

Conserv-Vision Conference Proceedings

The University of Waikato



A CELEBRATION OF 20 YEARS OF CONSERVATION BY
NEW ZEALAND'S DEPARTMENT OF CONSERVATION

CONFERENCE PROCEEDINGS EDITED BY:

Dr Bruce Clarkson, Dr Priya Kurian, Todd Nachowitz, & Dr Hamish Rennie

Article © 2008 Matthew Baber, Kimberly Babbitt, Ria Brejaart, Graham Ussher,
Nicole DiManno and Graham Sexton

Article Title: "Does mammalian pest control benefit New Zealand's Hochstetter's frog (*Leiopelma hochstetteri*)?"

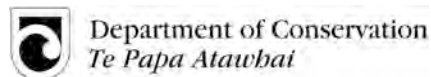
Author(s): Matthew J. Baber, Kimberly J. Babbitt, Ria Brejaart, Graham T. Ussher, Nicole DiManno,
and Graham Sexton

Publication Date: 4 November 2008

Source: Proceedings of the Conserv-Vision Conference, University of Waikato, 2-4 July 2007

Published by: The University of Waikato, Private Bag 3105, Hamilton, New Zealand

Stable URL: www.waikato.ac.nz/wfass/conserv-vision



Does mammalian pest control benefit New Zealand's Hochstetter's frog (*Leiopelma hochstetteri*)?

Matthew J. Baber^{a*}, Kimberly J. Babbitt^b, Ria Brejaart^c, Graham T. Ussher^d, Nicole DiManno^b, and Graham Sexton^{a,b}

^{a*} Auckland Regional Council, Private Bag 90012, Auckland New Zealand.

^b Department of Natural Resources, University of New Hampshire, Durham New Hampshire 03824, USA

^c EcoQuest Education Foundation, RD3, East Coast Road, Pokeno, New Zealand

^d Tonkin and Taylor Ltd, 105 Carlton Gore Road, Newmarket, Auckland, New Zealand

* Corresponding Author: Tel.: +64 09 4863-229. E-mail addresses: matt.baber@arc.govt.nz

Abstract

Introduced mammalian predators are considered the primary threat to New Zealand's native amphibians, yet efforts to control or eradicate these predators for recovery of threatened amphibian populations are few. Control of introduced mammalian predators for recovery of a threatened bird (North Island kokako, *Callaeus cinerea wilsoni*) is conducted in an area that includes the threatened Hochstetter's frog (*Leiopelma hochstetteri*). We compared the relative abundance of Hochstetter's frog to levels of mammalian pest control in the Hunua Ranges, Auckland, New Zealand. Study areas were subject to either long-term (> 14 years) high intensity pest control (within the Kokako Management Area, KMA), or long-term low intensity pest control. We sampled a total of 24, 20 m-long stream reaches in five streams within the KMA, and 48, 20m-long stream reaches in four streams outside the KMA in November 2005 and again in April 2006. Frog abundance / person hour searched was significantly higher within the KMA ($T_{1,7} = 6.51, p = 0.001$), and mean snout-urostyle length (SUL) of frogs was lower ($T_{1,141} = 2.632, p = 0.009$), which corresponded to a higher the proportion of juveniles. Our study suggests that mammalian pest control for the recovery of the kokako may benefit Hochstetter's frog populations, and that Hochstetter's frog may be a useful bio-indicator for measuring the success of mammalian pest control/eradication initiatives. As such, this study also implies that single-species management for recovery of target species may confer benefits to non-target native taxa. However, the contribution of single-species conservation management for threatened species to overall ecosystem integrity and recovery is not well monitored, and further research is warranted to improve management techniques.

Keywords: Amphibians; Anurans; Ecological Restoration, Frogs; Hochstetter's Frog; Introduced Mammals; Introduced Pests, *Leiopelma hochstetteri*; New Zealand; Pest Control; Restoration Ecology

1. Introduction

Amphibians are suffering from extinctions, range contractions, and population declines on a global scale (Blaustein et al., 1994; Stuart et al., 2004; Lips et al., 2005). These trends are strongly linked to anthropogenic disturbances, including habitat alteration, disease and pathogens, global climate change, increased UVB radiation, invasive species, chemical contamination, and commercial trade (Blaustein et al., 1994; Stuart et al., 2004). Accordingly, increasing focus is now placed on amphibians both for their conservation value, and because they are good indicators of ecosystem change and health (Semlitsch, 2000).

New Zealand's native anurans (genus *Leiopelma*) are an ancient endemic group that have retained unique and primitive characteristics not found in more derived species (Daugherty et al., 1994; Bell, 1994). Although native amphibian diversity is low, New Zealand's amphibians have suffered the highest proportional biodiversity loss in the world. Before human colonization, native anurans included seven known species, which were widespread and abundant. Since human arrival, three species have declined to extinction, and the remaining four species, Archey's frog (*L. archeyi*), Hamilton's frog (*L. hamiltoni*), Hochstetter's frog (*L. hochstetteri*), and Maud Island frog (*L. pakeka*) have suffered drastic range reductions and population declines. Archey's and Hochstetter's frogs still exist in scattered localities on New Zealand's North Island, whereas Maud Island and Hamilton's frog are confined to small offshore island(s) free of introduced mammals (Bell et al., 2004). Loss of New Zealand's native amphibian biodiversity is largely attributed to predation from introduced mammalian predators such as rodents and mustelids (Bell, 1994; Newman, 1996), although habitat alteration, and more recently, chytrid fungus (*Batrachochytrium dendrobatidis*) are significant contributors (Bell et al., 2004).

Introduced mammals are considered the primary threat to New Zealand's native biodiversity, thus control of introduced mammals is often employed to facilitate the recovery of targeted threatened species (Towns and Daugherty, 1994; Mander et al., 1998; Saunders and Norton, 2001). Pest management strategies often focus on the recovery of specific threatened species by controlling only those pests known to be significant predators or competitors. For example, recovery of the threatened North Island kokako (*Calleaus cinerea wilsoni*) is largely dependent on the effective management of Australian brushtail possums (*Trichosurus vulpecula*) and ship rats (*Rattus rattus*), rather than the entire suite of mammalian pests (Innes et al., 1999; Innes and Flux, 1999). This single-species management approach has been criticized in recent years as ecologists have become increasingly focused on restoring ecosystem function (Tracy and Brussard, 1994; Christensen et al., 1996; Simberloff and Suter, 1998; Fairburn et al., 2004). Nevertheless, it is possible that pest control efforts focused on recovery of a single species confer benefits to non-target native taxa, and therefore, contribute to overall ecosystem recovery. However, benefits of single-species management to non-target native taxa are rarely studied, and therefore, poorly understood.

To our knowledge, there is only one pest control/eradication initiatives conducted specifically for the recovery of native amphibians (Haigh et al. 2007). However, the distribution of native amphibians overlaps at several sites where pest management is occurring for the benefit of other threatened species or ecosystem health in general. One of these sites is in the Hunua ranges, Auckland, where

control of introduced mammalian predators for recovery of kokako is conducted in an area that includes the threatened Hochstetter's frog (*Leiopelma hochstetteri*). The objective of this study was to determine if pest control management for kokako confers benefits to Hochstetter's frog. Hochstetter's frog is nocturnal and semi-aquatic, lives in wet habitats alongside shaded streams and seepages, and tends to shelter beneath rocks and logs (McLennan, 1985; Newman and Towns, 1985; Wakelin et al., 2003). This species is the most widespread and abundant of the extant native amphibians, yet is classified as "at risk" in the Red Data Book of the IUCN (International Union for the Conservation of Nature), and is ranked as "sparse", in the Department of Conservation (DOC) threatened species ranking system (Hitchmough, 2002).

We examined relative abundance and population structure inside and outside an area managed for kokako recovery to determine if the intensity of pest control benefits Hochstetter's frog populations. We hypothesized that populations in areas with intensive mammalian pest control would be more abundant and would have a higher proportion of younger age classes compared with areas receiving only low intensity mammalian pest control. This study is important because it is one of the first to examine the potential influence of mammalian pests on a native New Zealand amphibian, and the degree to which mammalian pest control initiatives can lead to recovery of native amphibian populations.

2. Methods

2.1. Study Area

We conducted this study in the Hunua Ranges, located approximately 90 km south-east of Auckland. Considerable areas of forest in the Hunua Ranges were felled or burnt prior to 1930, but since then many of those areas have reverted back to native forest, and the Ranges now supports the largest area of continuous forest cover (17,000 ha) in the South Auckland area. The forest consists of predominately of tawa (*Beilschmiedia tawa*) and taraire (*B. tarairie*) or tawa and kohekohe (*Dysoxylum spectabile*) with emergent podocarps. Areas of rimu (*Dacrydium cupressinum*), hard beech (*Nothofagus truncata*), and kauri (*Agathis australis*) forest also occur (Barton, 1972). Elevation ranges from 100 – 688 m above sea level (asl). Mean annual rainfall is 152 cm and mean annual temperature is 14 °C (Barton, 1972).

The Kokako Management Area (KMA) is 850 ha and has been subjected to intensive mammalian pest control since 1994, predominately to protect a relict kokako population. The forest canopy is dominated by mature tawa but includes northern rata (*Metrosideros robusta*), rewarewa (*Knightia excelsa*), and rimu (*Dacrydium cupressinum*), with abundant tawheowheo (*Quintinia serrata*) at higher altitudes. The KMA ranges from 400 – 688 m asl. Pest control within the KMA consists of bait stations and traps (ca. 1/ha) aimed at maintaining mammalian predators, particularly ship rats, possums, and stoats, to extremely low levels. The poison bait used in the KMA is Pestoff® possum pellets containing 20 ppm brodifacoum, manufactured by Animal Control Products Ltd., Wanganui, New Zealand, which is effective against rats and possums. The poison is delivered in Philproof® mini-

possum bait stations, which are baited between August and March each year. Mustelids are killed with Fenn traps (placed under wooden or wire mesh tunnels) baited with hen eggs or pieces of fresh rabbit. The programme closely follows management protocols and operational goals outlined in the Department of Conservation (DOC) Kokako Recovery Plan (Innes and Flux 1999). Target pest control indices are 1% residual trap catch (RTC) for possums and 1% tracking tunnel rate for ship rats, by 1 November each year (see Innes *et al.*, 1999). Feral goats (*Capra hircus*) and feral pigs (*Sus scrofa*) have been controlled by shooting, and at the time of the study numbers were well below 1 goat / 20 ha (Frank Pavitt, pers. comm.). Feral deer (*Cervus* spp.) are absent from the Hunua Ranges.

The Rata Ridge study area (ca. 200 ha) lies 3 km south-east of the KMA. It has similar tawa-dominated forest to the KMA, but its elevation is lower at 300 – 450 m asl. The Milne Stream catchment site (ca. 200 ha) lies 8 km south-east of the KMA and has younger, regenerating tawa forest, ranging in altitude between 150 and 300 m asl. These latter two sites have a history of baseline possum control, which is conducted over the entire Hunua Ranges on about a 3 – 4 year cycle using a combination of Victor[®] leg-hold traps, and Feratox[®] cyanide and brodifacoum poison baits. In addition to the baseline control above, Feratox (cholecalciferol) poison bait was used in the Milne Stream catchment in September 2005 in an attempt to control ship rats. However, monitoring with rodent tracking tunnels suggested that this baiting was ineffective and the bait was withdrawn after three months.

2.2 Study Design

We selected five streams (first and second-order) within the KMA using a random stratified procedure to ensure that streams in all areas of the KMA were equally represented. Four streams (first and second-order) were selected outside the KMA, three at Milne Stream area and one at Rata Ridge. Streams in these areas were selected because they were in relatively close proximity to the KMA, and had similar surrounding forest types and stream characteristics. However, this study was limited by the absence of suitable and accessible streams outside the KMA that were similar in elevation.

We sampled a total of 24, 20 m-long stream reaches in the five streams in the KMA, and 48, 20 m-long stream reaches in the four streams outside the KMA. Sampled reaches were selected randomly from all 20 m stream reaches that included at least 10 linear meters of suitable habitat, which consisted of year round waterflow, total canopy cover and the availability of loose rocks near the stream edge, which serve as habitat refugia for frogs. The number of reaches sampled within each stream ranged from 3 – 24, and was dependent on stream length (which ranged from 120 – 1060m), and the proportion of suitable habitat within the stream. Sites were sampled from the 10 – 19th November, 2005 and again from the 11 – 24th April 2006. Half of the reaches (odd numbered reaches) were sampled in November and the other half (even numbered reaches) were sampled in April. Patterns of relative abundance inside versus outside the KMA were similar across the two sampling periods

(Baber et al., unpub. data); therefore we combined data collected in November and April for all analyses.

To more directly attribute any differences in relative abundance of Hochstetter's frog among sites to mammalian pest control, we determined ship rat incidence using tracking tunnels in the three study areas. Methodology for tracking tunnels followed DOC national protocols. In each study area, we randomly placed three tracking lines, with each line consisting of 10 stations spaced at 50 m intervals. Each station included a single tracking tunnel with a card and ink pad in the middle of card, and baited with peanut butter. At each study area, stations were set and run over a single fine night (no rain) during both sampling periods (April and November).

2.3 Data Collection

Searching methods followed commonly used protocol for Hochstetter's frog surveys (Parrish, 1994; Whitaker and Alspach, 1998; Mussett, 2005). We conducted searches during the day when frogs are inactive and under cover (Newman 1996; Bell 1996). Search profiles extended between stream berms but did not include sites beneath the water level. We examined all available cover (i.e., loose rocks, logs, or other debris) for frogs provided it could be lifted and returned to virtually the same position without posing risk to frogs. We used headlamps to increase visibility of frogs. Before starting fieldwork each day, we liberally applied TriGene™ to boots and clothing to reduce the risk of spreading fungal pathogens (e.g., chytrid fungus), as per recommendations from the DOC Native Frog Recovery Group.

At each sampling site, we recorded stream width at 0, 10, and 20 m along the transect. We also recorded the number of cover objects turned (as an indication of relative availability of refugia), and time spent searching. We recorded snout-urostyle length (SUL) of each frog we located (to the nearest mm) by placing a ruler alongside the frog (as per DOC protocols). Frogs were not handled to minimise stress and the possibility of disease transmission. We used SUL to assign frogs into age classes based on size categories (juveniles < 18 mm, subadults 18 – 29 mm, adults 30 – 39 mm, and large females > 39 mm) to assess population structure (Bell 1978; Bell pers. comm.). We also measured microhabitat characteristics such as distance from stream edge, cover object type (rock, log, leaf litter), and surface area of each cover object under which we located a frog. The relationship between microhabitat characteristics and frogs will be reported elsewhere (Baber et al., unpub data).

2.4 Data Analysis

We tested for significant differences in the mean relative abundance (mean frog abundance / 20 m / person hour searched) and mean size (SUL) of Hochstetter's frogs between streams outside the KMA (Rata Ridge and Milne Stream) and streams within KMA study areas. To minimise spatial autocorrelation, each stream (n = 4 outside KMA and n = 5 inside KMA) functioned as an independent replicate for statistical analysis. The 20 m sections surveyed within each stream were

therefore considered subsamples from which we obtained (for each stream) an average mean number of frogs / 20 m / person hour searched. We also tested for differences among study areas in measured habitat and search effort descriptors (mean stream width, mean cover objects turned, and mean time searched). All data conformed to assumptions of normality, as determined by one sample Kolmogorov-Smirnov tests ($p < 0.05$) and we therefore used T-tests to test for significant differences in frog, habitat, and search time descriptors between streams in the KMA and outside the KMA. We used a generalized linear model to determine if there was a significant relationship between the number of frogs detected at a site and search time. Significance was set at $p < 0.05$, and statistical analyses were conducted using SYSTAT 10.0 (SPSS 2002).

3. Results

3.1. Frog abundance and size

We detected 149 frogs during 35.9 person hours of searching. Of the 143 individuals measured (6 escaped before measurements were obtained), mean SUL was $27.7 \text{ mm} \pm 0.70$ (SE), and ranged from 6 – 48 mm. The mean number of frogs recorded per person hour searching time was higher in streams in the KMA than those outside KMA ($T_{1,7} = 6.51, p = 0.001$) (Fig. 1). Mean frog size (SUL) was significantly lower in the KMA than outside the KMA ($T\text{-test}, T_{1,141} = 2.632, p = 0.009$) (Fig. 2), which was due to the higher relative proportion of juveniles in the KMA (21.0%) compared to outside the KMA (9.9%) (Fig. 3).

3.2 Stream habitat and search time descriptors

Neither the number of available habitat refugia (as indicated by the number of cover objects searched) ($T_{1,7} = -0.215, p = 0.838$) nor stream width ($T_{1,7} = -1.487, p = 0.181$) differed significantly between study areas (Table 1). Mean search time was significantly higher within the KMA study area ($T_{1,7} = 2.582, p = 0.037$). Differences in search between study areas reflects the increase in time processing found frogs as reflected by the positive relationship between search time and the number of frogs found ($F_{1,70} = 21.387, p < 0.0001$).

3.3 Ship Rat Tracking Indices

We documented RTIs of 8% in the KMA, and 38.75% in study areas outside the KMA (Milne and Rata Ridge combined).

4. Discussion

4.1 Effects of mammalian pest control on Hochstetter's frog

This study examined the relative abundance of New Zealand's native Hochstetter's frog in relation to mammalian pest control efforts in the Hunua Ranges, Auckland, New Zealand. Our findings indicate that frog abundance was significantly higher within the KMA than in areas outside the KMA that were subject to much lower levels of pest control. In support of our findings, Baber (2006) also found higher relative abundances of frogs inside the KMA than outside. The relative abundance of Hochstetter frogs recorded in the KMA (this study, Mussett, 2005; Crossland et al., unpub data; Baber, 2006) are the highest recorded (Parrish, 1994; Whitaker and Alpsach, 1998; Ziegler, 1999; Baber et al., 2006). Coincidentally, this is the only amphibian study, for which data is available, that is conducted in an area subject to mammalian pest control.

Introduced mammals may also influence population structure, as indicated by the smaller mean size (SUL) of frogs, and the higher proportion of juveniles in the KMA. Other frog surveys conducted (in areas not controlled for mammalian pests) also found a relatively low proportion of juvenile frogs. Bradfield (2005) recorded only 1.4% of frogs as juveniles, in the Waitakere Ranges, Auckland, and similarly juveniles made up only 2.7% of frogs recorded in the Coromandel Peninsula (Whittaker and Alpsach, 1998). It is not known why differences exist in the proportion of juveniles in Hunua Ranges compared to other sites. Furthermore, it is unclear how introduced mammals may be influencing population structure. This may be attributed to ontogenetic differences in palatability or susceptibility to introduced mammals or a whole suite of other indirect or direct effects. Palatability of several amphibians is known to be higher in early larval or juvenile stages due to incomplete development of toxic granular glands in the skin (Formanowicz and Brodie, 1982; Pearl and Hayes, 2002). This has never been tested for native New Zealand amphibians.

Introduced mammals are likely to be the most serious threat to Hochstetter's frogs. Ship rats (*Rattus spp.*) are considered a primary factor contributing to the extinction of New Zealand's herpetofauna (Towns and Daugherty, 1994; Bell, 1994; Thurley and Bell, 1994) and are known to predate on both Archey's and Hochstetter's frog (Thurley and Bell, 1994). At present, only ship rats occur in high abundance in the Hunua Ranges, although the Pacific (*R. exulans*) and Norway rat (*R. norvegicus*) attained high abundances on the New Zealand mainland in the past. Ship rats generally avoid wetlands and stream areas. However, Hochstetter's frogs are known to disperse across upland habitats and there can be considerable movement between streams (Slaven, 1992).

Other introduced mammalian predators such as mustelids and cats (*Felis catus*) are also likely to contribute to the decline of native anurans and are present in the Hunua Ranges. In April 2005, conservation workers observed a stoat with a live Hochstetter's frog in its mouth. The frog was recovered but died shortly afterwards, presumably from teeth puncture wounds and stress. It is also likely that two dead frogs found in the KMA during this study were predated on by stoats, as

indicated by puncture wounds (Smale, DOC, pers. comm.). Feral cats and stoats were controlled in the KMA but not outside the KMA. Feral pigs can destroy frog habitat by trampling and foraging on the edge of streams (Townsend and Daugherty, 1994; Mussett, 2005). Pigs are known to feed on lizards and tuatara (Townsend and Daugherty, 1994) and are likely to opportunistically predate Hochstetter's frogs. Pig disturbance was low in streams surveyed during this study but has been reported high elsewhere (Baber et al., 2006). Feral pigs were not controlled for in the KMA.

This is the first study to report on the effect of mammalian pest control on a New Zealand native frog population and our results suggest that Hochstetter's respond positively to mammalian control. As such, the control or eradication of mammalian pests may be important to the continued survival of Hochstetter's frog. Moreover, where they occur, native frogs may be useful bioindicators with which to assess the effects of pest control on native species. However, these findings should be treated with caution as this was a preliminary study and further research is needed. Future studies should include increased replication of streams, selection of study areas more similar in habitat characteristics (in particular, we were unable to control for elevation as the KMA was also the highest area in the Hunua Ranges), baseline data on relative abundance of Hochstetter's frog prior to initiation of pest control operations, better measures of predator abundance, and more direct evidence on rates of predation by mammalian predators. Furthermore, it is very difficult to make inferences based on comparisons with other studies as raw data counts are largely influenced by spatial and temporal variations in detection probability, e.g., among habitats, seasons, age classes, or observers (MacKenzie and Kendall, 2002; Bailey et al., 2004; Crossland et al., 2005). Alternate monitoring techniques based on site-occupancy modeling (MacKenzie et al., 2002; 2003) are currently being assessed for Hochstetter's frogs to improve the quality and reliability of data (Crossland et al., 2005).

4.2. Single-species Management

The importance of taking an ecosystem approach to species conservation is well documented in the ecological and conservation literatures. Consequently, single-species management has been increasingly challenged as our understanding of the need to incorporate ecosystem management approaches has developed (Simberloff and Suter, 1998; Fleming and Alexander, 2002; Fairburn et al., 2004). However, the results of this study suggest that the single-species management approach may confer benefits to non-target native species, and therefore provide wider ecosystem benefits. Likewise, (Baber et al. in review) attributed the higher abundance of several native bird species within the KMA to lower abundances of mammalian predators and competitors, particularly ship rats and possums. To our knowledge, benefits of single-species management programs to non-target native wildlife are generally not factored into cost-feasibility of single-species management programs in New Zealand, largely because the response of non-target species are rarely monitored (Fairburn et al., 2004). We recommend, where feasible, increased efforts to conduct ecological monitoring at multiple taxonomic levels to better understand the effects of environmental management on native non-target wildlife and ecosystem processes. Through such efforts, managers may better predict or

determine pest control efforts necessary to improve ecosystem function to desired levels beyond just management of targeted threatened species.

Table 1. Comparisons of habitat descriptors and indices of sampling effort (mean ± se). inside and outside the Kokako Management Area (KMA) in the Hunua Ranges, Auckland, New Zealand.

Descriptors	Combined	Inside KMA	Outside KMA
Mean Stream Width (cm)	140 ± 17.6	118 ± 12.1	167.2 ± 34.3
Mean Search Time.	29.9 ± 2.07	33.5 ± 2.15	25.3 ± 2.33
Mean Cover Objects Turned	229 ± 17.9	225 ± 22.0	233.6 ± 33.3

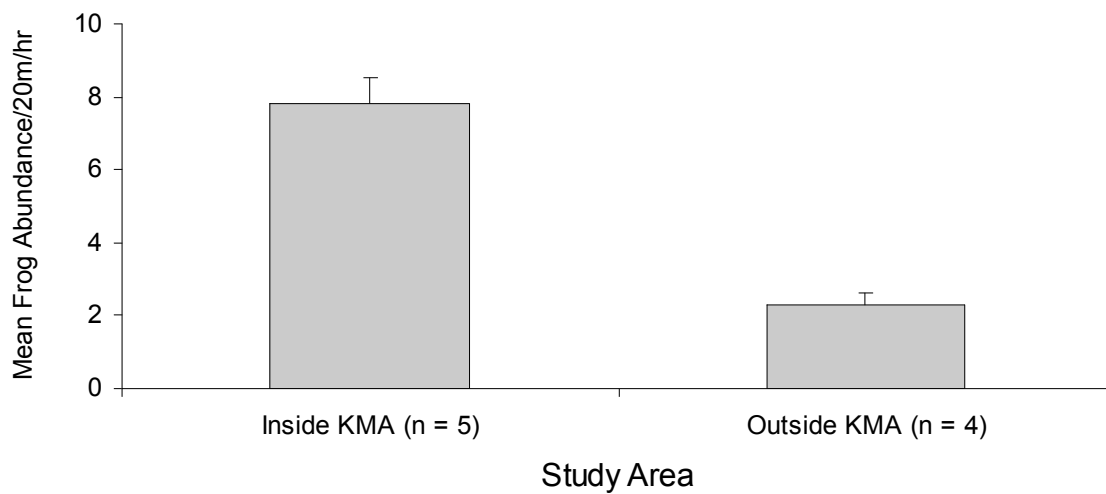


Fig. 1. Mean relative abundance of Hochstetter’s frogs / 20m / hour searched inside and outside the Kokako Management Area (KMA), Hunua Ranges, Auckland, New Zealand. Number of streams sampled in each study area is indicated in brackets.

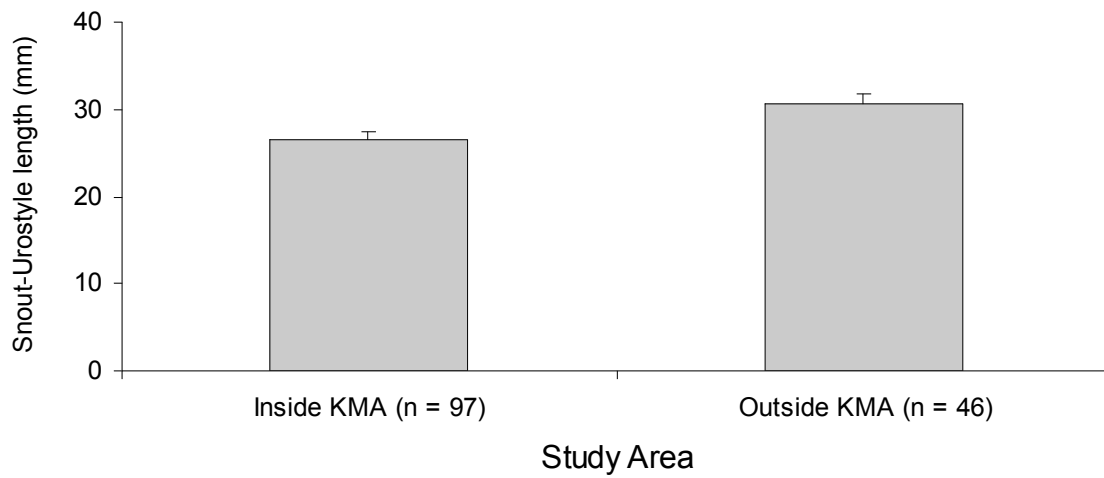


Fig. 2. Mean Hochstetter's frog snout-urostyle length (SUL) inside and outside the Kokako Management Area (KMA). The number of individuals measured are indicated in brackets.

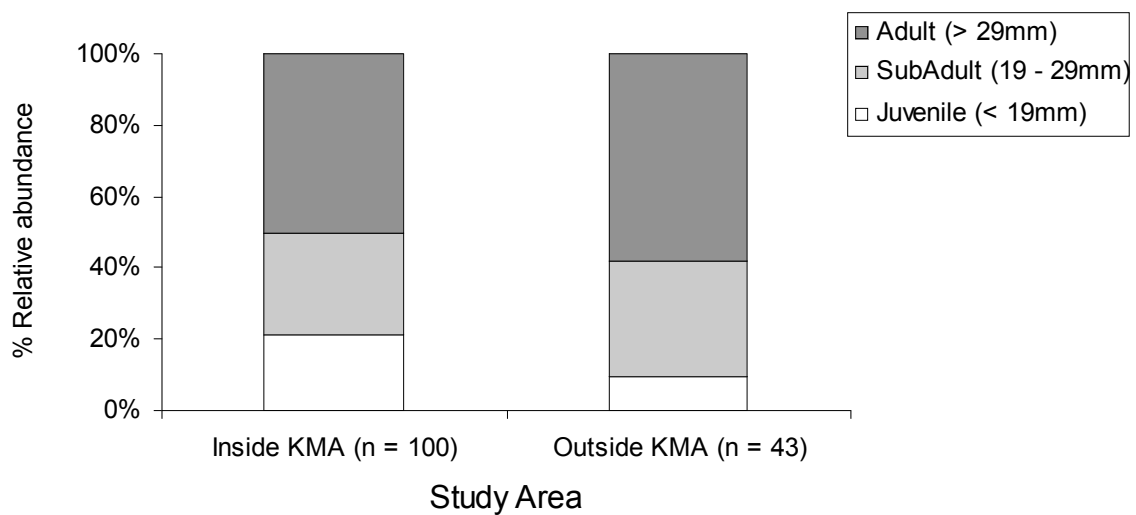


Fig. 3. Population structure of Hochstetter's frogs inside and outside the Kokako Management Area (KMA) in the Hunua Ranges, Auckland, New Zealand.

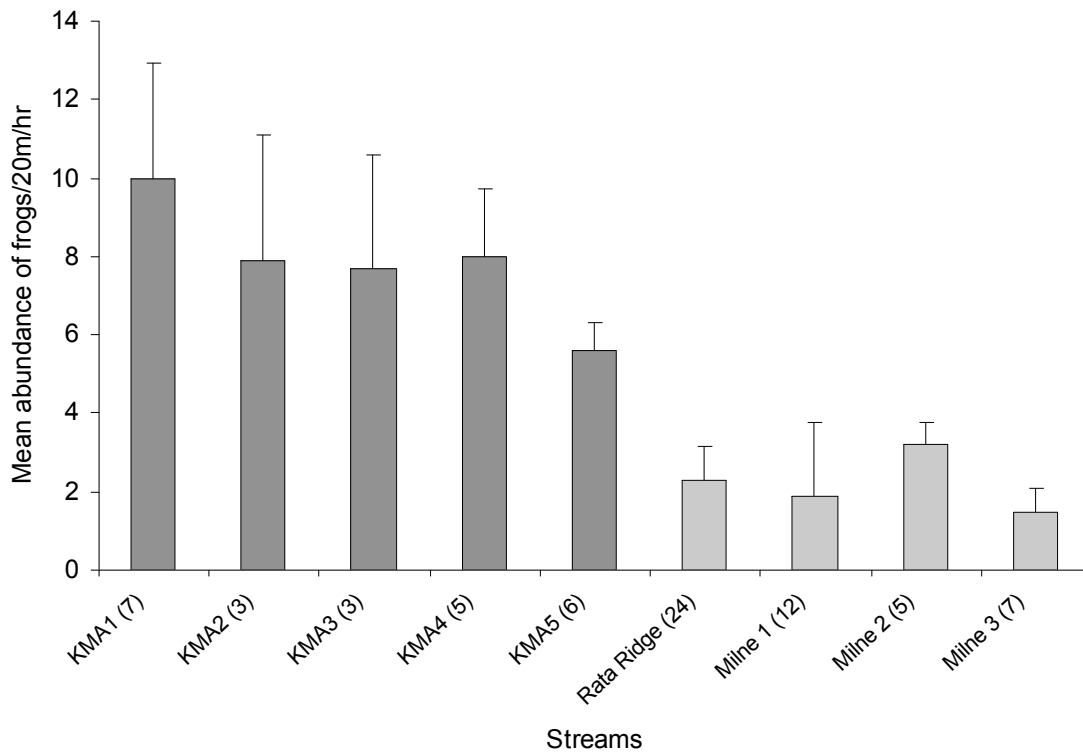


Fig. 4. Mean relative abundance of Hochstetter’s frogs / 20m / hr searched for each of the nine streams searched in the Hunua Ranges, Auckland, New Zealand.

ACKNOWLEDGMENTS

We are very grateful to Caroline Crofton and Meghan Laird for undertaking fieldwork as part of their EcoQuest Directed Research Projects and a special thanks to Elizabeth Jones, for field assistance and leadership. We thank the Department of Conservation and Ngati Paoa, Ngati Whanaunga, and Ngaitai-ki-Umupuia, for permission to undertake frog surveys in the Hunua Ranges. We particularly thank Hazel Speed (DOC), Rosemary Gatland (ARC) and the volunteers for their pest control and kokako monitoring work in the Kokako Management Area. Finally, we wish to thank Leigh Marshall and an anonymous reviewer for comments on earlier drafts of this manuscript.

REFERENCES

- Baber, M.J., 2006. A Survey for Hochstetter's frog in the Hunua Ranges, May – July, 2006. Report to Heritage Division, Auckland Regional Council, Auckland, New Zealand.
- Baber, M.J., Moulton, H., Smuts-Kennedy, C.A., Gemmell, N., Crossland, M., 2006. Discovery and spatial assessment of a Hochstetter's frog (*Leiopelma hochstetteri*) population recently discovered in Maungatautari Scenic Reserve, New Zealand. *New Zealand Journal of Zoology*, 33, 147–156.
- Baber, M.J., Brejaart R., Babbitt, K.J., Lovegrove, T.G., Ussher, G.T. In Review. Response of non-target native birds to mammalian pest control for kokako in the Hunua Ranges, Auckland, New Zealand. *New Zealand Journal of Ecology*.
- Bailey, L.L., Simons, T.R., Pollock, K.H., 2004. Estimating detection probability parameters for *Plethodon* salamanders using the robust capture-recapture design. *Journal of Wildlife Management* 68, 1–13.
- Barton, I.L., 1972. On the vegetation of the Hunua. Ranges. *New Zealand Journal of Botany* 10, 8–26.
- Bell, B.D., 1978. Observations on the ecology and reproduction of the New Zealand native frogs. *Herpetologica* 34, 340–354.
- Bell, B.D., 1994. A review of the status of New Zealand *Leiopelma* species (*Anura Leiopelmatidae*), including a summary of demographic studies in Coromandel and on Maud Island. *New Zealand Journal of Zoology* 21, 341–349.
- Bell, B.D., 1996. Aspects of the Ecological Management of New Zealand Frogs: Conservation status, location, identification, examination and survey techniques. *Ecological Management* 4, 91–111.
- Bell, B.D., Pledger, S., Dewhurst, P.L., 2004. The fate of a population of the endemic frog *Leiopelma pakeka* (*Anura: Leiopelmatidae*) translocated to restored habitat on Maud Island, New Zealand. *New Zealand Journal of Zoology* 31, 123–131.
- Bell, B.D., Carver, S., Mitchell, N.J., Pledger, S., 2004. The recent decline of a New Zealand endemic: how and why did populations of Archey's frog *Leiopelma archeyi* crash over 1996 –2001? *Biological Conservation* 120, 189–199.
- Blaustein, A.R., Wake, D.B., Sousa, W.P., 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations in local and global extinctions. *Conservation Biology* 8, 60–71.
- Bradfield, K.S. 2005. A Survey for Hochstetter's frog (*Leiopelma hochstetteri*) in the Waitakere Ranges and Tawharanui Regional Parklands, 2004/05. ARC Internal report. Auckland Regional Council, Auckland, NZ.
- Bridges, C.A.M., Boone, M.D., 2003. The interactive effects of UV-B and insecticide exposure on tadpole survival, growth and development. *Biological Conservation* 113, 49–54.
- Campbell, D.J., Aitkinson, I.A.E., 1999. Effects of Kiore (*Rattus exulans*, Peale) on recruitment of indigenous coastal trees on northern offshore islands of New Zealand, *Journal of the Royal Society of New Zealand* 29, 265–290.
- Christensen, N.L.; Bartuska, A.M., Brown, J.H., Carpenter, S., D'Antonio, C.A., Francis, R., Franklin, J.F., MacMahon, J.A., Noss, R.F., Parsons, D.J., Peterson, C.A.H., Turner, M.G., and Woodmansee, R.G., 1996. The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management, *Ecological Applications*: 6: 665–691.

- Crossland, M.R., Mackenzie, D.I., Holzapfel, S., 2005. Assessment of site-occupancy modeling as a technique to monitor Hochstetter's frog (*Leiopelma hochstetteri*) populations. DOC Research and Development Series 218, Department of Conservation, Wellington, New Zealand.
- Daugherty, C.A., Patterson, G., Hitchmough, R., 1994. Taxonomic and conservation review of the New Zealand Herpetofauna. *New Zealand Journal of Zoology* 21, 317–323.
- Fairburn, G.A., Hughey, K.F.D., Cullen, R., 2004. Cost effectiveness of endangered species management: the kokako (*Callaeas cinerea*) in New Zealand. *New Zealand Journal of Ecology* 28, 83–91.
- Fleming, C.A.M., Alexander, R.R., 2002. Single species versus multiple species models: the economic implications. Discussion paper in natural resource and environmental economics no. 23. Center for Applied Economics and Policy Studies, Massey University, Palmerston North, NZ.
- Formanowicz, D.R. Jr., Brodie, E.D. Jr., 1982. Relative palatabilities of members of a larval amphibian community. *Copeia*, 1982, 91–97.
- Haigh, A., Pledger, S., and Holzapfel, S. 2007. Population monitoring programme for Archey's frog (*Leiopelma archeyi*): pilot studies, monitoring design and data analysis. DOC Research and Development Series 278, Department of Conservation, Wellington, NZ.
- Hitchmough, R., 2002. New Zealand threat classification systems lists, 2002. Threatened Species Occasional Publication, vl 23, Department of Conservation, Wellington.
- Innes, J., Flux, I., 1999. North Island Kokako Recovery Plan. Department of Conservation Threatened Species Recovery Plan 30. Department of Conservation, Wellington, NZ.
- Innes, J., Hay, R., Flux, I., Bradfield, P., Speed, H., Jansen, P., 1999. Successful recovery of North Island kokako *Callaeas cinerea wilsoni* populations, by adaptive management. *Biological Conservation* 87, 201–214.
- Lips, K.R., Borrowes, P.A., Mendelson, J.R., Parra-Olea, G., 2005. Amphibian declines in Latin America: Widespread population declines, extinctions, and impacts. *Biotropica* 37, 163–165.
- MacKenzie, D. I.; Kendall, W. L. 2002. How should detection probability be incorporated into estimates of relative abundance? *Ecology* 83: 2387-2393.
- MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Royle, J.A., Langtimm, C.A.A., 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83, 2248–2255.
- MacKenzie, D.I., Nichols, J.D., Hines, J.E., Knutson, M.G., Franklin, A.B., 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology* 84, 2200–2207.
- Mander, C.A., Hay, R., Powlesland, R., 1998. Monitoring and management of kereru (*Hemiphaga novaeseelandiae*). Department of Conservation Technical Series 15. Department of Conservation, Wellington, N.Z.
- McLennan, J.A., 1985. Some observations on Hochstetter's frog in the catchment of the Motu River, East Cape. *New Zealand Journal of Ecology* 8, 1–4.
- Mussett, S.L., 2005. The effects of pest control on Hochstetter's frog (*Leiopelma hochstetteri*). Unpublished M.Sca. Thesis, University of Auckland.
- Newman, D.G., 1996. Native frog (*Leiopelma* spp.) recovery plan. Threatened Species Recovery Plan Series 18. 29 p. + appendices.

- Newman, D.G., Towns, D.R., 1985. A survey of the herpetofauna of the northern and Southern blocks, Great Barrier Island, New Zealand. *Journal of the Royal Society of New Zealand* 15, 279–287.
- Parrish, R., 1994. Hochstetter frog survey of the Mareretu Forest and Waipu Caves Area. *Moko* 94, 7–8.
- Pearl, C.A.A., Hayes, M., 2002. Predation by Oregon Spotted Frogs (*Rana pretiosa*) on Western Toads (*Bufo boreas*) in Oregon. *American Midland Naturalist* 147, 145–152.
- Saunders, A., Norton, D.A., 2001. Ecological Restoration at mainland islands in New Zealand. *Biological Conservation* 99, 109–119.
- Semlitsch, R.D., 2000. Principles for management of aquatic-breeding amphibians. *Journal of Wildlife Management* 64, 615–631.
- Simberloff, D. Suter, W., 1998. Flagships, umbrellas, and keystones: is single-species management passé in the landscape era. *Biological Conservation* 83: 247-257.
- Slaven, D., 1992. *Leiopelma hochstetteri*: a study of migratory thresholds and conservation status. Unpublished MSc Thesis, University of Auckland.
- Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L., Waller, R.W., 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306, 1783–1786.
- Thurley, T., Bell, B.D., 1994. Habitat distribution and predation on a western population of terrestrial *Leiopelma* (Anura: Leiopelmatidae) in the northern King Country, New Zealand. *New Zealand Journal of Zoology* 21, 431–436.
- Towns, D.R., Daugherty, C.A.H., 1994. Patterns of range contractions and extinctions in the New Zealand herpetofauna following human colonization. *New Zealand Journal of Zoology* 21, 325–339.
- Tracy, C.A., Brussard, P.F., 1994. Preserving Biodiversity: Species in Landscapes *Ecological Applications*, Vol. 4, No. 2 (May, 1994), pp. 205-207
- Wakelin, M., Smuts-Kennedy, C., Thurley, T., and N. Webster. 2003. Artificial cover objects for leiopelmatid frogs. DOC Science Internal Series 120. Department of Conservation, Wellington 17p.
- Whitaker, A.H., Alspach, P.A., 1998. Monitoring Hochstetter's frog (*Leiopelma hochstetteri*) populations near Golden Cross mine, Waitekauri Valley, Coromandel. *Science for Conservation* 130. Department of Conservation, Wellington, New Zealand.
- Ziegler, S., 1999: Distribution, abundance, and habitat preferences of Hochstetter's frog in the Waitakere Ranges. Unpublished MSc Thesis, University of Auckland.

SYSTAT 10.0. SPSS Inc, Chicago, Illinois, USA.