundance following exclusion of feral cats. Biological Conservation 225: 213–221.
Sunday JM, Bates AE, Kearney MR, Colwell RK, Dulvy NK, Longino JT, Huey RB 2014. Thermal-safety margins and the necessity of thermoregulatory behavior across latitude and elevation. Proceedings of the National Academy of Sciences 111(15): 5610–5615.
Thierry A, Lettink M, Besson AA, Cree A 2009. Thermal properties of artificial refuges and their implications for retreat-site selection in lizards. Applied Herpetology 6(4): 307–326.
Thompson GG, Thompson SA 2009. Comparative temperature in funnel and pit traps. Australian Journal of Zoology 57(5): 311–316.
Tocher MD 1992. Paradoxical preferred body temperatures of two allopatric *Hoplodactylus maculatus* (Reptilia: Gekkonidae) populations from New Zealand. New Zealand Natural Sciences 19: 53–60.
Towns DR, Elliott GP 1996. Effects of habitat structure on distribution and abundance of lizards at Pukerua Bay, Wellington, New Zealand. New Zealand Journal of Ecology 20: 191–206.
Towns DR, Ferreira SM 2001. Conservation of New Zealand lizards (Lacertilia: Scincidae) by translocation of small populations. Biological conservation 98(2): 211–222.
Townsend AJ, de Lange PJ, Duffy CAJ, Miskelley CM, Molloy J, Norton DA 2008. New Zealand threat classification system manual. Wellington, Department of Conservation. 36 p.
Turner MK 2021. Improving the management of Canterbury's lizards. Unpublished MSc thesis. University of Canterbury, Christchurch, New Zealand.
van Winkel D, Baling M, Hitchmough R 2018. Reptiles and amphibians of New Zealand: A field guide. Auckland, Auckland University Press. 366 p.
Virens J, Cree A 2019. Pregnancy reduces critical thermal maximum, but not voluntary thermal maximum, in a viviparous skink. Journal of Comparative Physiology B 189(5): 611–621.
Walker S, Wilson DJ, Norbury G, Monks A, Tanentzap AJ 2014. Effects of secondary shrublands on bird, lizard and invertebrate faunas in a dryland landscape. New Zealand Journal of Ecology 38(2): 242–256.
Waudby HP, Petit S, Gill MJ 2019. The scientific, financial and ethical implications of three common wildlife-trapping designs. Wildlife Research 46(8): 690–700.
Wilson DJ, Mulvey RL, Clarke DA, Reardon JT 2017. Assessing and comparing population densities and indices of skinks under three predator management regimes. New Zealand Journal of Ecology 41: 84–97.
Woolley CK, Knox C, Watson M 2021. Evaluating the risk of predation for lizards constrained in live traps. New Zealand Journal of Zoology 49(2): 166–173.

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