drones

Communication

Testing Drones as a Tool for Surveying Lizards

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Abstract: A lack of effective methods for sampling lizards in terrain that is inaccessible to human observers limits our knowledge of their ecology and conservation needs. Drones are increasingly being used in wildlife monitoring, but their potential use for surveying lizards has not been evaluated. We investigated: (1) the detectability of model lizards using a drone relative to a human observer, and (2) the response of four lizard species to an approaching drone in three habitat types. Model lizards placed in potential basking positions within a defined search area were detected by both the drone operator and human observer, but the probability of detection was lower with the drone. Jewelled geckos (*Naultinus gemmeus*) in shrubland and grand skinks (*Oligosoma grande*) in rocky habitats showed surprisingly little reaction to the approaching drone, enabling close approaches (means of 59 cm and 107 cm, respectively) and accurate species identification with photos taken by the drone camera. For highly patterned jewelled geckos, identification was also possible to individual level. However, the drone was unsuccessful at detecting two alpine skink species in a near-vertical cliff habitat. Collectively, our results suggest that drones have potential as a tool for detecting small-bodied lizards in habitats inaccessible to human observers.

Keywords: alpine; gecko; *Naultinus*; *Oligosoma*; method development; monitoring; skink; unmanned aerial systems

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1. Introduction

In wildlife conservation and monitoring, many habitats are inaccessible to humans due to the nature of the terrain or fragility of the ecosystems [1]. Consequently, species restricted to habitats such as alpine environments, on cliffs, and in tall canopy are poorly understood [2,3]. Due to their relatively inaccessible locations, conservation efforts and monitoring for these populations are extremely difficult [4]. For other species, habitat use and animal behavior make objective sampling and behavioral observations difficult due to access issues for human observers [5]. Developing and testing methods that could be used to survey and monitor populations of threatened, cryptic, or poorly known species is a research priority for conservation. Novel techniques will be required to achieve this in terrain that is inaccessible to human observers or where the approach of humans impacts the behavior and physiology of wildlife, e.g., [6,7].

Lizards inhabit a wide range of habitats, many of which are inaccessible to human observers. A range of standard techniques exist for the inventory and monitoring of lizards, namely: complete inventory, visual encounter surveys, quadrat sampling, permanent plots with mark-recapture, transect surveys, pitfall trapping, sampling with artificial cover, and reptile sign [8,9]. Many of these methods are labor intensive, requiring the implementation of multiple field methods by skilled observers and are only possible where the habitat is relatively accessible to, and safe for, humans. Development of more effective field methods for species that are not sampled well by these standard techniques, such as arboreal species, and for populations persisting at low densities have been identified as key research priorities for lizards [8]. Method development is also identified as a research need for alpine lizards where the lack of access for humans restricts options for surveying and monitoring [10–12]. An extreme example of a species in need of novel method development is the Sinbad skink (*Oligosoma pikitanga*), which is considered Critically Endangered under IUCN Red List criteria [13]. The only known population of this species lives on a sheer rock wall of 200 vertical meters in the alpine zone of Sinbad Gully in Fiordland National Park, Aotearoa New Zealand. Lack of access to this cliff habitat severely limits our knowledge of the species. Information collected to date has been limited to observations on a small accessible ledge at the base of the cliff and by skilled climbers via ropes at very specific locations on the cliff which, together, represent <10% of the potential habitat available to the skinks [14,15]. As such, it has been impossible to estimate the total number of Sinbad skinks, which hampers conservation efforts for the species. Many other New Zealand lizards are similarly restricted to the alpine zone, likely because it provides refuge from some of the suite of invasive mammalian predators that are the primary threat to their persistence [3,12]. This suite of alpine lizards is among the most poorly known of New Zealand's lizard taxa due to the inaccessibility of their habitat [3].

Drones are becoming tools of particular interest for ecological field surveys and wildlife monitoring [7,16–18], including in remote locations and terrain that is inaccessible to human observers [6,19,20]. However, concerns remain about their potential disturbance to wildlife and hence implications for policy concerning the use of drones [19,21]. The use of drones has been explored in various wildlife studies around the world, such as in bird nest monitoring, and to survey marine animal populations, breeding patterns, and behavioral ecology, e.g., [5,6,19,20,22,23]. One study involving nesting seabirds on cliffs demonstrated the ability of drones to access nesting sites without damaging either the area or the bird population [22]. Studies of seabirds and marine mammals have investigated detailed behavioral and physiological responses to the approach of drones at different altitudes with the aim of minimizing the behavioral impacts of population monitoring and informing policy for the monitoring of wildlife using drones [6,19]. In wildlife herpetology, drone use has rarely been investigated, especially in the terrestrial environment. One pest control study in Japan, however, used drone footage alongside deep neural network technology to identify an invasive species of lizard in grasslands [24]. A recent review of scientific literature on using drones to approach wildlife found only 15 studies on reptiles, all of which were on crocodilians and turtles in an aquatic environment [25]. We know of no studies to date that have evaluated the response of lizards to approaching drones. However, Chabot and Bird [18] suggest that drones have potential as a survey tool for lizards in habitats in which ground access by humans is difficult, such as wetlands. Both the utility of drones in lizard surveys and the potential disturbance effects of drones on lizards as absolutely protected wildlife are in need of scientific attention.

Inaccessibility of alpine and cliff ecosystems in Aotearoa New Zealand has limited knowledge acquisition about lizards and their conservation needs in these places [3,8,10,26]. Technological advances in drone technology make the use of drones a potential tool for the detection and survey of lizard populations. Our key objectives were to: (1) evaluate the detectability of model lizards using a drone compared with a human observer, and (2) quantify the responses of lizards to approaching drones in three habitat types: shrubland, rocky tor habitat, and cliffs.

2. Materials and Methods

We used a model DJI FPV drone (Shenzen DJI Sciences and Technologies Ltd., Shenzen, China) throughout the study. This study utilized two methods of data collection: firstly, we evaluated the detectability of physical models of lizards in realistic basking positions on shrubs and on the ground; next, we quantified the responses of live lizards to an approaching drone in their natural habitat. Pixels on photos taken by the drone were 3840×2160 (width $\times$ height). Both horizontal and vertical resolution were 240 dpi. At that resolution, the small model and actual lizards we studied were visible at a distance of ca. 3–5 m from the drone.

2.1. Detectability of Model Lizards

Model data were collected using ten three-dimensional models made from tinfoil, papier-mâché, and acrylic paint and were ca. 150 mm in total length (snout to tail), which is a typical size for lizards in Aotearoa New Zealand [27]. Half of the models were painted green to imitate jewelled geckos (*Naultinus gemmeus*) and the other half were painted brown to imitate skinks (*Oligosoma* spp.; Figure 1). We undertook this part of the study at the Long Beach Recreation Reserve near Dunedin on the South Island of Aotearoa New Zealand.

(**a**) (**b**)

Figure 1. Model lizards and typical habitat used in this study: (**a**) The ten models used to represent jewelled geckos (*Naultinus gemmeus*) and brown skinks (*Oligosoma* spp.) in this study; (**b**) a close-up photo of a model brown skink situated in a typical basking position as part of evaluating detectability by a human observer in comparison to a drone. Note that the variation in patterns on the green gecko models reflects variation in patterning in the natural population.

Each survey was undertaken for a duration of 13.5 min (the battery life of the drone). A field assistant placed the models within a clearly defined area, either on the ground or in surrounding shrubs, in positions that mimicked the natural basking behavior of lizards. Jewelled geckos and most *Oligosoma* skinks are strongly heliothermic and bask avidly whenever conditions allow, especially in southern New Zealand where the environment seldom reaches preferred body temperatures [28–30]. Model lizards were in place for the duration of both the drone and human surveys and the order of methods (drone vs. human observer) was randomized. The drone operator (HW) flew the drone around a pre-defined search area looking for the models in real time through goggles (DJI FPV Goggles V2). The drone operator identified each model lizard found as green or brown in color and on the ground or in a shrub. A scribe recorded these details and the time at which each model was found. A human observer who did not know the location of the models, conducted a visual search of the defined area for the same amount of time as the drone user, and recorded the same data. Visual searching involved a carefully timed search of a suitable habitat looking for emerged lizards without moving potential cover objects [8].

Both the drone operator and human observer were relatively inexperienced in the field of herpetology, but had viewed the model lizards to create a search image prior to commencing the searches. They also had an understanding of lizard basking behavior and how to search habitats for likely lizard basking positions. The drone operator for this part of the study (HW) was also relatively inexperienced in flying a drone, but had undertaken multiple drone flights concentrating on close flying and detecting model lizards prior to starting the consistent data collection reported here.

We analyzed data in the programming language R using the RStudio interface (version 2021.09.2, RStudio Team, PBC, Boston, MA, USA) using the package lme4 [31]. We tested whether the detection of models (found or not found; using a binomial distribution) was influenced by the model color, or by the type of survey (with or without a drone) using a generalized linear mixed-effects model fitted by maximum likelihood (Laplace approximation). The survey number was included as the random effect to account for the variability in how well models were hidden among surveys.

2.2. Approach Distances to Lizards in the Wild

The four species of lizards included in this study were: jewelled geckos, grand skinks (*Oligosoma grande*), Sinbad skinks, and mahogany skinks (*O.* aff. *inconspicuum* "mahogany"). Jewelled geckos are a diurnal, shrub-dwelling species that reach 80 mm snout-vent length (SVL) and are found in the southern South Island [27]. The population we investigated was located on Otago Peninsula, where both adult males and females are bright green in coloration and have distinctive markings that enable accurate identification of individuals from photographs [32]. Grand skinks are relatively large (up to 115 mm SVL) skinks from the Otago region of the South Island strongly associated with schist rock outcrops in tall tussock grasslands [27]. We used a population at Macraes Flat Conservation Area in this research. Sinbad skinks are medium-sized (to 91 mm SVL) diurnal, cliff-dwelling lizards known from only one site, Sinbad Gully, in the north-western part of Fiordland National Park in the Southland region [15,27], as shown in Figure 2. Mahogany skinks also occur on cliffs in Sinbad Gully (our study site) and are small (to 65 mm SVL) diurnal members of the cryptic skink (*O. inconspicuum*) species complex [26,27,33].

(**a**) (**b**)

Figure 2. Critically Endangered Sinbad skinks are only known from a single alpine cliff system where access limits biological knowledge and conservation: (**a**) A Sinbad skink, *Oligosoma pikitanga*, pictured basking on a ledge within (**b**) the cliff system in Sinbad Gully, Fiordland National Park. The photo of the Sinbad skinks' vertical cliff habitat was taken by the drone, the rotor blades of which can be seen in the bottom right corner of the photo.

In evaluating the response of lizards to the drone, we restricted work to fine weather conditions in which lizards were active. Our general approach was to firstly undertake visual surveys to locate lizards from a distance before flying the drone horizontally towards the lizard to see how close it could get before the lizard reacted. We took photos of lizards with the drone to evaluate whether this footage was of sufficient quality to identify lizards at species, or even individual, level based on markings [32,34]. A relatively inexperienced drone operator (HW) piloted the drone for the shrubland and rocky tor lizards and a relatively experienced drone operator and very experienced herpetologist (CK) operated the drone in the cliff habitat.

We were particularly interested in testing the application of the drone survey method on cliff-dwelling species in Sinbad Gully, Fiordland, where access difficulties severely limit visual observation. Therefore, in addition to quantifying the approach distance to cliff-dwelling lizards by the drone as for lizards in shrub and rocky tor habitats, we included additional survey work. We undertook a total of 15 drone flights, which included: (1) developing methodology for flying the drone up the cliff (4 flights), (2) a thorough search of a small part of the cliff accessible to humans where both Sinbad and mahogany skinks occur at a reasonably high density (3 flights), and (3) searching other potential habitats on the cliff, including vertical transects, up the full height of the cliff (200 + m) and concentrating on habitats similar to that at the accessible site (8 flights). For each drone flight, we recorded weather variables (ambient temperature, relative humidity, cloud cover, and mean wind speed), duration of search time of the flight, and number and species of lizards seen. For comparison, human observers undertook a number of visual searches along the accessible ledge at the base of the cliff in fine weather and recorded their search effort and the number and species of lizards seen.

3. Results

3.1. Detectability of Model Lizards

We undertook 13 surveys in which we searched for 10 model lizards independently using a drone and visual observations of a defined search area. Both the drone operator and the human observer were successful at detecting model lizards placed in positions that mimicked natural basking positions (Figure 3). Human observers detected a higher proportion of models (mean 0.73, range 0.2–1) than were found with the drone (mean 0.38, range 0–1) (z = 5.905, $p < 0.001$) (Figure 3). Green models were detected more readily than brown models (mean 0.69 for green models vs. 0.42 for brown models; range 0–1 for both) (z = 4.984, $p < 0.001$) (Figure 3). Mean time to first detection was 0.77 min (range = 0–2 min) by the visual observer and 2.85 min (range = 0–13 min) by the drone operator. A higher proportion of first detections in each survey were of model lizards in a shrub habitat as opposed to on the ground for both methods (69% of first observations were in shrubs for drone surveys compared to 54% for visual observations).

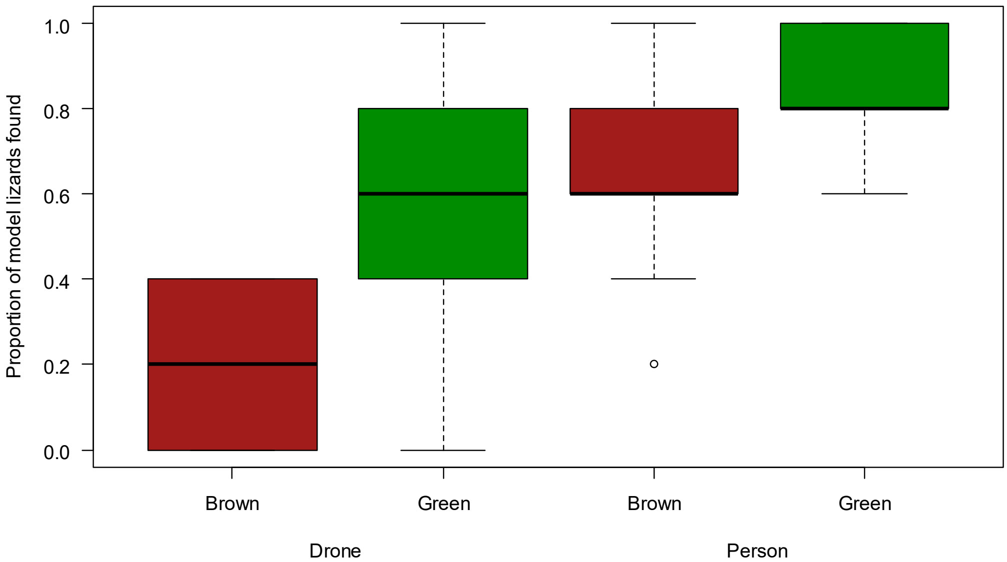

Figure 3. Detectability of model lizards by a drone operator ('Drone') compared to a person undertaking a visual survey ('Person'). Model lizards were painted either brown to mimic brown skinks (*Oligosoma* spp.) or green to mimic jewelled geckos (*Nautlinus gemmeus*). For each group, the median data point is represented by a solid black horizontal line; upper and lower limits to the boxes are the upper quartile and lower quartile respectively. The whiskers (dotted lines) extend to the range of the data, except for the single instance in which the minimum data point is >1.5 times the interquartile range below the lower quartile (this minimum value is indicated by an open circle).

3.2. Approach Distances to Lizards in the Wild

The drone was able to make close approaches to both shrub-dwelling jewelled geckos and saxicolous grand skinks before triggering a behavioral response. In all four approaches towards jewelled geckos, the drone was able to approach within 1 m of the gecko (mean approach distance = 59 cm; Table 1) and the approach distance was limited by the proximity of the drone to the vegetation and potential for a crash rather than the behavioral response of the gecko. Grand skinks were slightly warier, reacting at distances between 60 and

200 cm (mean = 107 cm; Table 1). Most lizards that fled the approaching drone into a nearby retreat were observed basking again soon after the drone had left the area (HW, pers. obs.). For both species, photos from the approaching drone were of sufficient quality to easily identify lizards to species level (Figures 4 and 5). When the drone was able to get a clear view of the dorsum of jewelled geckos, they were able to be individually identified by comparing markings with an existing photo reference library for the site (Figure 4) [32].

Table 1. Distance at which lizards found by visual searchers reacted to the approaching drone by fleeing into a nearby retreat. Species investigated were: jewelled geckos (*Naultinus gemmeus*) on Otago Peninsula, grand skinks (*Oligosoma grande*) at Macraes Flat Conservation Area, and mahogany skinks (*O.* aff. *inconspicuum* "mahogany") at Sinbad Gully, Fiordland National Park. The 'age' category is coded as: A = adult; SA = sub-adult; J = juvenile. An * indicates that this lizard was seen only by the visual searcher and not by the drone operator.

Species	Habitat	Date	Lizard Number	Age	Distance (cm)
Jewelled gecko	Shrub	24 November 2021	1	A	70
		24 November 2021	2	A	90
		5 February 2022	3	A	35
		5 February2022	4	A	40
Grand skink	Schist tor	1 February 2022	1	A	40
		1 February 2022	2	SA	100
		1 February 2022	3	J	200
		1 February 2022	4	J	80
		1 February 2022	5	A	60
		1 February 2022	6	A	130
		1 February 2022	7	SA	100
		1 February 2022	8	SA	150
		1 February 2022	9	SA	110
		1 February 2022	10	A	100
Mahogany skink	Cliff	22 March 2022	1	A	>300 *
		22 March 2022	2	A	>300 *
		22 March 2022	3	A	>300 *

(**a**) (**b**)

Figure 4. Drone photographs showing: (**a**) a jewelled gecko (*Naultinus gemmeus*) at Otago Peninsula within the island of shrub habitat in which it was detected (the gecko is highlighted in a white circle); (**b**) a zoomed-in image of the same gecko showing the distinctive patterning that allowed us to identify it at an individual level.

Figure 5. Drone photograph of a grand skink (*Oligosoma grande*) at Macraes Conservation Area. The skink is highlighted in the pale circle in the center of the photograph.

In contrast, the cliff-dwelling lizards were wary of the approaching drone. All three mahogany skinks that were actively observed by people on the cliff fled the approaching drone before the drone operator was able to detect them at a distance of >3 m (Table 1). We were unable to undertake a drone approach towards a Sinbad skink that was being simultaneously observed by a person positioned on the cliff due to logistical constraints. However, the 15 drone flights we undertook searching for both alpine skink species yielded only a glimpse of a single mahogany skink, which fled from the approaching drone at a distance of ~3 m (Appendix A). In comparison, and for context, 2.5-person hours of visual surveying in fine weather on a small accessible ledge at the base of the cliff yielded nine Sinbad skink sightings and thirteen mahogany skink sightings.

4. Discussion

Overall, our results suggest that drones have potential for lizard surveys in a range of habitats that are relatively inaccessible to visual searchers on foot. Our trial with model lizards demonstrated that both a person undertaking standard visual surveys and a drone operator were able to detect model lizards placed in potential basking positions within a defined search area. However, the probability of detection was lower with the drone, and time to first detection was higher, which signals that the drone does not outperform a human observer undertaking a visual lizard survey in accessible terrain. This knowledge informs our understanding of the probability of detection in the use of drones compared with traditional lizard sampling techniques and will be useful for interpreting results from future lizard surveys using drones. Perhaps most significantly, we found that some skink and gecko species show surprisingly little reaction to drones, which enables close approaches (107 cm and 59 cm for grand skinks and jewelled geckos, respectively) and accurate species identification with photos taken by the camera onboard the drone. Coupled with the observation that lizards that did flee an approaching drone returned to normal basking behavior very soon after the drone departed, our research will likely allay some concerns about the disturbance effect of drones, e.g., [16], at least for some taxa. However, the drone was unsuccessful in detecting diurnal skinks (Sinbad and mahogany skinks) on near-vertical cliff habitats, which signals limitations in the use of drones for lizards surveys because at least some species exhibit an avoidance response to the drone in particular habitats.

The finding that visual surveys resulted in a higher probability of detection for model lizards than drone surveys did in accessible terrain is not surprising. The drone had a more restricted view of the surrounding habitat than the human observer did, which was limited to the width of the lens of the drone camera. While the drone had a fisheye lens, this then made objects appear slightly further away, thereby making it slightly harder to pick up model lizards. Furthermore, obstacles such as hanging branches and long grass limited drone access in some areas of the site, but did not provide an impediment to the visual surveys. Additionally, moderate to strong wind gusts made it more difficult to fly the drone accurately, whereas a human observer was not affected by the wind. However, the benefits of using the drone in surveys included being able to search from above, which allowed a clearer view of models situated on top of shrubs and in taller vegetation and would have enabled the observation of lizards in canopy away from forest margins inaccessible to visual observers. In this respect, our results support the idea that drones have potential for lizard surveys in areas that are not accessible to searchers [18].

Both the drone and human observers were able to get close enough to identify individual jewelled geckos by comparing quality photographs of the geckos' unique dorsal patterns taken during the survey with an identification reference library [32]. As such, data from drone surveys has potential use in population estimation via photo-resight population surveys, at least for some taxa [29]. Drone technology is developing rapidly, which will further improve the utility of this method for lizard survey. For example, recently developed drone models that have the ability to zoom in with the camera may enable detection and identifications of lizards at greater distances, reducing disturbance to lizards and decreasing the probability that lizards will flee before detection via the drone. Furthermore, the use of drones may enable an expansion of the survey area to include areas accessible to a drone but not a human observer, hence helping address a major limitation in the knowledge of lizard populations [8] which currently limits the evaluation of conservation status and management needs of many lizard taxa [26].

In contrast to the results for jewelled geckos in shrubland and grand skinks in a rocky tor habitat, our attempt to use the drone to survey cliff-dwelling Sinbad and mahogany skinks was unsuccessful. An experienced herpetologist and relatively experienced drone operator (CK) operated the drone for this part of the work, so we can rule out lack of experience as the reason for lack of detections of cliff-dwelling lizards when compared with results for lizards in shrubland and rocky tors, which were readily detected by an inexperienced drone operator with limited herpetological experience. We suggest two potential reasons for the lack of detectability of cliff-dwelling lizards: firstly, Sinbad skinks, in particular, are behaviorally cryptic, basking secretively in sub-alpine scrub pockets within the bluff systems and the drone may fail to detect them due to camouflage ([15]; CK and JM, pers. obs.); secondly, living on a vertical cliff means that avian predators such as kea (*Nestor notabilis*) and kārearea (New Zealand falcons; *Falco novaeseelandiae*) are likely to approach horizontally rather than vertically as they would in other habitats, meaning that these cliff-dwelling lizards may be warier of an object, like a drone, which is similar in size to these avian predators, approaching horizontally. Because human observers were relatively successful in approaching and observing both Sinbad and mahogany skinks on the small, accessible part of the cliff (this study), we feel that behavioral crypsis is insufficient to explain the wariness of these species to the approaching drone. Instead, the idea that cliff-dwelling lizards have a heightened awareness of potential predators approaching the cliff horizontally seems the most likely explanation for our lack of success with this method on cliff-dwelling species. The size, color, and noise of the approaching drone may influence the detection of lizards if they perceive it as a potential predator, as has been demonstrated for red-winged blackbirds, *Agelaius phoeniceus* [35]. As drone camera technology improves further, and small animals can be detected via a drone at greater distances, it may be worth revisiting the utility of drones to detect cliff-dwelling lizards and consider factors that may influence a lizard's perception of an approaching drone as a threat in the design.

Unsurprisingly, a human observer outperformed a drone operator in detecting model lizards in places accessible to both methods. However, many lizard habitats are inaccessible to humans, which severely limits our knowledge of lizards in these places. Although our drone trial in the cliff habitat was unsuccessful in detecting cliff-dwelling lizards, the proximity with which a drone was able to approach lizards in shrubland and rocky sub-alpine habitats is encouraging. Collectively, our results suggest the potential for the use of drones in detecting lizards where lizard behavior is amenable in habitats inaccessible to human observers. Habitats worthy of further investigation include tall canopy, wetlands, alpine ridges, and mobile alpine screes. We hope this pilot work paves the way for further investigation of the utility of drones in the detection and survey of lizards inhabiting inaccessible or fragile terrain.

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Institutional Review Board Statement: Both a Wildlife Act Authorization for disturbance to absolutely protected wildlife and a permit to fly a drone above Public Conservation Land were waived by Te Papa Atawhai, the New Zealand Department of Conservation, because the focus of the work was to support the core management needs for threatened lizards in Aotearoa New Zealand. Animals were not handled during the study. Our research was endorsed by the University of Otago's Ngāi Tahu Research Consultation Committee.

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Appendix A

Table A1. Drone flights undertaken at Sinbad Gully, Fiordland National Park in search of Sinbad skinks (*Oligosoma pikitanga*) and mahogany skinks (*O.* aff. *inconspicuum* "mahogany"). T = ambient temperature at 1.4 m above ground in the shade; RH = relative humidity; 'Wind' refers to mean wind speed. An additional four flights were undertaken in warm, sunny weather on 21 March 2022 prior to those recorded in this table, to develop methodology for flying the drone up the cliff. These included two flights at the accessible site and two vertical transects (of 110 m and 200 m) up the cliff. No skinks were detected on these four reconnaissance flights.

Flight	Date	Flight Description	Start Time	Duration (min)	T (°C)	RH (%)	Wind (ms^{-1})	Skinks Seen
1	21 March 2022	Accessible site	16:01	9	18.0	68	0.6	0
2		Long diagonal ledge	17:43	8	21.1	58	0.3	0
3		200 m vertical transect	18:00	11	16.0	68	0	0
4	22 March 2022	Long diagonal ledge	08:54	9	12.3	73	0.6	0
5		Lower cliff, near accessible site	09:57	11	17.9	59	0.3	0
6		Accessible site	10:14	11	18.2	58	0.3	0
7		Accessible site	12:05	11	22.5	56	0.6	0
8		Lower cliff, near accessible site	13:37	12	16.5	50	0.9	1 [1]
9		Upper cliff	15:02	10	22.0	55	0.8	0
10		200 m vertical transect	16:39	11	19.5	60	0.5	0
11		Lower cliff, near accessible site	17:00	9	19.0	62	0.4	0

[1] The skink seen on drone flight 8 was a mahogany skink.

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