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A NOVEL TECHNIQUE FOR MONITORING HIGHLY CRYPTIC LIZARD SPECIES IN FORESTS

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***Abstract.*—There are few effective or efficient methods for monitoring arboreal forest lizards, especially in areas with low lizard densities. This is problematic for their conservation and research. I developed a novel technique for capturing lizards using closed-cell foam covers as artificial retreats placed on tree trunks. I tested the method at three sites in New Zealand by comparing lizard occupancy rates with the outcomes from conventional methods (lizard houses, g-minnow traps, pitfall traps, Onduline artificial retreats, and spotlighting). At the site where Duvaucel's Geckos (*Hoplodactylus duvaucelii*) were abundant, most methods detected their presence, but the foam cover technique detected geckos much more effectively (39 geckos per 100 observations). Also, I was able to sample juvenile lizards better using foam covers than any other technique, and both sexes used foam covers equally. On a per unit effort basis, night spotlighting resulted in 0.6–1.6 geckos per hour, whereas covers returned 3.1 geckos per hour. At the other two sites where either Pacific Geckos (*H. pacificus*) or Forest Geckos (*H. granulatus*) were at low densities, only foam covers detected them. Lizard houses typically caught either zero to one gecko per 100 observations; whereas, at these sites, foam covers returned four geckos per 100 observations, despite low gecko abundance. This is a significant improvement in detection. Foam covers offer improved population sampling of arboreal forest lizards, improved efficiency, and lower costs compared to other sampling techniques. They may also reduce some potential biases experienced when using other sampling techniques. This study suggests that foam covers are an effective method for inventorying and monitoring arboreal lizard communities.**

Key Words.—Duvaucel's Gecko; Forest Gecko; *Hoplodactylus duvaucelii*; *Hoplodactylus granulatus*; *Hoplodactylus pacificus*; Pacific Gecko; sampling, technique

INTRODUCTION

Inventory and monitoring of forest lizards, especially cryptic aboreal species like small nocturnal geckos, are currently among the most difficult tasks in herpetological conservation, management, and research. Successful conservation relies on robust sampling and monitoring (Dodd and Seigel 1991; Grant et al. 1992; Francke 2005; Lettink and Seddon 2007). Conventional methods for surveying and monitoring lizards include lizard houses/boxes (Francke 2005), pitfall traps (e.g., Towns 1991; Newman 1994), g-minnow traps (Bell and Patterson 2008; Halema Jamieson, pers. comm.), Onduline artificial cover objects (ACOs; Lettink and Cree 2007), tracking tunnels (Siyam 2006), direct searching during the day or night (Whitaker 1994), and occupancy estimates (Roughton 2005). Investigators commonly compare capture rates and catch-per-unit efforts across sites to reflect relative animal densities (Lettink and Seddon 2007). At present, these methods are largely ineffective or uneconomical for use in structurally complex forests, and may carry important biases. This is because of: (1) the complex three-dimensional structure, and difficult access, of forests; (2) the nocturnal and/or arboreal nature of some lizard species, combined with the limited activity cycles of these lizards; (3) the potentially sparse or spatially clumped distribution of forest lizards; (4) a much-reduced species richness and abundance as a result of invasive predator effects, especially in New Zealand; and (5) the cryptic nature of lizards in forest ecosystems due to their small size and camouflage in the environment.

The poor ability of conventional techniques to monitor lizard populations in forest ecosystems means there is little understanding of lizard population density and dynamics. In New Zealand, baseline population monitoring of forest lizards that exist in conservation areas and at sites undergoing ecological restoration is a high priority (Hitchmough 2002; Towns et al. 2002). Reintroductions of many lizard species into protected areas is another priority in New Zealand, but this will also require effective post-translocation monitoring techniques.

One of the key attributes of an effective sampling device is an increased ability to detect rare or cryptic species (Sutton et al. 1999; Hoyer and Stewart 2000; Wakelin et al. 2003; Lettink and Patrick 2006). Here, I tested a novel method using covers constructed from closed-cell foam (hereafter denoted as foam covers; Fig. 1; Rubbermark Industries, Manukau City, Aukland, NZ) as a potential new device on which to build monitoring protocols for forest lizards. Forest lizards use bark and hollows on trees as refuges (Department of Conservation BioWeb Herpetofauna database, http://dataversity.org.nz/guide/systems/bh/ accessed June 2008). The use of foam covers placed on tree trunks and branches may mimic these microhabitats.

Development of novel sampling techniques aims to improve on contemporary methods. Such improvemed methology may be more robust, reduce bias, cost, efficiency, and yet sufficiently sample populations at any time (Francke 2005; Lettink and Cree 2007). Refuge attributes that are likely to attract lizards include being of sufficient size to remain dry, having narrow openings, a rapidly heating surface, and are positioned in warm locations (Schlesinger and Shine 1994; Rock et al. 2000; Webb and Shine 2000; Shah et al. 2004). I conducted a search for materials that could also meet the following additional criteria: (1) fit the contours of tree structures, regardless of tree size; (2) effectively insulate against environmental elements; (3) economical to purchase in bulk; (4) light in weight; (5) easy to deploy; and (6) resistant to decay. Closed-cell foam met all of these criteria.

The objectives of this pilot trial were to determine the acceptability of covers to lizards by analyzing occupancy rates, and demonstrate wide acceptability for different species of forest lizards. I used a range of conventional sampling techniques during this study to compare their respective ability to detect different species and provide abundance information. However, this is not a population study of the animals involved; it is a test of new methodology.

It is important to demonstrate that any novel method is at least as effective as existing sampling methods (Pearman et al. 1995; Hyde and Simons 2001; Wakelin et al. 2003; Lettink 2007) and that the sample obtained from the new technique is useful (Kjoss and Litvaitis 2001; Marsh and Goicochea 2003). In this study, foam covers would be considered the superior sampling technique if the occupation rate by arboreal forest lizards was higher than for other methods.

MATERIALS AND METHODS

Site selection.—The study sites included one with high lizard abundance and two sites of unknown lizard abundances. Inclusion of one site known to have a high abundance of lizards was to ensure that occupancy reflected preference for the covers by lizards. This was essential in determining whether poor occupancy at the other sites was not simply an artifact of low population abundances at these sites. The latter two sites are mainland sites undergoing ecological restoration, where I expected the lizard abundances to be low. However, detection of several geckos under covers would indicate that the method

FIGURE 1. Examples of closed-cell foam covers used to monitor arboreal lizards. Left = 360-degree wrap, Fanal Island, New Zealand; Right = 1 m × 0.4 m vertical cover, Windy Hill Pest Management Area, Great Barrier Island, New Zealand. (Photographed by Trent Bell).

was capable of detecting highly cryptic forest lizard populations at low densities within a complex habitat.

Site A was Fanal Island (Motukino) in the Mokohinau (Pokohinu) Island Group. This island is the largest (73 ha) offshore island in the Mokohinau Islands Nature Reserve (35°0' S, 175°10' E) and is a wildlife sanctuary now free of invasive mammalian predators following the eradication of Black Rats (*Rattus rattus*) in 1997 (Veitch 2002). The forested areas of Fanal Island consist of coastal broadleaved forest (Wright 1980). There are no active lizard monitoring programs on the island, apart from occasional pitfall trapping for large terrestrial Skink species (Halema Jamieson, pers. comm.). Duvaucel's Gecko (*Hoplodactylus duvaucelii*; Fig. 2) is an abundant forest lizard species on the island (Halema Jamieson, pers. comm.).

Site B was the Windy Hill Pest Management Project on Great Barrier Island (36°10′ S, 175°23′ E). This is a large (270 ha) ecosystem restoration project where intensive mammal control has occurred since 1999, with occasional, but suppressed irruptions of nonnative rodent populations in autumn (Judy Gilbert, pers. comm.). Windy Hill consists of mature coastal broadleaved–podocarp forest. Lizard monitoring started recently using Onduline ACOs (Judy Gilbert, pers. comm.) and g-minnow traps (Ben Barr, pers. comm.) for forest skinks (Ornate Skinks, *Oligosoma ornatum*; Copper Skinks, *O. aeneum*; and Chevron Skinks, *O. homalonotum*). There have been recent sightings of Pacific Geckos (*H. pacificus*) and Common Geckos (*H. maculatus*; Judy Gilbert and Kevin Parsons, pers. comm.).

Site C was Zealandia (formerly the Karori Wildlife Sanctuary) in Wellington. Zealandia (41°17' S, 174°45' E) is a large (230 ha) ecosystem restoration project and is fenced to keep out invasive mammals. The forest at Zealandia consists of mixed regenerating native and exotic species, following fire and agriculture in the past (Moles and Drake 1999). Intensive control and removal of all introduced mammalian predators has occurred since 1992 within the pest-proof fence (Day and MacGibbon 2007; Clapperton and Day 2001; Saunders and Norton 2001) surrounding the sanctuary. Mice (*Mus musculus*) now remain the only species of invasive mammal species within the sanctuary (Raewyn Empson, pers. comm.). The project conducts active lizard monitoring programs using lizard houses and pitfall traps. Forest lizard species known within Zealandia include Copper Skinks, Ornate Skinks, Common Skinks, (*O. nigriplantare polychroma*), and Brown Skinks, (*O. zelandicum*). Forest Geckos (*Hoplodactylus granulatus*) and Wellington Green Geckos (*Naultinus elegans punctatus*) appear in surveys and through casual observations in the area (Raewyn Empson, pers. comm.).

FIGURE 2. Duvaucel's Gecko *Hoplodactylus duvaucelii*, from Fanal Island, New Zealand. This adult female was one of 31 geckos captured during one check of 80 covers during April 2008. (Photographed by Trent Bell).

Experimental design.—With the assistance of field members, I nailed foam covers (Rubbermark Industries, Manukau City, Auckland, NZ) of two sizes and alignments (1 × 0.4 m × 3-4 mm placed flat on tree trunk surface, and 0.5 × 0.4 m × 3-4 mm wrapped around a tree trunk), to 20–40 medium to large trees (basal diameter at least 0.5 m) along transects or grids at each site (Fig. 1). On another experimental grid (Tui Glen) in Zealandia, I used small (0.7 × 0.2 m x 3-4 mm) covers in forest of mature Kanuka (*Kunzea ericoides*) and young Mahoe (*Melicytus ramiflorus*). I chose several predominant canopy tree species; forest canopies varied in height from 6 to 40 m. I placed the covers on lower trunks accessible from the ground and in such a way as to allow gaps of 1.5–6 mm between the contour of tree trunks and the cover. From a time–effort perspective, it took a full day (7 h) to place around 80 covers, depending on terrain and access inside a forest.

On Fanal Island, I placed 80 covers along two transects (40 on each) in coastal broadleaved forest during October 2007. In Zealandia, I placed 230 covers in three locations: along one transect (mature Fuchsia [*Fuchsia excorticata*]–Mahoe forest; $n = 40$) and two forested grids of Mahoe–Fivefinger (*Pseudopanax* sp.) forest and mature Kanuka–young Mahoe forest; $n = 60$ and $n = 130$). On Windy Hill, I placed 200 covers on five transects (40 on each) in old-growth coastal broadleaved–podocarp forest. I placed the covers in Zealandia and Windy Hill in March–April 2007.

I labeled each cover by transect letter and cover number (e.g., from A1, A2, A3 to A40) using a white Sharpie™ paint pen (Sanford L.P., Sandford, Manitoba, Canada). I recorded cover size and cover alignment (horizontal or vertical), the distance from one cover to the next (mean distance = 8.5 m; range = 1–22.4 m). The mean transect length was 340 m. I identified tree species and visually estimated the total tree height (to the nearest vertical meter up to the first 10 m; thereafter, to the nearest 5 m).

I checked all covers in March–April 2008 during daylight hours (0800–1800), by peeling the cover back off the trunk through nail-holes and pushing the cover back into place afterwards. I identified and photographed any lizards captured, and took the following measurements (to the nearest 1 mm): snout-

TABLE 1.—Lizards "captured" by closed-cell foam covers, trapping, and spotlighting at three New Zealand study sites in March–April 2008.

Site	Lizard species	Method	Units[1]	Rate
Fanal Island	Duvaucel's Gecko, *Hoplodactylus duvaucelii*	CCF covers	80	0.387 (*n* = 31) occupancy rate plus 4 sign (skin, scats)
		G-minnow traps	18 over 20 trap nights	0.25 catch rate (*n* = 5)
		Pitfall traps	9 over 33 trap nights	Zero gecko captures (14 skinks : 10 *O. moco*; 4 *O. aeneum*)
		Transect spotlighting	7.5	0.6 geckos CPUE[2] (*n* = 5)
		Opportunistic spotlighting	8	1.6 geckos CPUE (*n* = 13)
Windy Hill	Pacific Gecko, *H. pacificus*	CCF covers	200 (196)[3]	0.04 (*n* = 8) occupancy rate plus 1 sign (skin)
		G-minnow traps	20;	60 trap nights; zero gecko catch rate (2 skinks: *O. ornatum*)
		Onduline ACOs	10[4]	20 checks, zero gecko occupancy rate (9 skinks: *O. ornatum*)
		Spotlighting	7.5	Zero gecko CPUE
Zealandia	Forest Gecko, *H. granulatus*	CCF covers	96	0.041 (*n* = 4) occupancy rate plus 3 sign (skins)
		Tui Glen CCF covers	130[5]	Zero gecko occupancy rate
		Lizard houses	103 (84)[6]	Zero gecko occupancy rate
		Spotlighting	6.5	Zero gecko CPUE
		Pitfall traps	81[7]	81 trap days; 0 geckos captured (48 skinks: 1 *O. aeneum*, 8 *O. ornatum*, 39 *O. n. polychroma*, 1 *O. zelandicum*)

[1]Unit: CCF = number of covers; g-minnow traps and pitfall traps = number of traps; spotlighting = person hours
[2]CPUE = catch per unit effort
[3](196) = no. functioning units at time of check
[4]Data from Judy Gilbert, pers. comm.
[5]Tui Glen grid was stratified in this analysis due to habitat and cover differences (mature kanuka – young mahoe forest) and smaller covers (0.7 × 0.2 m)
[6](84) = no. functional houses at time of check
[7] Data from R. Empson and R. Romijn, pers. comm.. 2008.

vent length (SVL), tail length (TL), length of regenerating portion of tail, if any (r), and tail base width (TW). I weighed the lizards to the nearest 0.25 g using a 30-g or 100-g Pesola™ (Pesola AG, Baar, Switzerland) spring scales, determined sex, and then immediately released the lizards back under the cover. I recorded lizard sign (skin and scats) under vacant covers as evidence of occupancy.

I also identified and counted any macro-invertebrates occupying the covers; and in the case of weta and spiders, classified them by length into size classes (large, ≥ 10 mm; or medium, 5–9 mm). Due to time constraints, I did not count the smaller invertebrates.

I then compared the outcomes from the covers with the results of several other lizard monitoring techniques in use at the same time. These techniques included lizard houses, g-minnow traps, pitfall traps, Onduline ACOs, and spotlighting. I could not compare all methods in the same area due to cost, logistics and opportunity, nor standardize trapping effort due to time-limitations and logistics. I baited pitfall trap stations (Fanal Island and Zealandia) and g-minnow traps (Fanal Island and Windy Hill) with pears or a honey–banana combination and checked traps daily. I checked lizard houses (Zealandia) and Onduline ACOs (Windy Hill) once. Spotlighting by transect occurred at all three sites from 2000 to 0200 hours during calm nights, mostly using two Pelican™ Recoil 2410 torches (aka flashlights) where possible. However, torch equipment varied for some observers. I condensed the results of all techniques into occupancy/capture ratios or catch per unit effort. I also considered the results on a time–effort basis.

Statistical analyses.—Because the large sample sizes provided some statistical power, I conducted statistical analyses for the abundant Duvaucel's Gecko population. I analyzed the proportion of adults to immature geckos, size distributions, and sex ratios across different sampling techniques, and also which cover design (360-degree wrap or 1 × 0.4 m vertical covers) was the most readily accepted by geckos. The association between different tree species and occupancies was explored. An index of dispersion assessed the possible presence of aggregation

Table 2.—Number and proportion (in brackets) of invertebrate species found under covers at three New Zealand study sites in March–April 2008.

	Fanal Island n = 80 covers	Windy Hill n = 196 covers	Zealandia n = 96 covers
Cockroach, *Ceratoblatta* spp.	c. 489 (6.11)	70 (0.35)	8 (0.08)
Auckland Tree Weta, *Hemideina thoracica*		8 (0.04)	
Wellington Tree Weta, *H. crassidens*			161 (1.68)
Large Cave Weta, *Gymnoplectron* spp.		49 (0.25)	6 (0.06)
Small Cave Weta, *Isoplectron* spp.	27 (0.33)	48 (0.24)	9 (0.09)
Giant Centipede, *Cormocephalus rubriceps*		7 (0.04)	
Banded Tunnelweb Spider, *Hexathele hochstetteri*		20 (0.10)	
Black Tunnelweb Spider, *Porrhothele antipodiana*		4 (0.02)	3 (0.03)
Sheetweb Spider, *Cambridgea* spp.		7 (0.04)	3 (0.03)
Large spider, various species	1 (0.01)	34 (0.17)	18 (0.19)
Medium spider, various species	4 (0.05)	14 (0.07)	16 (0.17)
Native Slug, *Pseudaneitea papillatus*			206 (2.15)
Peripatus, *Peripatoides novaezealandiae*			9 (0.09)
Carabid beetles, Family Carabidae	1 (0.01)	2 (0.01)	18 (0.19)
Slaters, Class Isopoda	3 (0.04)	15 (0.08)	
Flatworm, Phylum Platyhelminthes		2 (0.01)	8 (0.08)
Millipedes, Class Diplopoda	9 (0.11)	33 (0.17)	2 (0.02)
Earthworm. Class Oligochaeta		8 (0.04)	3 (0.03)

behavior. I classified Duvaucel's Geckos into two life stages (adults and non-adults) across sampling techniques and conducted a chi-square test analysis with Fisher's exact test.

Results

Fanal Island.—I found 31 Duvaucel's Gecko under 80 covers during one check in March–April 2008 (Table 1). I found gecko sign (skin, scats) under a further four covers. Ten geckos were mature adults, and 21 were immature, with a ratio of male–female–juvenile–neonate of 4:6:15:6. The mean SVL of geckos under covers was 99 mm (range 56–149 mm), and mean mass was 30.75 g (range 5.5–96.5 g). I recorded more than one gecko under a cover in six instances (range 2–4 individual geckos, total number of geckos sharing covers n = 17).

I recorded five Duvaucel's Gecko in concurrent g-minnow trapping of 20 trap nights. Spotlighting during a standard transect search of 7.5 person hours encountered five geckos. Opportunistic searches at night consisting of five person-hours encountered a further 13 geckos. Geckos in g-minnow traps were all mature adults (one male, four females). Geckos captured in transect spotlighting were also all mature adults (n = 5 cf. no immature geckos), and in opportunistic spotlighting, there were 11 mature and two non-mature geckos. The ratio of male–female–juvenile–neonate was 1:4:0:0 and 6:5:2:0, for transect and opportunistic spotlighting, respectively. The mean SVL of geckos captured in g-minnows was 107.2 mm (range 87–117 mm); and for transect and opportunistic spotlighting was 126.5 mm SVL (range 106–142 mm) and 115.6 mm SVL (range 79–133 mm), respectively. The mean mass of geckos was 36.7 g (range 12.5–49 g) for g-minnow traps, 60.75 g (range 30–89 g) for transect, and 50.8 g (range 13–71 g) for opportunistic spotlighting. Concurrent pitfall trapping captured no geckos, but 10 Moko Skinks (*Oligosoma moco*) and four Copper Skinks were captured. Cockroaches (*Ceratoblatta* spp.) were by far the most abundant invertebrate species occupying covers on Fanal Island, along with the occasional Small Cave Weta (*Isoplectron* spp.) (Table 2). There was a notable absence of large-sized weta or spiders under covers.

Windy Hill.—I recorded eight Pacific Geckos from 196 covers (seven live animals and one skin; Table 1). Seven of the geckos were adult, one was a juvenile, and the sex ratio was 3:3:1 with one of unknown sex. Measurement data are not given because four evaded capture; therefore, the data are unlikely to be representative.

Spotlighting for 7.5 person hours resulted in no geckos being sighted. Sixty g-minnow trap days also resulted in no geckos, but captured two Ornate Skinks. Ten Onduline ACOs during November and May resulted in capture of nine Ornate Skinks (Judy Gilbert, pers. comm.).

The invertebrate fauna using covers on Windy Hill was diverse; we found Auckland Tree Weta (*Hemideina thoracica*), Large Cave Weta (*Gymnoplectron* spp.), Small Cave Weta (*Isoplectron* spp.), Giant Centipedes (*Cormocephalis rubriceps*), two species of Tunnel-web Spiders (*Hexathele hochstetteri* and *Porrhothele antipodiana*) and various large and medium-sized spider species (Table 2).

Zealandia.—We recorded seven Forest Geckos from 96 covers (four live animals and three skins) plus one Common Skink (Table 1). None of the 130 small covers in the Tui Glen grid had lizards. Of the four live animals, two were males and two females, all adult. The mean SVL was 79.5 mm (range 74–89 mm) and the mean weight was 14.37 g (range 10–19.5 g).

Night spotlighting of 6.5 person hours revealed no

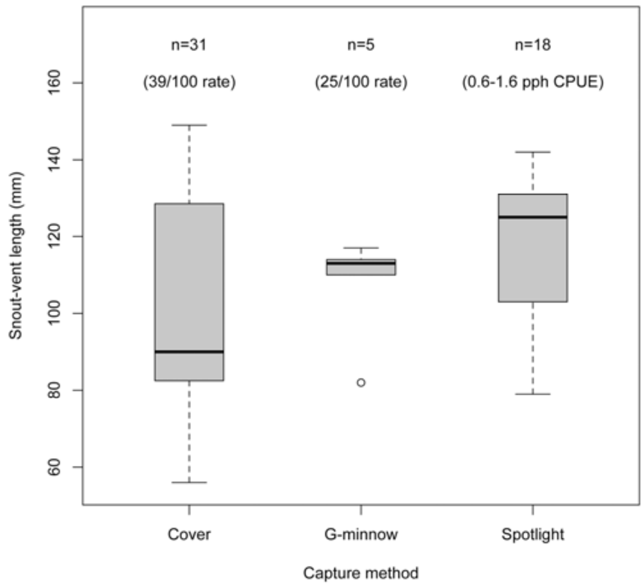

FIGURE 3. Size of Duvaucel's Geckos by capture method. Foam covers captured the widest size ranges of geckos of the three methods used, and detected significantly more non-adult geckos within the population. Box plots show the median, inter-quartile range, and range of the data.

geckos, but this was inconclusive due to marginal temperatures for lizard activity at the time. Eighty-four lizard houses revealed no geckos. Eighty-one days of pitfall trapping during January 2007 resulted in 49 skinks (one Copper Skink, eight Ornate skinks, 39 Common Skinks, and one Brown Skink; Raewyn Empson and Richard Romijn, pers. comm.). Wellington Tree Weta (*H. crassidens*) and large Native Slugs (*Pseudaneitea papillatus*) were the most abundant invertebrate species occupying covers in Zealandia (Table 2). Various large and medium spider species were common. I also recorded Peripatus (*Peripatoides novaezealandiae*).

Occupancy rate.—On Fanal Island, Duvaucel's Gecko occupied closed-cell foam covers at a rate of 0.387 in an area of high gecko abundance. Pacific Geckos had low occupancy rates in Windy Hill (0.04), and Zealandia Wildlife Sanctuary (0.041). Further occupancy by geckos was evident in the form of skin and scats. The Tui Glen grid returned no lizards at all.

Statistical analyses.—There was a significant difference between the sampling technique and life stage of Duvaucel's Geckos detected by the various methods ($P < 0.001$; Table 3). Sex ratios were not significantly different for adult geckos for the sampling techniques used. Size distribution of geckos also differed by sampling technique (Fig. 3). Covers sampled a wider range of geckos, from the smallest individuals to the largest adults.

Covers detected more Duvaucel's Geckos (3.1 per person hour [pph]; $n = 31$) in a shorter time frame (10 person hours) compared with regulated transect spotlighting (0.6 pph; $n = 5$) and opportunistic spotlighting (1.6 pph; $n = 13$). Covers were therefore more efficient than spotlighting in sampling geckos.

There was no preference by geckos for the 360-degree wrap-around or the 1 × 0.40 m vertical covers ($\chi^2_1 = 0.27$, $P = 0.61$). There also was no significant difference for occupancy associated with particular tree species ($P = 0.15$); however, due to the small initial sample per tree species, the power of this test is weak. Fivefinger (*Pseudopanax arboreus*), Puriri (*Vitex lucens*), and Coastal Maire (*Nestegis apetala*) were the tree species most frequently occupied by lizards (0.63, 0.45 and 0.33, respectively).

Geckos were highly aggregated under the covers as the variance/mean ratio (1.79) was significantly greater than 1 ($\chi^2_{79} = 141.9$, $P < 0.001$; using the method of Elliott 1983). Fourteen geckos were solitary and 17 shared covers. Of those covers with more than one animal, three covers had two, one had three, and two had four geckos. Sixty covers had no geckos.

DISCUSSION

A new sampling technique needs to be more effective than conventional sampling methods if it is to be adopted (Pearman et al. 1995; Lettink 2007). Proving that covers are an improved technique over other methods is problematical, however, given the inability to test statistical significance due to very low occupancy rates in some methods (Francke 2005). For example, occupation rates demonstrated in conventional monitoring using lizard houses at several sites on the New Zealand mainland have not exceeded

TABLE 3.—Duvaucel's Geckos (*Hoplodactylus duvaucelii*) sampled by different methods on Fanal Island, New Zealand, in March and April 2007.

	Sampling method			
	Foam Covers	G-minnow	Spotlight	Opportunistic spotlight
Adults (*n*)	10	5	5	11
Non-adults (*n*)	21	0	0	2
Proportion adults	0.32	1.00	1.00	0.85

0.01 (i.e., only 1% of houses, or less, are occupied by lizards), due to the long-term effects of invasive mammalian predators (e.g., Whitaker 1973, 1978; Towns 1991; Francke 2005). Low occupation rates are typical even in some areas where invasive predators have been controlled for as long as 10 years (Department of Conservation. 2000. Boundary Stream Mainland Island 1996–1998 project report. DOC East Coast/Hawke's Bay Conservancy, Gisborne, New Zealand; Edward Waite, pers. comm.; Karori Wildlife Sanctuary, Raewyn Empson, pers. comm.; and Eglinton Valley, Marieke Lettink, pers. comm.).

I found covers were the most effective technique for sampling geckos where they are abundant (Duvaucel's Geckos on Fanal Island). Although the results for covers at both Windy Hill and Zealandia were apparently poor, these results were still encouraging in that covers, unlike other methods, detected at least several individual geckos even when populations were at very low densities in complex forests. This suggests the foam covers are more effective than conventional techniques in detecting sparsely populated arboreal gecko species in complex forests, and therefore the results may be biologically significant for index monitoring.

Given the greater abundance of non-adult Duvaucel's Geckos under covers, this method appears to be more capable of obtaining representative samples of arboreal forest lizard populations than other techniques. This is important for any sampling technique (Kjoss and Litvaitis 2001; Marsh and Goicochea 2003). G-minnow trapping and spotlighting on Fanal Island sampled only adult geckos, and pitfall trapping captured only terrestrial skinks. Lizard houses were unfortunately not available on Fanal Island, so it was not possible to look at age or sex structure of lizards that might have occupied these structures. However, Francke (2005) indicates that within remnant forests on Mana Island, 23 adult and seven non-adult Common Geckos were present in 22 houses (which is statistically significant, $\chi^2_1 = 8.533$, $P < 0.005$ using Yates' correction); with a sex ratio of 11:12:4:3, indicating a bias towards adult geckos.

Statistically speaking, Duvaucel's Geckos were highly aggregated under covers. However, these geckos did not appear to physically contact each other (individuals were spaced at least 10 cm apart) and all combinations were seen. We considered geckos found sharing covers to be behaviorally non-aggregated individuals and considered that occupation was base on individual preference for covers, not 'attraction' towards one another. This may be a phenomenon atypical of Duvaucel's Gecko as an outcome of resource supplementation. Clumping may occur in natural refuges due to resource limitations, although this is not always the case (e.g., Common Geckos on Mana Island; Hare and Hoare 2005).

The low occupation rates found at the two sanctuaries, Windy Hill and Zealandia, may be due to longer-lasting effects of invasive mammalian predation on forest lizard populations, even after several years of predator control. The life history of New Zealand lizard species generally makes them slowly responsive to conservation management (Cree 1994; Lettink and Cree 2007). For example, Pacific Geckos and Forest Geckos have a low annual reproductive output (usually 1–2 young per year; Towns 1991), are slow to mature (estimated 3–4 years; Towns 1991), have a long lifespan (approximated from data from a similarly sized analogous species, the Common Gecko, a mean minimum longevity of 12.7 years; range 7–17 years; Anastasiadis and Whitaker 1987; Green 2001), and show a slow annual population rate of increase ($r = 2.6$–9%) after the removal of introduced predators (Towns and Parrish 1999; Towns 2002).

The low density of Pacific Geckos at Windy Hill contrasts strongly with highly abundant Pacific Geckos on offshore islands free of rats (*Rattus exulans*; 6.70 geckos per person hour on three islands; $n = 43$, 0–8.3 range; Whitaker 1973, 1978). Geckos were conversely rare and "severely reduced" on islands with Kiore (none on five islands; Whitaker 1973). On Kiore-free Green Island, 25 Pacific Geckos per hour were counted at night, but on Red Mercury and Korapuki islands, where Kiore were present, none were found in four hours of searching (Whitaker, A.H. 1970. Report on a visit to the Mercury Islands, 18–30 June 1970. Unpublished DSIR Ecology Division file report. Landcare Research Library, Lincoln, New Zealand. 3 p.). Lizards within forests were particularly affected (Whitaker 1973, 1978). Given that Black Rats are a more capable predator than Kiore (King 2005), it is possible that Black Rats on Great Barrier Island may have affected the Pacific Gecko particularly severely due to limited super-predator mitigating effects on rodent populations (the only super-predator present on Great Barrier Island are feral Domestic Cats, *Felis catus*). Interestingly, on Windy Hill, we found all seven Pacific Geckos on three transects (120 covers) in an area where mammal control had been ongoing since 1999. There was only one sign (skin) in an adjacent area (76 covers) where mammal trapping was first initiated in 2001.

The low lizard numbers we observed in covers at Zealandia may also be due to torrential rainfall, which lasted for two days prior to this work. Rainfall might have driven out some lizards from the covers due to water flow down trunks. The occupation rates we obtained during April 2007 for Zealandia may have been a temporary under-representation of potential rates. This is supported by the evidence of three instances of lizard sign in vacant covers.

Three species of lizard readily occupied covers across all sites in this study, indicating the covers may be suitable for monitoring a range of species. It is likely that further cover trials at other sites and on other offshore islands will show greater species diversity under covers. Indeed, additional species were found underneath the covers during subsequent trials at new sites in April 2009 (T. Bell, unpubl. data). High numbers (61 from one check of 78 covers) of Common Geckos used the covers on Mana Island. One Striped Skink (*Oligosoma striatum*) was found under a cover at Windy Hill. Two Common Skinks were recorded under covers at Zealandia by April 2009. Common Skinks are typically diurnal, terrestrial species of open grasslands, and I consider these finds interesting aberrations. The presence of these skinks, however, suggests some potential for using covers with arboreal skinks.

Pitfall trapping and Onduline artificial covers were biased towards terrestrial skinks in forests (e.g., as in Towns 1991; Newman 1994). G-minnow traps captured more arboreal forest lizards compared with the two above methods, but these traps are expensive (Halema Jamieson and Ben Barr, pers. comm.).

Artificial refuges, such as lizard houses and covers, are likely to offer advantages in reducing potential observer and environmental biases, compared to methods that use detection that is influenced by optimal foraging conditions, such as during spotlighting (Francke 2005). There is much support in the literature for the use of artificial refuges for sampling populations (e.g., Kjoss and Litvaitis 2001; Wakelin et al. 2003; Francke 2005; Lettink and Cree 2007) because of improved detection, low time and cost commitments, ease of standardization, reduced observer bias, reduced habitat disturbance, and lower animal mortality. These were true of the foam covers tested here.

Spotlighting is subject to three major biases: operator skill, habitat (Towns 1991), and environmental conditions at the time of sampling, all of which vary widely. Spotlighting is also likely to suffer from effects on animal behavior in the form of avoidance responses to light and noise disturbance. Animals encountered are not always caught (Towns 1991); therefore, they cannot always be identified accurately or individual data collected. Detection probability is likely to decrease vertically under taller forest canopies (Francke 2005). Night spotlighting is not recommended as a sampling technique by non-specialists, not only for the above reasons, but also for safety reasons in forests (Francke 2005). Our spotlighting did detect 18 Duvaucel's Gecko on Fanal Island; although, we could not find any Pacific Geckos on Windy Hill during ideal forest lizard foraging conditions. Conditions in Zealandia were suboptimal for gecko foraging; however, surveys by Tony Whitaker and Bruce Thomas in 2003 and 2004 found 23 Forest Geckos in a total of seven nights, although catch-per-unit effort data were not available (Raewyn Empson, pers. comm.).

Lizard houses appear to be a poor indicator of lizard abundances in forests on the mainland, with no or comparatively few animals captured at several sites where invasive mammals have been controlled for several years (Boundary Stream Mainland Island, Edward Waite, pers. comm.; Zealandia Wildlife Sanctuary, Raewyn Empson pers. comm.; and Eglinton Valley, Marieke Lettink, pers. comm.). Although Francke (2005) counted 30 Common Geckos from 22 houses (a rate of 1.36) in remnant forest on Mana Island where these geckos reach extremely high densities, and five geckos from 22 houses (rate of 0.22) on Stephens Island in similar habitat, our use of the same design failed to record any lizards within Zealandia during this study. Only one Forest Gecko has been found in a house in Zealandia since 2006 (one in 290 checks over three years from 2006 to 2008; rate = 0.003; Raewyn Empson, pers. comm.). Similarly, no geckos have been detected in houses in the Eglinton Valley in 360 checks over the past three years (Marieke Lettink, pers. comm.). The best results on the mainland are currently those for Boundary Stream Mainland Island. At Boundary Stream, about 1235 checks have been made in both treatment (invasive-predator-controlled areas) and non-treatment sites and have revealed 17 geckos (one Common Gecko and 16 Forest Geckos; rate = 0.01; Boundary Stream Mainland Island (BSMI) project and annual reports 1996–2004; Edward Waite, pers. comm.). In areas of apparently low forest lizard density, covers seem to have a higher occupation rate, based on results from Zealandia (0.041 compared with 0.003) and Windy Hill (0.04). The differences are more apparent if these results are calibrated into a rate of 1,000 checks. These lizard house results suggest that 0–10 lizards per 1,000 checks were likely in areas of low lizard abundance, which is relatively poor compared with 40 per 1,000 checks from foam covers for relatively similar areas under similar management regimes.

The functional integrity of covers was remarkably high over the 12-month period for two sites (99%) and over the 5-month period for the other site (100%). Those covers that failed were largely due to falling trees after storms; 99% of covers on Windy Hill survived three strong storms during the trial which saw trees blown over (Judy Gilbert, pers. comm.). There were no signs of insect damage to covers, apart from only two instances of borer grubs out of 372 covers, but these did not affect the functional integrity of the covers.

There are no known techniques to monitor arboreal lizard species using this concept; however since this trial, it has come to my attention that tree-bands of corrugated cardboard and polyethylene bubble wrap have been used to sample spiders (Isaia et al. 2006). I suggest that covers are an improved technique because they mimic a natural choice of retreat, and the spread of the cover across a tree trunk improves lizard-cover encounters during foraging. As an artificial retreat, covers also overcome these sampling biases during foraging times, resulting in relatively more animals during sampling.

Conclusion.—The demonstration that forest lizards will readily occupy closed-cell foam covers is a first step towards establishing this novel method for wider use in arboreal forest lizard monitoring in New Zealand and elsewhere. Covers offer advantages over other conventional techniques for monitoring these lizard populations. These include more representative samples of lizard populations, the ability to detect lizards in low-density populations, and lower costs and maintenance requirements. Covers may also reduce some potential biases experienced using conventional sampling techniques; however, an investigation needs to be conducted to see whether covers are subject to other biases, such as placement and occupant behavior.

This method is most likely to be used by conservation and restoration managers as count-based indices of forest lizard populations to measure relative population change over time. Lizards are possible indicator species for the effects of conservation management (Carignan and Villard 2001). However, at this early stage I advise caution with the use of cover indices because the relationship between the index and the true population size is not known (Nicholls and Pollock 1983; Anderson 2001, 2003) and detectability by use of artificial refuges is likely to vary across sites, weather, seasons, habitat heterogeneity, and even individuals over spatial and temporal scales (Kjoss and Litvaitis 2001; Anderson 2001, 2003; Hyde and Simons 2001; Francke 2005; Lettink and Seddon 2007; Wilson et al. 2007). Wilson et al. (2007) also raise the problem that count indices may not be suitable for detecting small differences in density between treatment and reference areas unless replication is substantially increased.

Any index monitoring of forest lizards should therefore be standardized *a priori* as much as possible, according to the habitat type and species, while recording relative site variables for *post hoc* analyses of potential effects (Lettink and Seddon 2007). I suggest stratified random sampling (Cochran 1977) to be the most suitable method for selecting site replications. This allows for more relativity in comparing and evaluating site differences in index data.

Clearly, there need to be long-term studies on effective sampling with and the longer term effects of covers on the resident lizard population. There may be a risk of covers boosting population abundance (Webb and Shine 2000; Souter et al. 2004; Francke 2005; Lettink and Cree 2007; Wilson et al. 2007), and also attracting predators (Souter et al. 2004; Lettink and Cree 2007). The putative effect of artificial refuges providing resources is likely to be weaker in forest ecosystems due to their structural complexity (Souter et al. 2004), but does require investigation.

Research on covers is needed to (1) determine their potential suitability for lizard monitoring (e.g., mark-recapture type studies), (2) indicate potential sampling biases, (3) determine time to optimal occupancy and possible seasonal effects, (4) infer the ideal sampling frequency (Marsh and Goicochea 2003; Wilson et al. 2007), (5) evaluate habitat use of several species of forest lizards, and (6) examine individual lizard behavior in relation to covers. These include potential social interaction and home effects of resident lizards occupying artificial refuges (Souter et al. 2004; Lettink and Cree 2007).

There is potential to improve further the design of covers. This includes trialing new cover materials and attachment methods. The technique described here may have further potential internationally for monitoring of other arboreal lizard species, tree frogs, and invertebrates.

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