Monitoring of a population of Galápagos land iguanas (*Conolophus subcristatus*) during a rat eradication using brodifacoum

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Abstract Little is known about the toxic effects on reptiles of the anticoagulant rodenticide brodifacoum, which is often used to eradicate introduced rodents from islands. While many islands have both introduced rats and native lizard fauna, the impacts of large scale use of brodifacoum bait on native reptile populations have been largely unstudied. The population of Galápagos land iguanas (*Conolophus subcristatus*) on Seymour Norte, Galápagos, was monitored during a ship rat (*Rattus rattus*) eradication operation. Klerat bait (50 ppm brodifacoum) was applied at approximately 3 kg/ha in two applications in October 2007 in an apparently successful eradication. Six iguanas were found dead afterwards, apparently due to consumption of bait and/or poisoned rats, with overall mortality rate estimated at approximately 4.5% of the population. Iguana deaths were recorded more than two months after bait application, suggesting that reptile mortality may be delayed after a brodifacoum baiting operation and monitoring intervals need to be extended to detect this. The relatively low rate of poison application suggests rat eradication on arid islands may be achievable using less brodifacoum than elsewhere.

Keywords: *Rattus rattus*, density, arid, Seymour Norte.

INTRODUCTION

Introduced rats (*Rattus* spp.) threaten island faunas worldwide. In response, there have been numerous campaigns to eradicate these species in order to safeguard island populations of native birds, reptiles and invertebrates (Howald *et al*. 2007). The most efficacious method for eradication has been the application of 2nd generation anticoagulant rodenticides, particularly brodifacoum, either through aerial or hand broadcast of bait (Howald *et al*. 2007). In general there is a positive response in numbers and condition of native species after rat eradications (Parrish 2005; Daltry 2006; Towns *et al*. 2007; Olivera *et al*. 2010). However, applications of brodifacoum bait can put at risk some of the native species conservation managers are trying to save.

Brodifacoum is known to have non-target impacts on species of mammals and birds, but there is little information about its potential effects on reptiles at a population level through primary and secondary poisoning (Eason and Spurr 1995; Hoare and Hare 2006). Reptiles are known to consume cereal based rodent baits, which appear to be more palatable when wet (Merton 1987; Freeman *et al*. 1996; Marshall and Jewell 2007). On Round Island, Mauritius, during a 1986 rabbit (*Oryctolagus cuniculus*) eradication using cereal-based Talon 20P (20 ppm brodifacoum), at least 100 Telfair's skinks (*Leiolopisma telfairii*) died (Merton 1987). Only the largest lizards were apparently affected and deaths were recorded between three and six weeks after the poison was laid. However, there was no evidence of any effect at a population level and two years later Telfair's skinks were still numerous on the island. In contrast, although Wright's skinks *Mabuya wrightii* consumed Talon 50WB (50 ppm brodifacoum) and Talon 20P during a rat eradication in the Seychelles, no dead skinks were found despite searches for them (Thorsen *et al*. 2000). Secondary exposure of reptiles to brodifacoum was reported by Burbridge (2004), who noted that bungarras (*Varanus gouldii*) ate dead and dying ship rats (*Rattus rattus*) after a 1996 eradication on the Montebello Islands, West Australia, using Pestoff 20R pellet baits (20 ppm brodifacoum). Bungarras were apparently common and in some cases ate so many rats, their droppings were dyed green, presumably from the bait still present in the rats' gastrointestinal tracts. No dead or moribund bungarras were found despite active searches for dead animals. Similarly, there was no detectable decline in a monitored Selvagem Grande, Portuguese Madiera, population of endemic geckos (*Tarentola bishoffii*) after an eradication of mice (*Mus musculus*) and rabbits in 2002 (Olivera *et al*. 2010). The operation used hand-laid Pestoff 20R initially and later Talon wax blocks or Klerat wax block (50 ppm brodifacoum) in bait stations at an overall application rate of approximately 20kg/ha.

This limited evidence suggests that reptiles have a low risk of population-level declines through brodifacoum-induced mortality after rodent eradications. However, to our knowledge, there have been no direct measures of population density of reptiles immediately before, during, and after a field application of brodifacoum baits. Conceivably, populations could decline soon after an eradication through primary or secondary poisoning, or later through multiple year effects on survival or reproduction with potential adverse effects on population genetics. Galápagos land iguanas (*Conolophus subcristatus*: Iguanidiae) are a large (mean adult size: 100 cm) reptile that has undergone severe declines in abundance and distribution through predation by cats (*Felis catus*) and dogs (*Canis lupis familiaris*) and habitat destruction by goats (*Capra hircus*). On Seymour Norte, land iguanas were the only reptile capable of swallowing entire cubes of rodent bait to be used in an eradication attempt. The iguanas were also ideal for monitoring, because of their large size and terrestrial habits.

As a rat eradication was planned for Seymour Norte, we aimed to monitor the effect of brodifacoum on a large reptile in a more systematic manner than previous described and present the results to assist other pest eradications where anticoagulants use was planned and native reptile fauna may be at risk. In this paper, we describe the potential effects of the exposure of iguanas to brodifacoum during an eradication campaign against rats. We undertook small trials with captive iguanas presented with rodent bait and poisoned rodent carcasses. We also conducted a larger field study to investigate potential immediate effects of brodifacoum exposure on iguanas and measure the species' abundance during the rat eradication and over the subsequent six months. We also aimed to determine whether baiting had detectable delayed effects by searching for dead or moribund individuals after the operation.

Pages 309-312 In: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds.). 2011. Island invasives: eradication and management. IUCN, Gland, Switzerland.

METHODS

Poison trials with captive land iguanas

Prior to carrying a rat eradication on Seymour Norte, small-scale bait acceptance trials were carried out on land iguanas in captivity in Charles Darwin Foundation enclosures at Puerto Ayora, Santa Cruz, Galápagos Province, Ecuador. Two young land iguanas deprived of other food for two weeks, were only offered shredded Klerat and a single adult male land iguana was deprived of food for three weeks, at the end of which it was offered five cubes of Klerat. After a further two weeks of fasting the male iguana was then offered a fresh corpse of a ship rat poisoned with Klerat.

Field eradication site

Isla Seymour Norte (184 ha, 90° 17' W, 0° 23' S) north of Baltra and Santa Cruz Islands, Galápagos Province, Ecuador (Fig. 1) is a raised basaltic platform overlaid with a thin layer of soil and open forest of *Opuntia echios* cactus, *Bursera malacophylla*, *Parkinsonia aculeate* and *Scalesia crockeri* (Hamann 1979). Rainfall is highly variable (mean annual precipitation of 228 mm) and mainly in the 'hot' season from January to June.

Native fauna includes Galápagos land iguanas, Galápagos lava lizards (*Microlophus albemarlensis*), and sea bird species such as blue-footed boobies (*Sula nebouxii*) and great frigatebirds (*Fregata minor*). Ship rats were known to be present since 1986 and probably invaded from the nearby Baltra Island, where ship rats and mice are present.

The proposed eradication of ship rats used a hand broadcast of Klerat a wax-based bait, coloured dark blue, with a loading of 50ppm of brodifacoum. A single cube of Klerat weighs 3.5-5 gm. Captive ship rats eat Klerat when offered with other natural food and Klerat would also be taken by free-roaming rats on the Seymour Norte (unpubl. data). Land iguanas are opportunistic omnivores, often feeding on carrion in addition to their normal diet of *Opuntia* vegetation and fruit, and are at a high risk of poisoning through eating Klerat or poison-killed rats.

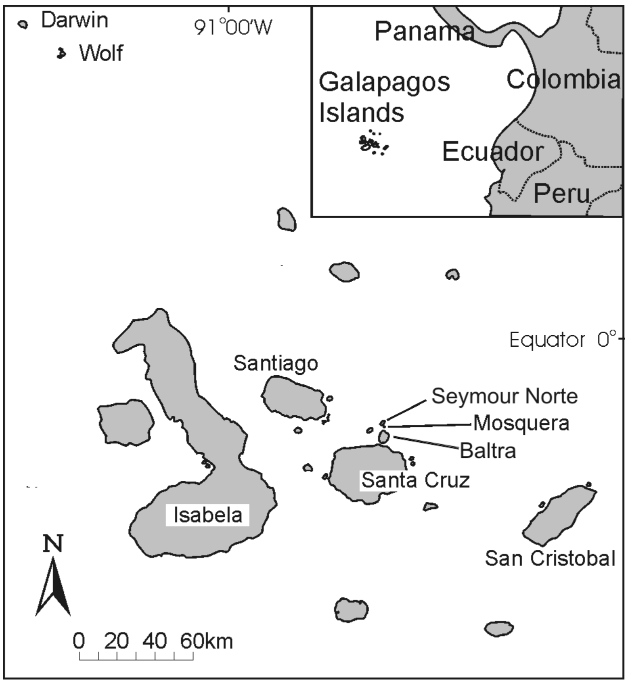

Fig. 1 The Galápagos Islands showing the location of Seymour Norte.

Bait take and rat carcass removal by iguanas

From 5-12 September, a small-scale poisoning trial was conducted on the island to investigate bait take by iguanas. Bait was hand laid across 2.5 ha in one morning in piles of 10-15 cubes every 20 metres following lines 20 metres apart to simulate conditions of the planned eradication. Over the next eight days and in subsequent visits all iguana droppings in the area were checked for signs of the blue bait. Ten rats caught on the trapping grid were used to investigate consumption of rats by iguanas. The bodies were placed in the vicinity of male iguanas' digging burrows to observe removal of rats.

On 7 November 2007, after the second bait application, six people on foot searched Seymour Norte for dead or moribund iguanas and/or fresh iguana droppings to detect any bait consumption along east-west transects 100 m apart. If any blue droppings or dead iguanas were found, surveyors in that transect stopped for 5-10 minutes and thoroughly inspected the surrounding area looking for more blue droppings or dead iguanas. A post-monitoring trip on 2-5 January 2008 counted iguanas using the transect lines established in September 2007.

Rat density

From 5-12 September 2007, a 10 x 10 grid of rat traps (Tomahawk live traps 40 x 12 x 12 cm) set at 25m intervals was established at the eastern end of the island. Traps were baited with a mixture of rolled oats and peanut butter, rolled into a ball within a small piece of grease proof paper. Bait was suspended from the top of the trap at the back with a short piece of wire to reduce interference by ants. Any rats trapped were humanely killed. To estimate the Effective Trapping Area (ETA) for the rats, a boundary strip was added to the edge of the trapping grids (Dice 1938). The width of the boundary strip was set by adding the radius (56 m) of a circular average home range of ship rats from a forested habitat (Hooker and Innes 1995). An approximate density was estimated by dividing the total number of rats caught by the ETA. This calculation assumed that during an intensive, short period of trapping immigration, emigration and reproduction by rats would be nil (Brown *et al*. 1996).

Monitoring land iguana population

In order to detect changes in the abundance of land iguanas on Seymour Norte, estimates of population density were made before and after the eradication. Thirty 200 m transects were marked out across the island. On 20 September 2007 all iguanas, and the distance each one was from the transect line, was recorded. The transects were sampled again on 2-5 January 2008. Using these data the density of iguanas was calculated using the Program DISTANCE (Buckland *et al*. 1996; Thomas *et al*. 2006).

Eradication operation

Klerat was first applied on 10th October 2007. Pre-programmed points at 25 m intervals along lines 25 m apart were loaded into personal GPS units for each person broadcasting the poison and 15 cubes of Klerat deposited at approximately 25m intervals along east-west lines across the entire island. Bait was deposited close to low vegetation and other cover, rather than leaving it on open soil. Baits were also deposited around the coast. Lines logged by each person were downloaded onto a computer at completion of the transect lines and the map checked for gaps in coverage. Any gaps were then located and extra poison bait laid in the gaps. The second application of poison bait was on 30 October. Because the first application of poison required less time than expected, an additional east-west line of bait was broadcast between the earlier bait lines. Once the east-west lines were completed, a north-south set of lines was used with baits distributed in the same manner, but at a lower application rate than on 10 October. Two groups also applied bait along the high tide line and on coastal cliffs. After completion, any gaps in poison application were located and filled as on 10 October. On 7 November 2007, 46 poison bait stations were established on Mosquera Island, 475m south of Seymour, to create a barrier for rats invading from Baltra Island, which is 340m further to the south.

On the first poison application, approximately 250 kg of Klerat was applied at a rate of 1.40 kg/ha or 310 cubes/ha. On the second application, 20 days later, approximately 280 kg of Klerat was applied at a rate of 1.52 kg/ha. A total of 530 kg/ha of poison bait was broadcast on Seymour Norte at a rate of 2.92 kg/ha

RESULTS

Poison trials with captive land iguanas

Neither of the two young iguanas accepted the Klerat and the adult male did not consume the five Klerat cubes. However, this animal did consume the poisoned rat with no apparent ill effects on behaviour or activity.

Bait take and rat carcass removal by iguanas

No fragments of bait or blue-coloured droppings were found immediately after the initial small-scale poisoning trial or in subsequent visits. Of the ten dead rats placed next to male iguana burrows: three were removed over the next six days from one site by a short-eared owl (*Asio flammeus*); another disappeared by the next visit two weeks later; and none of the remaining rats were moved from their original locations.

Before the second bait application, blue-coloured iguana droppings were found on Seymour Norte, which indicated that some iguanas had eaten bait or dead rats that contained bait. The latter possibility seemed unlikely as no hair or bone was found in these droppings. Some droppings contained Klerat in cubes, which suggests ingestion of baits with little chewing by the iguanas. Of 91 recent iguana scats, five in one group on the coast contained Klerat, suggesting that one animal was responsible. With so few droppings with Klerat, the decision was made to continue with the operation. No Klerat was found on the island by January 2008, despite several days searching.

Rat density

Over six days of trapping, 49 rats were caught before captures declined to zero. The ETA of the rat trapping grid was calculated as 14.01 ha. Assuming that we caught all rats within the ETA over six days, the approximate density of rats on the grid was 3.5 rats/ha (95% C.I.: 2.8-6.4 rats/ha). Of the captured rats, 27 were males (4 juveniles) and 22 were females (4 juveniles). No rats were detected subsequent to the eradication operation on eight lines of 25 live-traps for 3 nights (600 TN). The most recent negative result was 18-21 March 2009.

Iguana population estimates

The DENSITY programme suggested that a Uniform Cosine model provided the best fit for estimating iguana density on Seymour Norte and indicated a detection probability close to 1.0 out to the truncation point at 10 m from the transect lines. The pre-poison population estimate was 2467 (95% C.I.: 1744-3397) and the post-operation estimate 2222 (95% C.I.: 1816-2718), indicating a potential population decline of up to 9.9%. However, because the CIs of the second estimate fall within the range of the first, there is no statistical support for any difference in the population estimates.

During the post-operation monitoring on 7 November, 263 live and no dead iguanas were detected on the east-west transect. Two dead rats were located.

The first post-eradication monitoring trip on 2-5 January 2008 located six dead and 128 live iguanas on the 200m transects. Two iguanas were desiccated, and four had died more recently, two of which were located down burrows due to the smell. Two of the carcasses had blue paste or whole cubes in the alimentary tract but no bones or fur, which suggested consumption of Klerat only. These results indicated an observed mortality rate of 4.7%.

DISCUSSION

There was some loss of Galápagos land iguanas from bait ingested after the hand broadcast of brodifacoum on Seymour Norte. If based on population estimates, there may have been a decline in density of up to 9.9%. This is the worse-case projection and lacks statistical support. A more supportable estimate derived from the population census, where the observed mortality was 4.5%. The pre-eradication trials suggest that iguanas were not likely to eat the bait and the presence of only a few iguana droppings in discrete piles, suggest that only few individuals were eating the bait or dead rats. Blue objects, like Klerat, are not a preferred colour for some reptiles (Tershey and Breese 1994) so this may also explain why only a few blue scats were discovered. The lack of bait take by captive animals may be due to the very small sample size or better body condition, whereas in a larger population more diverse foraging behaviour or interspecific competition may predispose island iguanas to more opportunistic prey sampling.

Two months after the eradication, four recently dead iguanas were found. It is unknown whether death was caused by ingestion of brodifacoum because no samples were taken for analysis. If poison was responsible, it may have taken at least six weeks to kill the iguanas, unless iguanas found bait two months after the operation. Delayed mortality was found for Telfair's skinks on Round Island, Mauritius, three to six week after a poison bait application, often during particularly hot days or times of day (Merton 1987). The possibility that some reptiles have delayed effects from brodifacoum due to some aspect of their physiology that differs from birds and mammals (Merton 1987) deserves further research. Monitoring of poison effects on reptiles susceptible to bait intake should thus be extended to detect possible delayed mortality several months after application. This would reveal situations where reptiles die of chronic toxic poisoning during the post-operation period, rather than from immediate acute poisoning commonly documented in mammals and birds. We were unable to find any information on the effects of brodifacoum on snakes, geckos and many smaller lizards. Because our limited data suggests primary poisoning was the principal reason of death for iguanas, trials also need to be undertaken at higher bait application rates where an increased encounter rate may mean more bait is ingested by reptiles. Moreover, consideration should be given to sampling subdominant animals in less optimal habitat that may be more likely to eat poison bait than well-fed animals in prime habitat. Trials also need to investigate possible sub-lethal effects of brodifacoum exposure on reproduction and foraging in reptiles which may have long-term effects not shown by this research. The sparse available results suggest that the effects of brodifacoum on reptile populations are limited. However, until more research like radio-tracking or mark–recapture studies is conducted, conservation managers should consider non-target risk mitigation measures specifically for herbivorous or carrion feeding reptiles when using brodifacoum to eradicate rodents on islands with native reptiles.

It appears that eradications of rats on arid islands may be able to use quite low application rates of poison. Less than 3 kg/ha of Klerat was applied to Seymour Norte and after 18 months and one and a half breeding seasons (Clark 1980) rats were not present. The relatively low density of the non-breeding rat population on Seymour Norte and apparent palatability of the poison bait suggests that the population may be strongly food limited in the dry season (Clark 1980). Ship rat density in the Galápagos has a positive correlation with vegetation biomass (Clark 1980), so on islands with open, arid zone vegetation rat density should only be high during wet El Niño years when vegetation growth is substantial. In dry years eradications may be successful with low applications of bait which likely reduces non-target risk in addition to resources and time. Although Klerat has a higher loading of brodifacoum (50 ppm) than other bait formulations used for rat eradication operations (20-25 ppm) it was applied at a low rate (< 3 kg/ha) compared to previous eradications that used aerial application rates of 12 kg/ha or more (Empson and Miskelly 1999; McClelland 2002). This will substantially reduce the amount of resources and time required, as well as risks to non target species, and should be tested on smaller arid islands with a view to scaling up to larger arid islands (Cayot 1996; Harper and Carrion 2011).

ACKNOWLEDGEMENTS

This research was supported by funding from the Galápagos National Park Service and by grants from Saladin, Lindblad/National Geographic Fund, Boston Environmental Research, Frankfurt Zoological Society, Galápagos Conservancy and the Hawksglen Foundation. We particularly thank the staff of the Galápagos National Park Service who carried out the eradication operation and continue the monitoring and baiting to keep rats off Seymour Norte. The Charles Darwin Foundation staff provided assistance at many stages. We thank P. Buitrón, J. P, Gibbs, E. Sterling, K. Freyes, and H. Gibbs for field assistance. The text was much improved by comments provided by Penny Fisher and an anonymous reviewer. The fieldwork described within complies with the current laws of Ecuador.

REFERENCES

Brown, K.P.; Moller, H.; Innes, J. and Alterio, N. 1996. Calibration of tunnel tracking rates to estimate relative abundance of ship rats (*Rattus rattus*) and mice (*Mus musculus*) in a New Zealand forest. *New Zealand Journal of Ecology 20*: 271-275.

Buckland, S.T.; Anderson, D.R.; Burnam, K.P. and Laake, J.L. 1996. *Distance sampling: estimating abundance of biological populations*. Chapman and Hall, London.

Burbridge, A.A. 2004. Montebello Renewal: Western Shield Review – February 2003. *Conservation Science West Australia 5*: 194-201.

Cayot, L.J.; Muñoz, E. and Murillo, G. 1996. Conservation of the Tortoises of Pinzón Island. *Charles Darwin Research Station Annual Report 1988-1989*: 29-35.

Clark, D.B. 1980. Population ecology of *Rattus rattus* across a desert montane forest gradient in the Galápagos Islands. *Ecology 61*: 1422-1433.

Daltry, J.C. 2006. The effect of black rat *Rattus rattus* control on the population of the Antiguan racer snake *Alsophis antiguae* on Great Bird island, Antigua. *Conservation Evidence 3*: 30-32.

Dice, L. 1938. Some census methods for animals. *Journal of Wildlife Management 2*: 119-130.

Eason,C.T. and Spurr, E. B. 1995. Review of the toxicity and impacts of brodifacoum on non-target wildlife in New Zealand. *New Zealand Journal of Zoology 22*: 371-379.

Empson, R.A. and Miskelly, C.M. 1999. The risks, costs and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. *New Zealand Journal of Ecology 23*: 241-254.

Freeman, A.B.; Hickling, G.J. and Bannock, C.A. 1996. Response of the skink *Oligosoma maccanni* (Reptilia: Lacertilia) to vertebrate pest-control baits. *Wildlife Research 23*: 511-516

Hamann, O. 1979. On climatic conditions, vegetation types, and leaf size in the Galápagos Islands. *Biotropica 11*: 101-122.

Harper, G. A. and Carrion, V. 2011. Introduced rodents in the Galápagos: colonisation, removal and the future. In: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds.). *Island invasives: eradication and management*, pp. 63-66. IUCN, Gland, Switzerland.

Hoare, J.M. and Hare, K. M. 2006. The impact of brodifacoum on non-target wildlife: gaps in knowledge. *New Zealand Journal of Ecology 30*: 157-167.

Hooker, S. and Innes, J. G. 1995. Ranging behaviour of forest dwelling ship rats (*Rattus rattus*) and effects of poisoning with brodifacoum. *New Zealand Journal of Zoology 22*: 291-304.

Howald, G.; Donlan, J.C.; Galván, J.P.; Russell, J.C.; Parkes, J.; Samaniego, A.; Wang, Y.; Veitch, D.; Genovesi, P.; Pascal, M.; Saunders, A. and Tershey, B. 2007. Invasive rodent eradication on islands. *Conservation Biology 21*: 1258-1268.

Marshall, J. E. and Jewell, T. 2007. Consumption of non-toxic baits by grand (*Oligosoma grande*) and Otago (*O. otagense*) skinks. *DOC Research and Development Series* 272. Department of Conservation, Wellington.

Merton, D.V. 1987. Eradication of rabbits from Round Island, Mauritius: a conservation success story. *The Dodo 24*: 19-24.

McClelland, P.J. 2002. Eradication of Pacific rats (*Rattus exulans*) from Whenua Hou nature Reserve (Codfish Island), Putauhinu and Rarotoka Islands, New Zealand. In: Veitch, C.R. and Clout, M.N. (eds.). *Turning the tide: the eradication of invasive species,* pp. 173-181. IUCN SSC Invasive Species Specialist Group. IUCN Gland, Switzerland and Cambridge, UK.

Olivera, P.; Menezes, D.; Trout, R.; Buckle, A.; Geraldes, P. and Jesus, J. 2010. Successful eradication of the European rabbit (*Oryctolagus cuniculus*) and house mouse (*Mus musculus*) from an island in the Eastern Atlantic. *Integrative Zoology 1*: 510-525.

Parrish, R. 2005. Pacific rat *Rattus exulans* eradication by poison baiting from the Chickens Islands, New Zealand. *Conservation Evidence 2*: 74-75.

Tershy, B.R. and Breese, D. 1994. Color preference of the island endemic lizard *Uta palmeri* in relation to rat eradication campaigns. *Southwestern Naturalist 39*: 295-297.

Thomas, L.; Laake, J.L.; Strindberg, S.; Marques, F.F.C.; Buckland, S.T.; Borchers, D.L.; Anderson, D.R.; Burnham, K.P.; Hedley, S.L.; Pollard, J.H.; Bishop, J.R.B. and Marques, T.A. 2006. *Distance 5.0. Release 2*. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK.

Thorsen, M.; Shorten, R.; Lucking, R. and Lucking, V. 2000. Norway rats (*Rattus norvegicus*) on Frégate Island, Seychelles: the invasion, subsequent eradication attempts, and implications for the island's fauna. *Biological Conservation 96*: 133-138.

Towns, D.R.; Parrish, G.R.; Tyrell, C.L.M.; Ussher, G.T.; Cree, A.; Newman, D.G.; Whitaker, A.H. and Westbrooke, I. 2007. Responses of tuatara (*Sphenodon punctatus*) to removal of introduced Pacific rats from islands. *Conservation Biology 21*: 1021-1031.