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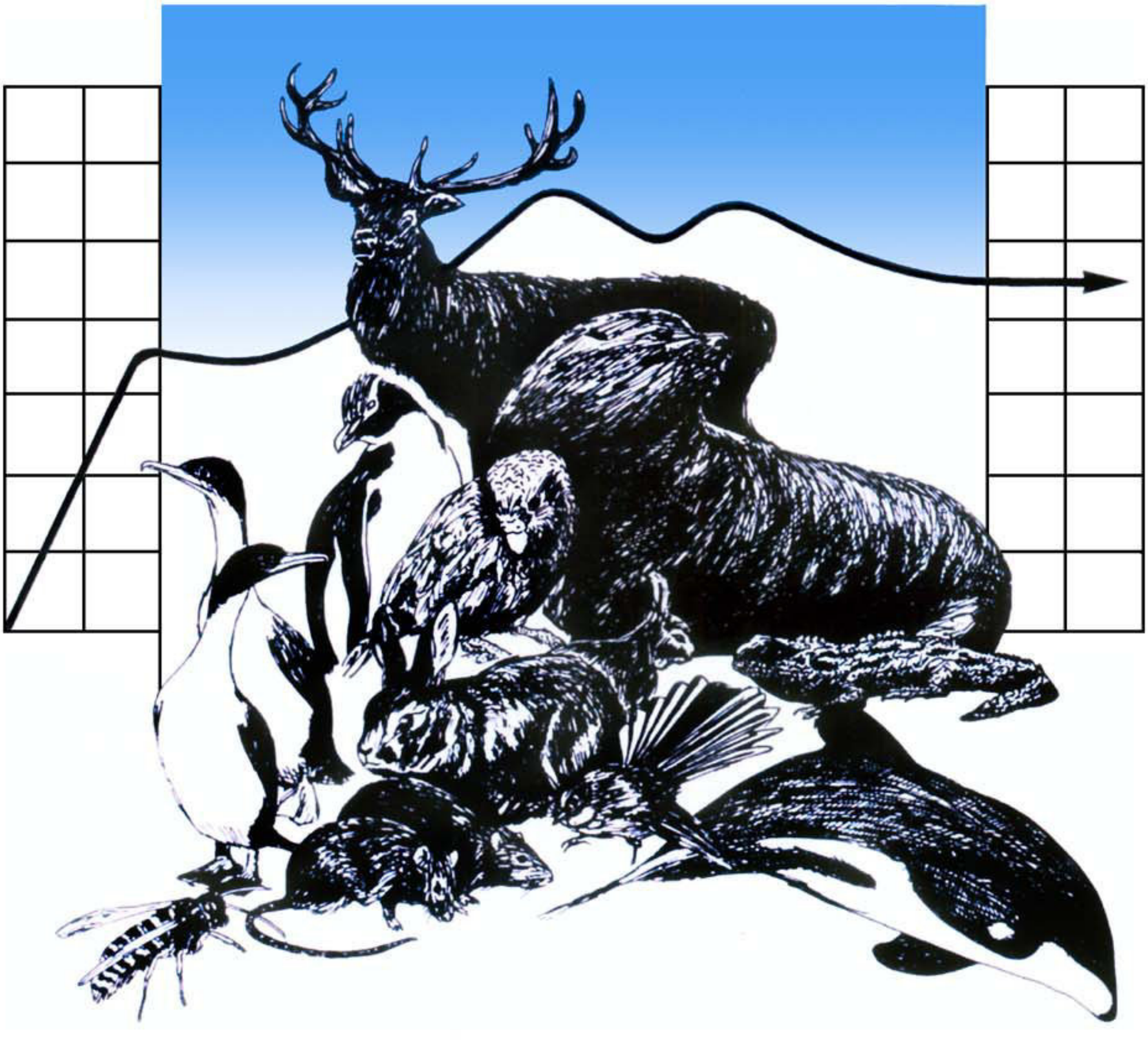

WILDLIFE MANAGEMENT

Habitat use and behaviour by forest geckos (Mokopirirakau granulatus) in relation to predator control on Waiheke Island, Hauraki Gulf, New Zealand

Ann-Kathrin Schlesselmann

A report submitted in partial fulfilment of the
Post-graduate Diploma in Wildlife Management

University of Otago

2014

University of Otago
Department of Zoology
P.O. Box 56, Dunedin
New Zealand

WLM Report Number: 284

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Forest gecko on hangehange Photo: J. Monks

Ann-Kathrin Schlesselmann

Practice of Wildlife Management

WILM 403

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Abstract

In order to effectively monitor lizard populations and evaluate responses to management actions, knowledge about habitat use and behaviour is essential, particularly for visually and behaviourally cryptic species, such as the forest gecko (Mokopririrakau granulatus). This study provides basic biological information and investigates whether the presence of introduced rodents, sex, temperature and relative humidity influence habitat use of forest geckos. Habitat use and behavioural data of seventeen geckos (male and female) in an area with predator control (treatment) and three females in an area without predator control (control) was collected through radio tracking individuals in and near Whakanewha Regional Park on Waiheke Island, Hauraki Gulf, New Zealand. Forest geckos predominantly used kānuka (Kunzea ericoides) trees, which were abundant at the site and were mainly observed in the foliage or on branches in both areas. Although there were clear differences in rodent densities between the two areas, no difference in habitat use by forest geckos was detected between the two areas. However the small sample size of forest geckos from the control area limited the ability to detect any differences. Male geckos were found on lower parts of the trees compared to females. This could be due to males searching for females and travelling between trees as the study was undertaken during the mating season. This preliminary study suggests that behaviour of forest geckos is not influenced by rodent density and therefore the same monitoring techniques can be used in both situations. However, further work is needed to understand habitat use and behaviour of forest geckos as well as the impacts of rodents on them to be able to evaluate management actions.

Acknowledgements

I wish to thank Jo Monks for providing the data set, being very approachable and for giving me good advice on any issue. Further I would like to thank the private landowners for allowing access, the many field workers collecting the data, Jonah Kitto-Verhoef from the Auckland Council for providing details on the predator control programme, Richard Earl from the Department of Conservation for GIS help and Sheena Townsend for some statistical advice. This study was funded by the Department of Conservation (Science Investigation Number 4231) and supported by the Auckland Council (Permit Number SS52). The study was carried out with approval of the Department of Conservation's Animal Ethics Committee (Permit Number AEC217).

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Introduction

The arrival of humans in New Zealand had a severe impact on its native biota as native vegetation was cleared and many animals were intentionally and accidentally introduced (Atkinson & Cameron 1993). Evolving with only minimal influence from terrestrial mammals, New Zealand's fauna was very naïve towards introduced predators and long life spans together with low reproductive rates only increased their vulnerability (Daugherty et al. 1993; Worthy & Holdaway 2002). Like many other groups, New Zealand's unique and diverse reptile fauna has since experienced many range contractions or even extinctions (Towns & Daugherty 1994). Rats (Rattus spp.) in particular, have been identified as a primary factor for causing this detrimental effect (Towns & Daugherty 1994; Towns et al. 2001). In places where native lizards are able to co-exist with introduced rats, it has been shown that it is due to changes in behaviour of native lizards to minimise spatial overlap with rats (Hoare et al. 2007).

To halt the decline, management actions are taken which mainly focus on controlling or eradicating mammalian predators (Towns et al. 2001). In order to evaluate conservation benefits, monitoring of population responses needs to be undertaken (Stem et al. 2005). However monitoring of population trends in New Zealand lizards is very challenging, because many lizards are visually cryptic, densities are often low and detections highly variable in time and space (Bell 2009; Hare et al. 2007; Hoare et al. 2009). Understanding habitat use and behaviour of a species is essential to optimise sampling techniques, accurately monitor populations and evaluate responses to management actions (Hare et al. 2007; Hoare et al. 2013; Romijn et al. 2013). Basic biological knowledge of many New Zealand reptiles is often lacking though and there exists a strong need for further information.

In addition, understanding why habitat is used in a certain way by a species is an important step in understanding population processes and designing conservation management strategies. Habitat use, for example, can be altered to avoid predation (Hoare et al. 2007) or vary due to intra-specific habitat partitioning or sexual segregation. This is defined here as differences in space and resource use by males and females and is observed in a range of species including reptiles (Ruckstuhl & Neuhaus 2005). For example stable isotope analysis has shown that male tuatara

(Sphenodon punctatus) prey more heavily on seabirds compared to females, which predominantly feed on insects (Cree et al. 1999).

The challenge posed of monitoring cryptic species with only little knowledge of their behaviour and habitat use applies particularly to the arboreal geckos, including the forest gecko Mokopirirakau granulatus (Bell 2009). Forest geckos are nocturnal and cryptic in both colouration and behaviour (Jewell 2011). Their distribution includes the northern North Island, from Hamilton to Kaitaia including offshore islands in the Hauraki Gulf and the northwest of the South Island. They are commonly found in regenerating forest and scrubland, primarily consisting of kānuka (Kunzea ericoides) and mānuka (Leptospermum scoparium). Forest geckos are classified as At Risk – Declining with the qualifier that they are Data Poor (Hitchmough et al. 2012).

The aim of this study was to provide basic biological knowledge about habitat use and behaviour of forest geckos in the presence of introduced mammals and in an area of intensive control of rodents and other introduced mammals. The main research question was whether the habitat use of forest geckos differed between the treatment (rodent control) and non-treatment (no rodent control) sites and the following, non-mutually exclusive, hypotheses were tested:

(1) Forest geckos living in an area with a higher population density of rats adjust their behaviour to spatially avoid rats by using areas at a higher level above ground and by being less conspicuous.

(2) There is intraspecific habitat partitioning, i.e. differences in habitat use are due to female and male forest geckos using different habitats.

(3) As activity of geckos is influenced by temperature and relative humidity, habitat use is primarily influenced by microclimate.

(4) Differences in habitat use are due to individual preferences.

Methods

Study area

The study was undertaken in and adjacent to Whakanewha Regional Park, Waiheke Island, Hauraki Gulf, New Zealand (36° 48' S/175° 6' E). The climate is sub-tropical with a mean annual temperature of 15.2°C and annual rainfall of 1460.6 mm (National Institute of Water and Atmospheric Research [NIWA] 2014). The sites comprised regenerating forest dominated by kānuka interspersed with mahoe (Melicytus ramiflorus), red mapou (Myrsine australis), karo (Pittosporum crassifolium), nīkau (Rhopalostylis sapida), kawakawa (Macropiper excelsum), Coprosma arborea, C. rhamnoides, hangehange (Geniostoma ligustrifolium), mingimingi (Leucopogon fasciculata), silver tree ferns (Cyathea dealbata) and occasional pōhutukawa (Meterosideros excelsa) and kohekohe (Dysoxylum spectabile).

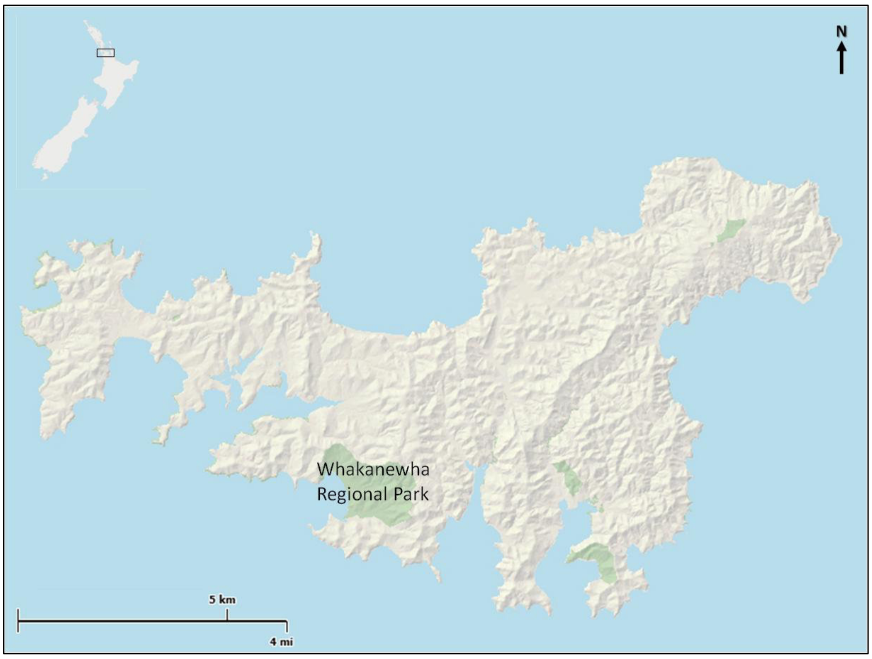

Figure 1 Map showing Whakanewha Regional Park on Waiheke Island, Hauraki Gulf, New Zealand (modified from Auckland GIS Viewer).

A suite of small mammals including ship rat (Rattus rattus), Norway rat (R. norvegicus), house mouse (Mus musculus), feral cat (Felis catus), stoat (Mustela erminea), rabbit (Orytolagus cuniculus) and hedgehog (Erinaceus europaeus) are present on Waiheke Island. It has remained however free of possums (Trichosurus vulpecula), ferrets (Mustela furo) and weasels (Mustela nivalis). Whakanewha

Regional Park was subjected to a continual predator control operation between August 2010 and May 2011 (Wiggenhauser 2011). Bait stations were used to control rodents and a range of kill and live traps were in place to target mustelids, cats and hedgehogs (J. Kitto-Verhoef, pers. comm. 2014). A total of 16 bait lines, spaced approximately 100 m apart with bait stations at 50 m intervals, made up a network of ca. 700 bait stations covering almost the entire park (Wiggenhauser 2011). Chocolate-flavoured waxed Pest-Off blocks (brodifacoum, second generation anti-coagulant poison) were used as bait every 3-4 weeks between August and March, while no bait was distributed over the winter months (Wiggenhauser 2011).

Six transects were sampled for forest geckos: three inside Whakanewha Regional Park, the treatment area with extensive predator control (TT 1-3) and three outside of Whakanewha Regional Park, the control area, where no predator control programme is in place (TC 1-3).

Index of rodent activity

The relative abundance of rodents (rats and mice) during the study period was measured using standardised footprint tracking tunnel lines (Gillies & Williams 2013) placed along each of the 6 transects in the study area (3 treatment, 3 control). Each tunnel line consisted of 10 tunnels set 50 m apart. The tracking tunnels were deployed on the 19th May 2011. Animals were lured into the tunnel with a small piece of peanut butter in the centre of an inkpad. They walked across an inkpad, then brown paper, where they left footprints. These were subsequently identified to species level and counted. Lines were treated as sampling units and tracking rates were summarised as percentage of tunnels/line with footprints after one night.

Radio tracking

Between 3rd and 17th May 2011, all transects were searched for forest geckos at night by using spot-lighting and looking for gecko eye shine, body shape and/or pale stomach colour, which contrasts with the surrounding vegetation. Night searches were conducted when the temperature was above 9°C and when it was not raining. Observers walked slowly along transects and forest geckos were caught once sighted. The time, temperature (°C), relative humidity (%RH), a GPS position and the gecko's age (adult, sub-adult or juvenile), sex, reproductive status (for adult females only, by palpation) and morphometrics (snout-to-vent length (SVL), mm; vent-to-tail length (VTL), mm; length of the regenerated portion of the tail, mm; mass, g) were recorded.

To investigate habitat use of forest geckos 0.7g BD-2 radio transmitters (Holohil Systems Ltd, Carp, Ontario) were used. These were attached to adult forest geckos weighing ≥ 10.0 g (i.e. transmitters weighing ≤ 7.5% of forest gecko body weight; Table S1). Transmitters were attached with micropore self-adhesive tape using an external ‘backpack’ design (Salmon 2002, Hoare et al. 2007) and tail mounts (Yet 2014). The tape was coloured black with a xylene-free permanent marker to minimise the chance of forest geckos being detected by predators and a small piece of reflective tape was attached to each side of the transmitter to aid searchers in finding forest geckos at night.

Radio-tagged individuals were tracked twice each night and once each day. Each time, the individual to be tracked first was randomly chosen to assure that tracking did not occur always at the same time for each individual. The other individuals were then tracked in a logical order to minimise the disturbance of other individuals.

Habitat use

A range of habitat characteristics were measured from the position where each forest gecko was first seen and then the subsequent locations where radio-tagged animals were resighted. Measurements included distance from the previous sighting (m), species of plant the forest gecko was on, the forest gecko’s height above the ground (m), the height of the tree (m), stem diameter at breast height (dbh at 1.3 m height), the microhabitat (branch, foliage, trunk, ground), and percentage cover within 20 cm and 1 m spheres around the forest gecko. Cover was assessed by estimating the percentage of the volume around the forest gecko that was cluttered with vegetation (estimated visually to the nearest 5%).

Habitat availability

Habitat availability was assessed using point-centred quarter plots (Causton 1988, Finsch 1989). Plot centres were determined by taking a random compass direction from the point where each forest gecko was first sighted and placing it a random distance away (up to 10 m). At each point, the four nearest trees in each of the four compass quarters were identified; their distances from the location measured (m), their height and stem diameter (dbh), and canopy cover (assessed from the base of the tree and visually estimated to the nearest 5%). The measurements on random plots were limited to plants that were considered to be potential habitat for forest geckos (i.e. the minimum dimensions observed for stem diameter and total height of forest gecko trees were used as a guideline to determine the lower limit acceptable for an available tree measurement (cf Smith 1997). The smallest stem diameter of a plant with a forest gecko was 1 cm dbh and the lowest total height was 0.95 m.

Statistical Analysis

All data analysis was carried out using R 3.0.3 (R Core Team 2014). In order to test which factors (presence of rodents, sex, temperature and relative humidity) influenced habitat use of forest geckos the most, a set of candidate models was obtained by building models with perceived biological relevance describing the hypotheses and combinations of them (Anderson 2008). The candidate models were linear mixed effect models with habitat use characteristics as response variables (height above ground and cover measurements), included one or several of the four predictor variables as fixed effects (treatment, sex, relative humidity and temperature) and individual forest gecko as the random effect. The R package 'lme4' (Bates et al. 2014) was used to build the models. Animals were only included in the analysis if data from a minimum of five sampling points were collected after excluding the point of capture. The response variables were log-transformed to improve the normality of the residuals and the predictor variables were centred and standardised to improve the interpretability of the regression coefficients (Schielzeth 2010). Normality of the residuals and homoscedasticity were visually assessed using diagnostic plots and the R package 'influence.ME' was used to test for influential observations (Nieuwenhuis et al. 2012; Nieuwenhuis et al. 2014).

All candidate models were ranked based on Akaike Information Criterion correction for small sample size (AICc) scores using the R package 'AICcmodavg' (Mazerolle 2013). A good fit was considered to be any model with a Δ AICc < 4 (Burnham & Anderson 2002). To identify the relative importance of the predictor variables for each habitat use characteristic and to generate weighted coefficient estimates, the models within Δ AICc < 4 were averaged using the R package 'MuMIn' (Bartón 2010). Only conditional averages are reported, i.e. the parameter estimate was averaged only across the models in which it appears, as it is still an unresolved problem how the variance of the estimate should be calculated using the zero method (Bartón 2010). Lists of the model sets are provided in the appendix (Tables S3 a-c).

Results

Rodent activity

No rodents were detected within the treatment area, while 16.7 % ± 8.8 (Mean ± SE) of tunnels had rat footprints and 33.3 ± 20.3 (Mean ± SE) of tunnels had mice footprints using the standard one-night survey (Fig. 1, Table S2). The tracking tunnel indices showed therefore a higher abundance of rodents in the control area compared to the treatment area (Fisher's exact test, P-value < 0.0001).

Radio-tracking forest geckos

A total of 61 forest geckos, 58 adults and three sub-adults, were captured between 3rd and 17th of May 2011. The habitat use of 17 forest geckos within the treatment area (seven female and ten male) and of three female forest geckos in the control area was analysed (Table 1). Though much effort was invested in catching forest geckos on all transects in the control area, it was only possible to collect habitat use data of three females on the TC 2 transect. Overall 13 adult forest geckos, 8 females and 5 males, were found on the TC 2 track; however individuals were either too light to carry a transmitter or found too late in the study to be fitted with a transmitter. The tails of five radio-tracked forest geckos using tail mounts were found over the course of the study, but no skin damage or other adverse impacts of the radio transmitters on animals were observed.

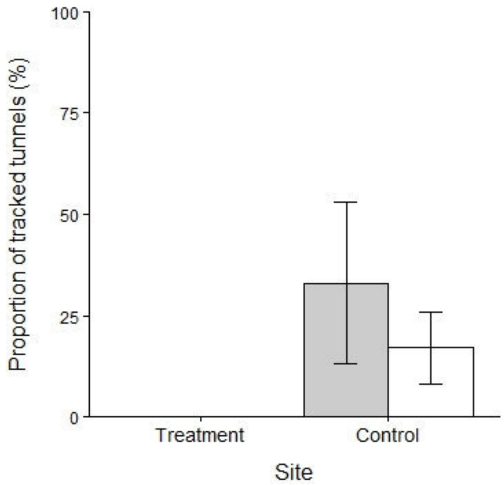

Figure 1 Footprint tracking rates (± SE) of mice (in grey) and rats (in white) in areas with rodent control (Treatment) and without rodent control (Control) on Waiheke Island, May 2011.

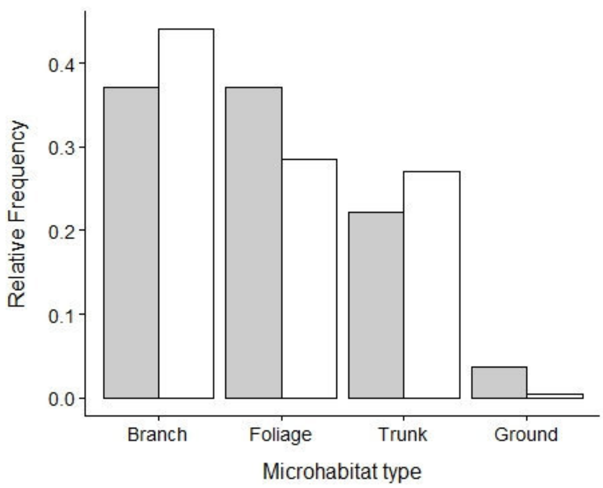

Figure 2 Microhabitat use of forest geckos (Mokopirirakau granulatus) in areas without (in grey) and with rodent control (in white) on Waiheke Island, May 2011.

Habitat use of forest geckos

Mokopirirakau granulatus used all structural habitats available to them, including foliage, branches, trunks and the ground (Fig. 2). Compared to the control area, forest geckos in the treatment area were more often found using branches (Treatment: 44% of observations compared to Control: 37%) and trunks of trees (Treatment: 27% compared to Control: 22%) and less often foliage (Treatment: 28% compared to Control: 37%) or the ground (Treatment: 4% compared to Control: 0.5%). Male forest geckos in the treatment area used lower parts of trees compared to females in the treatment area and control area (Table 1).

Table 1 Habitat use characteristics of forest geckos (Mokopirirakau granulatus) in an area with rodent control (Treatment) and without rodent control (Control) on Waiheke Island, May 2011.

				Height above ground (m)		**% cover in 20 cm sphere**		**% cover in 1 m sphere**	
Site	**Sex**	**Gecko ID**	**No. of fixes**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Control	F	WFG 18	25	2.7	1.8	35.8	26.8	44.1	24.6
Control	F	WFG 20	22	3.4	1.6	24.3	18.8	28.6	18.6
Control	F	WFG 34	8	2.6	1.8	13.3	14.4	36.7	37.5
Mean ± SE (Control)			**18.3 ± 5.2**	**2.9 ± 0.3**		**30.1 ± 4.8**		**39.0 ± 4.8**	
Treatment	F	WFG 2	18	2.2	1.4	37.6	44.1	40.5	41.3
Treatment	F	WFG 3	20	3.4	1	47.1	31.1	48.4	25.3
Treatment	F	WFG 5	24	2.5	1.9	43.8	21.8	46.3	20
Treatment	F	WFG 8	21	6.8	1.5	21.6	34.1	21.2	34.2
Treatment	F	WFG 9	28	3	2.3	25.9	22.9	41.6	31.5
Treatment	F	WFG 10	28	3.3	2.2	25.1	31.8	36.8	31
Treatment	F	WFG 32	14	4.5	2.2	35.4	33	39	30.5
Mean ± SE (Females/Treatment)			21.9 ± 2.0	3.5 ± 0.2		33.9 ± 3.5		39.4 ± 3.4	
Treatment	M	WFG 12	26	2.9	1.4	20	17	29.2	23.3
Treatment	M	WFG 13	27	2.7	1.6	27.7	28.7	36.8	32.2
Treatment	M	WFG 23	8	3.2	1.1	27.5	41.7	31.3	39.4
Treatment	M	WFG 25	25	1.8	1	26.6	24.3	35.1	23.4
Treatment	M	WFG 26	26	1.2	0.6	55.3	38.1	60	32.1
Treatment	M	WFG 28	26	1.8	0.5	51.9	26.5	50.3	19.2
Treatment	M	WFG 29	26	2.4	1.2	39.3	28.1	41.1	23.1
Treatment	M	WFG 31	8	1.9	1.3	66	23	64	20.7
Treatment	M	WFG 4	16	2.5	0.2	20	25.7	18.6	15.6
Treatment	M	WFG 6	24	2.7	2.1	24.8	31.4	22.8	25.1
Mean ± SE (Males/Treatment)			21.2 ± 2.4	2.2 ± 0.1		34.3 ± 2.8		37.9 ± 2.5	
Mean ± SE (Treatment)			**21.5 ± 1.6**	**2.8 ± 0.1**		**34.1 ± 2.2**		**38.5 ± 2.0**	

Habitat availability

Forest geckos were observed using a range of tree species, but were mostly found on kānuka. In relation to other available habitats in both the treatment and control areas, forest geckos predominantly used kānuka (Treatment: 67% of observations vs. 43% available, Control: 78% observed vs. 42% available; Fig. 3). In the control area, hangehange was used almost equal to its availability (9% observed vs. 8% available), but C. arborea (13% observed vs. 25% available) and particularly mahoe (0% observed vs. 25% available) were used less often. In comparison, in the treatment area hangehange (9% observed vs. 16% available), C. arborea (2% observed vs. 4% available) and mahoe (3% observed vs. 9% available) were used less in relation to their availability. The latter two species however were still used more often in the treatment area compared to the control area.

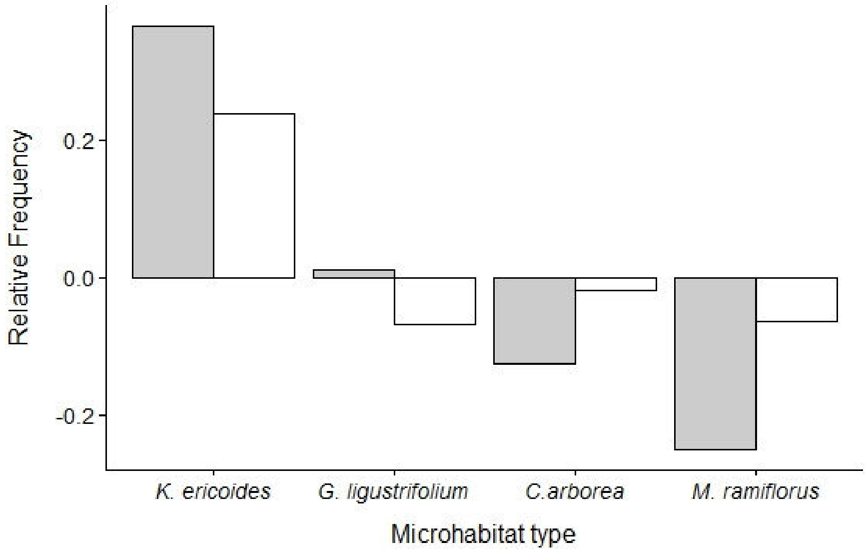

Figure 3 Differences of observed and potential use of tree species by forest geckos (Mokopirirakau granulatus) in an area without (in grey) and with rodent control (in white) on Waiheke Island, May 2011. Positive values indicate proportionally greater use of tree species in relation to availability whereas negative values indicate proportionally less use in relation to availability.

Trees used by forest geckos were on average taller in both areas, and bigger in size in the treatment area, compared to other trees available to them (Table 3). In the control area forest geckos used taller, but similar sized, trees compared to the treatment area.

Table 2 Differences in mean tree height (± SE) and mean diameter at breast height (dbh) (± SE) of potentially available trees and observed used trees by forest geckos (Mokopirirakau granulatus) in an area with rodent control (Treatment) and without rodent control (Control) on Waiheke Island, May 2011.

Habitat	Control			Treatment		
	N	**Tree height (m)**	**dbh (cm)**	**N**	**Tree height (m)**	**dbh (cm)**
Observed Use	46	6.3 ± 0.48	8.23 ± 0.88	250	5.08 ± 0.16	7.23 ± 0.43
Available	12	4.06 ± 0.48	8.13 ± 2.15	76	4.05 ± 0.30	6.32 ± 0.64

Effects on habitat use

Sex and temperature had the most effect on height above ground, cover in a 20 cm sphere and 1 m sphere around a forest gecko, given the confidence interval estimates and their relative importance values from the averaged models (Tables 2, S3 a-c). The effect of sex on all habitat use characteristics was the strongest as the confidence interval for the estimate of sex for these characteristics did not include zero, however the confidence intervals around the estimates are very close to zero. The median height above ground and the percentage of cover around males was lower compared to females. Treatment had a moderate effect on height above ground and cover in a 1 m sphere, however only a small effect on cover in a 20 cm sphere. The median height above ground and the percentage cover around forest geckos was higher in the treatment area compared to the control area. Temperature was included as a predictor for every habitat use characteristics in all models within Δ AICc < 4, but no significant effect was detected. Nevertheless this indicates that it is an important factor in the habitat use of forest geckos. With increasing temperature, the median height above ground of forest geckos and the median cover around them decreased. With increasing relative humidity, the median height above ground and the cover around them only slightly increased.

Table 3 Summary results of linear mixed effects models of different habitat use characteristics (Height above ground, cover in a 20 cm and 1m sphere around the animal) of forest geckos (Mokopirirakau granulatus) in an area with (Treatment) and without rodent control (Control) on Waiheke Island.

Habitat Use Characteristic	Variable	Estimate[§]	SE	Lower 95% CI	Upper 95% CI	Relative importance[+]
Height above ground (m)*	(Intercept)	1.071	0.059	0.955	1.187	
	Sex (Male)	-0.307	0.134	-0.570	-0.045	**1.00**
	Temperature	-0.081	0.050	-0.178	0.017	1.00
	Treatment (Treatment)	0.205	0.196	-0.178	0.589	0.33
	Relative Humidity	0.018	0.051	-0.083	0.118	0.24
Cover in 20 cm-sphere (%)*	(Intercept)	1.068	0.067	0.938	1.200	
	Temperature	-0.080	0.050	-0.177	0.017	1.00
	Sex (Male)	-0.286	0.128	-0.537	-0.036	**0.65**
	Relative Humidity	0.021	0.051	-0.079	0.122	0.08
	Treatment (Treatment)	0.010	0.205	-0.392	0.411	0.07
Cover in 1 m-sphere (%)*	(Intercept)	1.069	0.066	0.940	1.197	
	Temperature	-0.080	0.050	-0.178	0.017	1.00
	Sex (Male)	-0.308	0.134	-0.572	-0.045	**0.74**
	Treatment (Treatment)	0.167	0.213	-0.250	0.584	0.35
	Relative Humidity	0.021	0.051	-0.079	0.122	0.07

* Response variable has been log(x+0.5)-transformed to improve the normality of the residuals.

[§] Effect sizes have been standardised following Schielzeth (2010).

[+] Relative importance values in bold indicate that these parameter estimates do not include zero, thus indicating that these predictor variables have a strong effect on habitat use.

CI, confidence interval.

Discussion

The difficulties of finding forest geckos in the control area, where there is no predator control programme could indicate that rodents have either an impact on population density or on the behaviour of forest geckos, or possibly both, and potentially ecologically replace them (Hoare et al. 2007; Thoresen 2011). Hoare et al. (2007) found that capture rate of adult Duvaucel's geckos (Hoplodactylus duvaucelii) increased fourfold after rat eradication and prior to any recruitment. The behaviour of geckos was altered by the presence of rats making them more inconspicuous to observers. It is not possible to determine the reason for the lower detection rate in the control area in this study with certainty. The lower detection rate though led to a small sample size of forest geckos and only females being radio tracked in the control area, which severely limits the ability to address the primary hypothesis i.e. the effect of rodents on behaviour and habitat use of forest geckos. Nevertheless this study provides basic biological information on habitat use and behaviour of M. granulatus. This information is important to plan efficient conservation management actions and monitoring of forest geckos.

Effect of rodents on forest geckos and their habitat use

Although the pest programme appears to be successful at suppressing rodents within Whakanewha Regional Park, no strong effect of rodent control on habitat use of geckos was detected. This could be for various reasons. First, it could be possible that forest geckos do not show the same behavioural plasticity in the form of spatial avoidance of rodents as is known for Duvaucel's geckos (Hoare et al. 2007). Secondly, although no rodents were detected by the tracking tunnels, low levels of rodents still could be present, particularly on edges of the bait station network. Detection probability of rodents decreases with lower population density, however rodents can still be present (Russell et al. 2005). Our results could also indicate that even low levels of rodents affect forest gecko behaviour and habitat use. Thus, it could be that there is no difference between the habitat use and behaviour of forest geckos living in areas of very low compared to higher rodent densities. Thirdly, because the sample size in the control area was biased towards females and was very small, any effect of rodents on the behaviour of forest geckos could have been masked. Further study is necessary, although the lower population density of forest geckos in areas without rodent control will still pose a challenge in finding enough individuals for adequate sample sizes.

As ship rats, mice and stoats are very capable climbers (Innes 2005; King & Murphy 2005; Ruscoe & Murphy 2005), forest geckos using branches and tree trunks in areas without predator control might be vulnerable to foraging mammals, similar to M. 'Southern North Island' (Romijn et al. 2013). Thoresen (2011) found that the population density was higher and more forest geckos of larger body size were present in an area with predator control compared to an area without predator control on Waiheke Island. This indicates a negative impact of rodents on forest geckos. Male forest geckos using lower parts of trees compared to females might be at elevated risk of predation. Further Thoresen (2011) compared body condition (BCI) and body-tail condition (BTC) indices of male and female forest geckos in areas with and without rodent control. The BCI is the ratio between body weight and SVL and used to determine the general condition of a gecko (Floyd & Jenssen 1983) whereas the BTC index is calculated as the ratio of tail length and SVL and aims at identifying the impact of predators on reptiles by quantifying tail loss (Barr 2009). Thoresen (2011) found that the BCI and BTC indices of males were lower in areas without rodent control compared to areas with rodent control, while there was no difference in both indices of females. However the sample size of this study is too small to detect any sex bias and no sex bias of the population on Waiheke Island, neither in the treatment nor the control area, is reported in Thoresen's (2011) study.

Effects of sex and temperature on habitat use

Males on average used lower parts of trees compared to females. While sexual segregation is known in many taxa, it is mostly associated with a strong sexual size dimorphism (Ruckstuhl & Neuhaus 2005). Although some New Zealand lizards show sexual dimorphism e.g. Duvaucel's gecko (Barwick 1982), no size difference between the sexes is observed in forest geckos (J. Monks, unpubl. data). Andrews (1971) showed that both female and male of Anolis polylepsis use structural habitat differently, particularly perch heights. However he also showed that structural habitat use was highly related to activity, with males using higher perches for social interaction between other males. This behaviour was not experienced by females, which therefore used lower parts of trees overall (Andrews 1971). Temperature and time of day are strongly correlated and thus temperature generally links to the activity of lizards (Walls 1983). Given the relative importance of temperature as a predictor in all models, it might indicate that sexes are experiencing different activities at different times of the day. Although habitat use characteristics were not related to activity in this study. As the study was undertaken during the mating season of forest geckos (J. Monks, pers. comm. 2014), it could be that males where observed at lower heights as they were predominantly looking for mates and potentially moved more between trees. Further study at different times of the year would be needed to confirm that male and female forest geckos actually partition their structural habitat and linking habitat use to activity of the gecko would provide more insight into forest gecko behaviour.

Habitat use in relation to availability

Forest geckos were predominantly observed using kānuka trees in both areas. In the control area, small-leaved and densely growing species such as kānuka and hangehange were preferred over other species such as the bigger-leaved mahoe. This preference was still apparent in the treatment area, however it was less distinct. This could mean that in an area where rodent density is higher, forest geckos tend to use tree species which provide better camouflage to avoid predation. This effect could however not be observed by measuring cover around the gecko, as in both areas geckos had on average a similar amount of cover around them.

As trees were higher in the control area compared to the treatment area, detectability of geckos in the control area could have been affected. Furthermore this could have also masked the effects of using different heights of trees. However our results show clearly that regardless of the presence of rodents, forest geckos prefer taller trees over shorter ones. This is most likely linked to forest geckos preferring kānuka, which grows on average taller than other broadleaf forest species in early succession forests (Dawson & Lucas 2011).

Conclusion

This study highlighted the difficulties of understanding habitat use and behaviour of a highly cryptic species, as data collection can require a lot of effort and yet still lead to a small sample size. Detecting behavioural and habitat use differences in the presence of rodents can be challenging, if it is not known how much of the habitat overlaps between introduced mammals and native geckos. Nevertheless this study also showed how important it is to have a basic biological understanding of a species in order to design proper conservation strategies and monitoring techniques. Forest geckos primarily use foliage and branches of trees and are rarely found on the ground. Further forest geckos prefer kānuka over other tree species, particularly bigger-leaved species, which offer less cover. Finally this study indicated that female and male forest geckos might use their habitat differently, potentially elevating the predation risk to males. Of the hypotheses tested regarding habitat use and behaviour, this study resulted in the strongest support for intraspecific habitat partitioning and only little support for the other hypotheses. Further study is necessary to understand the relationship between rodent densities and behaviour of forest geckos and to use this in the design of appropriate conservation strategies for New Zealand's forest geckos.

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Appendix

Table S1 Morphometric details of radio-tracked forest geckos (Mokopirirakau granulatus) in an area with rodent control (Treatment) and without rodent control (Control) on Waiheke Island, May 2012.

Site	Gecko ID	Sex	Reproductive Status	Mass (g)	SVL (cm)	VTL (cm)
Control	WFG18	F	p(2)	11.9	78	90
Control	WFG20	F	p(2)	16.0	87	60
Control	WFG34	F		10.0	70	78
Mean ± SE (Control)				**12.63 ± 1.77**	**78.33 ± 4.91**	**76.00 ± 8.72**
Treatment	WFG2	F	p(2)	12.7	85	75
Treatment	WFG3	F	p(2)	13.9	85	93
Treatment	WFG5	F	p(2)	14.5	82	83
Treatment	WFG8	F		17.8	81	94
Treatment	WFG9	F	p	16.0	81	97
Treatment	WFG10	F	p(2)	14.3	85	83
Treatment	WFG32	F		16.3	85	92
Mean ± SE (Treatment/Females)				**15.07 ± 0.64**	**83.43 ± 0.75**	**88.14 ± 3.00**
Treatment	WFG12	M		12.8	80	91
Treatment	WFG13	M		16.3	85	83
Treatment	WFG23	M		12.0	79	89
Treatment	WFG25	M		16.2	95	114
Treatment	WFG26	M		13.0	82	99
Treatment	WFG28	M		13.1	70	75
Treatment	WFG29	M		21.0	87	106
Treatment	WFG31	M		13.0	84	89
Treatment	WFG4	M		17.6	88	86
Treatment	WFG6	M		18.4	90	92
Mean ± SE (Treatment/Males)				15.34 ± 0.95	84.00 ± 2.17	92.40 ± 3.58
Mean ± SE (Treatment)				**15.23 ± 0.61**	**83.76 ± 1.28**	**90.65 ± 2.43**

Table S2 Rodent footprint tracking rates in and adjacent to Whakanewha Regional Park, Waiheke Island, May 2012.

Area	**Transect**	**% tunnels tracked**	
		Rats	Mice
Control	TC 1	20	30
	TC 2	30	70
	TC 3	0	0
	Average (± SE)	**16.7 (± 8.8)**	**33.3 (± 20.3)**
Treatment	TT 1	0	0
	TT 2	0	0
	TT 3	0	0
	Average (± SE)	**0**	**0**

Table S3 Results of linear mixed effects models of different habitat use characteristics of forest geckos (Mokopirirakau granulatus) in an area with rodent control and without rodent control on Waiheke Island:

a) Height above ground (m)

Model	Intercept	Treatment	Sex	Temperature	Rel. Humidity	K	AICc	Δ AICc	AICc ω	Cumulative ω	LL
10	X		X	X		5	497.55	0	0.36	0.36	-243.69
13	X	X	X	X		6	498.53	0.98	0.22	0.58	-243.15
16	X		X	X	X	6	499.5	1.94	0.14	0.71	-243.63
5	X			X		4	499.92	2.37	0.11	0.82	-245.9
15	X	X	X	X	X	7	500.51	2.96	0.08	0.9	-243.09
11	X			X	X	5	501.81	4.25	0.04	0.95	-245.82
8	X	X		X		5	501.97	4.42	0.04	0.98	-245.9
14	X	X		X	X	6	503.88	6.32	0.02	1	-245.82
3	X		X			4	512.38	14.83	0	1	-252.13
6	X	X	X			5	513.4	15.85	0	1	-251.62
9	X		X		X	5	514.25	16.7	0	1	-252.04
1	X					3	515.14	17.59	0	1	-254.54
12	X	X	X		X	6	515.31	17.76	0	1	-251.54
4	X				X	4	516.95	19.4	0	1	-254.42
2	X	X				4	517.19	19.64	0	1	-254.54
7	X	X			X	5	519.01	21.46	0	1	-254.42

AICc, Aikaike Information Criterion corrected for small sample size; AICc ω, Aikaike weight; LL, log likelihood.

b) Cover in a 20 cm sphere (%)

Model	Intercept	Treatment	Sex	Temperature	Rel. Humidity	K	AICc	Δ AICc	AICc ω	Cumulative ω	LL
5	X			X		4	789.18	0	0.39	0.39	-390.5
10	X		X	X		5	791.16	1.98	0.15	0.54	-390.45
11	X			X	X	5	791.25	2.08	0.14	0.67	-390.49
8	X	X		X		5	791.27	2.09	0.14	0.81	-390.5
13	X	X	X	X		6	793.24	4.07	0.05	0.86	-390.43
16	X		X	X	X	6	793.24	4.07	0.05	0.91	-390.44
14	X	X		X	X	6	793.36	4.18	0.05	0.96	-390.49
15	X	X	X	X	X	7	795.34	6.17	0.02	0.98	-390.42
1	X					3	797.05	7.88	0.01	0.99	-395.47
3	X		X			4	799.02	9.84	0	0.99	-395.42
4	X				X	4	799.12	9.94	0	0.99	-395.47
2	X	X				4	799.12	9.95	0	1	-395.47
6	X	X	X			5	801.08	11.91	0	1	-395.41
9	X		X		X	5	801.1	11.92	0	1	-395.42
7	X	X			X	5	801.21	12.03	0	1	-395.47
12	X	X	X		X	6	803.18	14	0	1	-395.41

AICc, Aikaike Information Criterion corrected for small sample size; AICc ω, Aikaike weight; LL, log likelihood.

c) Cover in a 1 m sphere (%)

Model	Intercept	Treatment	Sex	Temperature	Rel. Humidity	K	AICc	Δ AICc	AICc ω	Cumulative ω	LL
5	X			X		4	679.44	0	0.38	0.38	-335.63
8	X	X		X		5	681.28	1.84	0.15	0.53	-335.51
11	X			X	X	5	681.47	2.03	0.14	0.67	-335.6
10	X		X	X		5	681.48	2.04	0.14	0.8	-335.61
13	X	X	X	X		6	683.17	3.73	0.06	0.86	-335.4
14	X	X		X	X	6	683.33	3.89	0.05	0.92	-335.48
16	X		X	X	X	6	683.52	4.08	0.05	0.97	-335.57
15	X	X	X	X	X	7	685.21	5.77	0.02	0.99	-335.36
1	X					3	688.25	8.81	0	0.99	-341.07
2	X	X				4	690.07	10.63	0	0.99	-340.95
4	X				X	4	690.26	10.82	0	1	-341.04
3	X		X			4	690.29	10.85	0	1	-341.06
7	X	X			X	5	692.09	12.65	0	1	-340.91
6	X	X	X			5	692	12.57	0	1	-340.87
9	X		X		X	5	692.31	12.87	0	1	-341.02
12	X	X	X		X	6	694.02	14.58	0	1	-340.83

AICc, Aikaike Information Criterion corrected for small sample size; AICc ω, Aikaike weight; LL, log likelihood.