The remnant *Leiopelma pakeka* (Anura: Leiopelmatidae) population on Maud Island: population size, distribution and morphology

By

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Abstract

Leiopelma pakeka is an archaic frog native to New Zealand, and until recently was restricted to a 15ha forest remnant on the south-east face of Maud Island. The *L. pakeka* population appears to be growing and spreading out from the forest remnant. This study investigated the population size, structure, and distribution of *L. pakeka* on Maud Island in 2006.

The forest remnant was searched using 106 randomly placed 25m^2 plots. Population size was estimated using a bootstrap method repeated 10,000 times, adjusted for likelihood of emergence, likely maximum plot population size, and area. The average population size was 34,449 frogs, which is much higher than a 1994 minimum number alive estimate of 19,312. The new figure, however, is similar to another recent estimate of 39,563, based on an update of the 1994 figure. Distributional patterns within the forest remnant were similar to the 1994 study, with most frogs between 90-170m above sea level. The comparability of the population size estimates indicates that *L. pakeka* numbers have reached the carrying capacity of the forest remnant.

The distribution of the remnant *L. pakeka* population was determined by thoroughly searching the south-east face of Maud Island, thereby minimising the possibility of missing frogs. A total of 232 frogs were found. Frogs generally colonised areas within 50m of the remnant; movement was greater in regenerating forest (75m in the south-west and 100m in the north east) than in pastoral areas (<25m). The size of frogs increased with distance from the forest remnant (weight, girth, condition index, and average snout-vent and tibio-fibula lengths). The size increases may be indications of competitive release, as frog density decreased with distance from the forest remnant. The size range of *Leiopelma pakeka* was extended by the current study from 50.5mm to at least 52mm snout-vent length.

A total of 15 *L. pakeka* were found on Fort Road, approximately 350m from the remnant. These frogs were most likely in the area before 1994. The Fort Road frogs were compared to the forest remnant *L. pakeka*, and were not morphologically distinct as only patterning differed significantly. Fort Road *L. pakeka* may belong to a separate subpopulation.

L. pakeka distribution was significantly affected by habitat. Important variables were vegetation type, and rock, canopy, sub-canopy, and leaf litter cover. The size of emergent frogs (tibio-fibula length) was significantly and positively correlated with relative humidity.

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Chapter 1

Introduction to the study

1.1. Study species, *Leiopelma pakeka*

1.1.1. The genus *Leiopelma*

The native New Zealand frogs are in the genus *Leiopelma* (Anura: Leiopelmatidae). They are small, nocturnal, reclusive, and restricted in range. Seven *Leiopelma* species have been identified, of which the three largest are now extinct (Towns & Daugherty 1994, Worthy 1987ab). The two largest extant species are each limited to a single predator-free island: *L. pakeka* on Maud Island, and *L. hamiltoni* on Stephens Island. The two smallest species, *L. archeyi* and *L. hochstetteri*, are limited to mountainous forest areas in the upper North Island (Bell 1978b, 1994, Bell *et al.* 1985, Bull & Whitaker 1975, Green & Tessier 1990, Stephenson *et al.* 1972).

Subfossil bone deposits in limestone caves indicate that the *Leiopelma* species were previously distributed across New Zealand (Bell 1977, Bull & Whitaker 1975, Worthy 1986, 1987ab, 1993, 1998, Worthy & Holdaway 1994b). When humans arrived in New Zealand, they brought with them three species of rat, three mustelids, and several other mammals (Bell *et al.* 1985, Towns and Daugherty 1994, Worthy 1987b). Mammals were previously almost entirely absent in New Zealand, and so these introduced animals are thought to have had a large impact on the indigenous biota. The *Leiopelma* species appear to have been particularly affected by *Rattus exulans* and declined country-wide (Bell 1977, 1978ab, 1994, Bell *et al.* 1985, Towns & Daugherty 1994, Worthy 1987b).

1.1.2. Taxonomy

New Zealand is home to many unique and archaic species, and the native frogs are no exception. The *Leiopelma* species have several primitive morphological features, including: amphicoelous vertebrae, nine presacral vertebrae (other frogs have eight), free ribs that are not fused to the vertebrae, and the retention of two “tail-wagging” muscles in adult frogs (Bell 1982, Bull & Whitaker 1975, Green & Cannatella 1993, Stephenson 1952, 1960, 1961). The *Leiopelma* species, together with *Ascaphus truei* of North America, are considered to be primitive, and are placed as a basal or sister group to all other living frogs. The exact taxonomy has been debated among many authors (Cannatella & Hillis 1993, Feller & Hedges 1998, Ford & Cannatella 1993, Gao & Wang 2001, Green & Cannatella 1993, Green *et al.* 1980, 1989, Hay *et al.* 1995, Hillis *et al.* 1993, Kluge & Farris 1969, Noble 1955, Roelants & Bossuyt 2005, Stephenson *et al.* 1972, Worthy 1986, 1987a), and an overview of the issue can be found in Bell and Wassersug (2003) and Dewhurst (2003).

The *Leiopelma* species divide into two groups, based on morphology and genetics (Bell 1994, Daugherty *et al.* 1981, 1982, Stephenson *et al.* 1974, Worthy 1987a). The semi-aquatic *L. hochstetteri* cluster together with the extinct *L. markhami* and *L. auroraensis* (Worthy 1987a). The terrestrial frogs, *L. archeyi*, *L. hamiltoni*, *L. pakeka* and the extinct *L. waitomoensis* form the other group (Worthy 1987a). Among the living terrestrial species, *L. archeyi* and *L. hamiltoni* are genetically more similar (Bell et al 1998a). This is unexpected, because of the three, *L. hamiltoni* and *L. pakeka* look alike, although the latter are slightly larger and have a greater range of colour variation (Bell *et al.* 1998a). *L. pakeka* was thought to be a second population of *L. hamiltoni* until 1998, when they were shown to be distinct, based on patterns of allozyme variation

(Bell *et al.* 1998a). The Maud Island frog was described as a new species, *L. pakeka*, in 1998 (Bell *et al.* 1998a). Holyoake *et al.* (1999, 2001), however, found that the amount of variation in mtDNA sequences between *L. pakeka* and *L. hamiltoni* was insufficient to warrant separate species status. The debate surrounding the species status is acknowledged. In this study, however, the Maud Island frog is discussed as *L. pakeka*, following recent publications such as Bell *et al.* (2004b) and Dewhurst (2003).

1.1.3. *Leiopelma pakeka*

Leiopelma pakeka is the largest extant native frog species, and is limited to Maud Island. They range from 10mm (Bell 1978b) to 50.5mm (Bell 1995) snout-vent length (SVL). Growth continues throughout their lives, although it slows down with age (Bell 1997b). There are several size/age classes into which the frogs can be divided: less than a year old (11-15mm), yearlings (16-20mm), juveniles (20-37mm), mature male/ immature female (37-43mm), and mature females (>42mm) (Bell 1978b).

L. pakeka is normally brown, although colour intensity and patterning vary between individuals (Bell 1978b, 1982, Bell *et al.* 1998a). These terrestrial frogs do not have webbed toes (Bell 1982). The pupil is rounded (Bell 1982, Bell *et al.* 1998a), and there is a reflective layer of cells in the retina – at night frogs can be seen from a distance by the pink eye-shine when a light is shone directly into their eyes (Bell 1978a, Cree 1989, Crook 1973). They lack an external eardrum (tympanic membrane), and middle ear structures (Bell 1982, Stephenson 1961), but possess the inner ear structures (Wagner 1934). *L. pakeka* is shown in Figure 1.1. Further descriptions of morphology can be found in Barwick (1961), Bell (1982, 1996), Bell *et al.* (1998a), Green (1988), McCulloch (1919), and Stephenson (1955, 1960).

Figure 1.1: *Leiopelma pakeka.* Note the lack of webbing between the toes. The pupils are rounded and there is no external eardrum.

Figure 1.2: A *Leiopelma pakeka* is in the centre of this photograph – note how cryptic and well camouflaged it is.

A translocated population of *L. pakeka* in Boat Bay on Maud Island became larger than frogs in the forest remnant (Bell 1982, 1995, Dewhurst 2003), possibly from intraspecific competitive release (Bell 1995, Bell *et al.* 2004b). These size increases may be indicative of phenotypic plasticity (Dewhurst 2003), which is when the morphology of an organism can be significantly affected by certain environmental factors (Thain & Hickman 2001).

Vocalisations in *L. pakeka* are limited to squeaks and chirps when alarmed or startled (Bell 1978b, Stephenson & Stephenson 1957). The anti-predator response is to stiffen the legs and rear up (Green 1988). They are ambush hunters and can remain motionless for long periods of time (Bell 1985b). *L. pakeka* is therefore highly cryptic (Figure 1.2).

These nocturnal frogs occupy daytime retreats under rocks and vegetation (Bell 1995, Newman 1990). *L. pakeka* distribution was found to be related to rocky substrate, and forest canopy height and cover (Bell 1995, Bell & Bell 1994, Newman 1990). They emerge at night to feed, and their diet includes mites and flies (Kane 1980). Emergence in *Leiopelma* species is positively related to weather variables, such as humidity, rainfall, and temperature (Bell 1978a, 1995, 1996, Bell *et al.* 1985, Newman 1990).

L. pakeka occupy discrete home ranges over most of their long lives (Bell 1997a, King *et al. in press*, Newman 1990). One known individual has occupied the same area for at least 34 years (B. D. Bell pers. comm.). Home ranges appear to be maintained using chemosignals (Lee & Waldman 2002, Waldman & Bishop 2004). The dispersal behaviour of *L. pakeka* is not well known. These frogs are known to have moved up to 26m in a translocated population (Bell *et al.* 2004, Trewenack *et al. in press*.). In a translocated population of *L. hamiltoni*, some individuals moved approximately 70m back to the original site (Tocher & Brown 2004). It is clear, therefore, that these frogs possess the ability to disperse reasonable distances. In both translocations the frogs involved were adults (Brown 1994, Bell 1994). Translocations do not represent natural conditions, however, so it remains unclear whether dispersal occurs in all *L. pakeka* or is limited to a certain lifestage or sex. In many amphibians, juveniles are the dispersive life-history stage (deMaynadier & Hunter 1999, Jameson 1956, Roble 1979). Cushman (2006) stated that "in amphibians, population connectivity is predominantly effected through juvenile dispersal." Adult *L. pakeka* are known to occupy home ranges (Bell 1997a, King *et al. in press*, Newman 1990), so if a dispersive life stage exists it may occur in younger, and therefore smaller, frogs.

Parasites are known to infect *L. archeyi* and *L. hochstetteri*, but none have been reported in *L. pakeka* (Baker & Green 1988, Stephenson & Stephenson 1957). Predators of the *Leiopelma* species may include tuatara, *Sphenodon punctatus* (Newman 1977b), laughing owls, *Sceloglaux alifacies* (Worthy & Holdaway 1994a), weka, *Galliralus australis*, introduced rats, especially *Rattus exulans* and *R. rattus*, and introduced frogs, *Litoria aurea* (Thurley and Bell 1994). Only morepork owls, *Ninox novaeseelandiae*, currently occur on Maud Island, however, it is unknown whether these animals predate *L. pakeka*. Weka were removed from the island, however, predation of *L. pakeka* from these birds is doubtful (Beauchamp 1995, 1996). The Department of Conservation maintains a control programme to prevent the arrival and establishment of mammalian predators on Maud Island. On several occasions, however, mammalian predators have arrived on the island although none have established (Bell 1982, 1985b, Bell *et al.* 1985, S. Ward *pers. comm.*).

Reproduction in *L. pakeka* has only been observed in captivity, and is described by Bell (1977, 1978ab, 1985a). Breeding occurs in December (Bell 1978ab). Small froglets, with four limbs and a tail, emerge from the large, yolky eggs (Bell 1977). The total development time from egg to fully metamorphosed frog is 19-21 weeks, and parental care during this time is carried out by the male (Bell 1978ab).

1.2. Study site, Maud Island

Maud Island is located in the Marlborough Sounds of the South Island, New Zealand (Figure 1.3), at 41°02′ S 17°54′ E (Newman 1990). The island is 309ha, rising to an elevation of 369m above sea level (a.s.l.). Figures 1.3-5 show the location (1.3), aerial photograph (1.4), and a map of Maud Island (1.5), respectively.

L. pakeka was reported on Maud Island in 1958 in a 15ha remnant of native forest on the south-east face (Figure 1.6) (Stephenson 1961). The remainder of the island was cleared for agricultural purposes under private ownership (Bell 1982, 1985b). The forest remnant was fenced off in 1965, and in 1975 Maud Island became a scientific reserve (Appendix 7.1). Today the island is managed by the Department of Conservation, and several other native animals have been introduced, including takahe, *Porphyrio mantelli*, and kakapo, *Strigops habroptilus*. The vegetation across the island has been regenerating, but the remnant is still clearly visible (Figure 1.6).

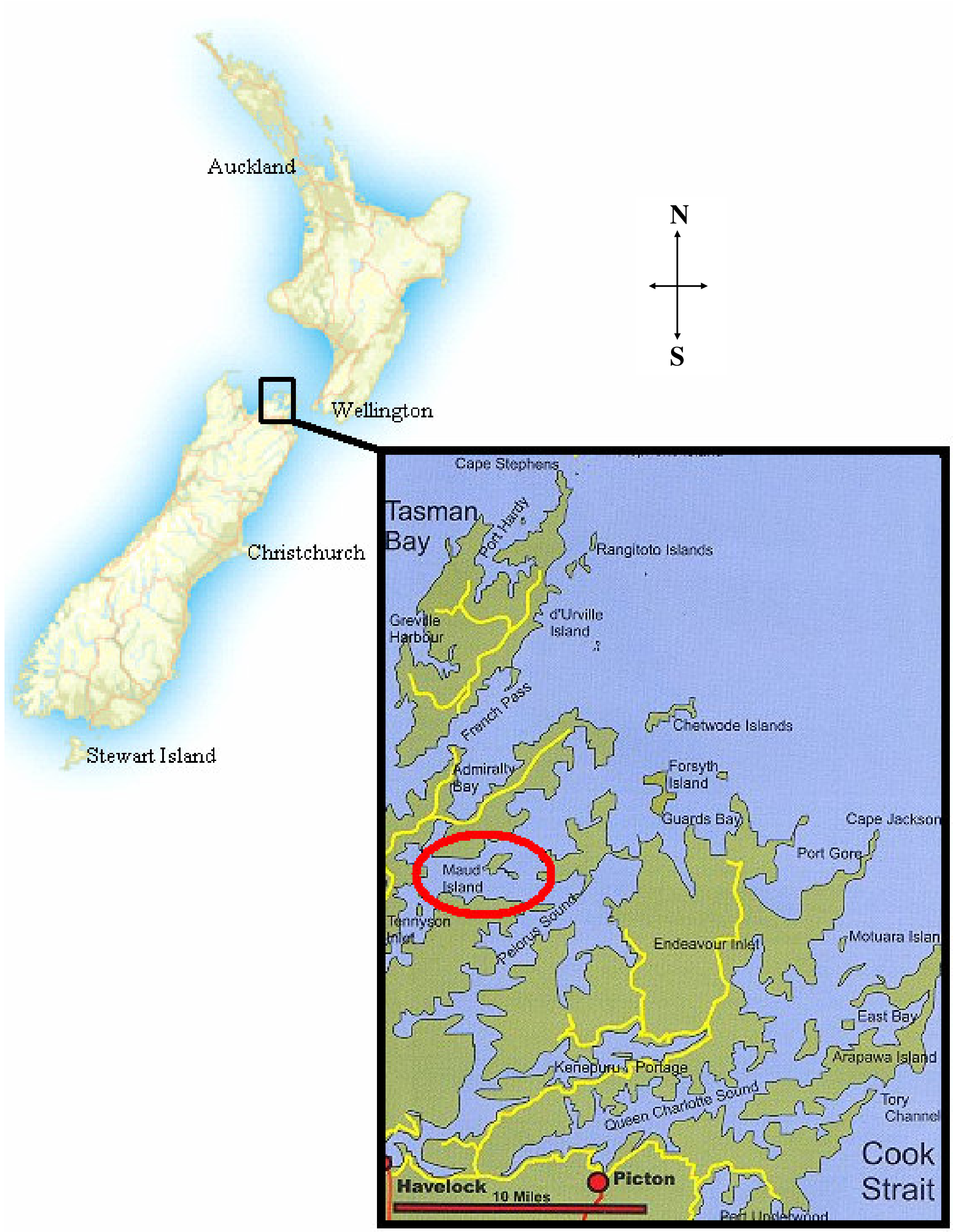

Figure 1.3: The location of Maud Island in the Marlborough Sounds of New Zealand. (Maud Island is encircled). The figures are taken from the websites of Expressions Holidays (left), and Picots New Zealand Charter Guide (right).

The forest remnant lies between 90-300m a.s.l., and ranges from 9-15m in height (Newman 1990). The remnant separates into two distinct altitudinal zones, with differing plant species (Bell 1995). Descriptions of the forest composition can be found in Bell (1995) and Newman (1990), and is summarised here. Between 90-200m a.s.l. more than half the canopy is kohekohe, *Dysoxylum spectabile*, and mahoe, *Melicytus ramiflorus*, whereas above 200m a.s.l. the forest is dominated by hinau, *Elaeocarpus dentatus*, and kamahi, *Weinmannia racemosa*. On the lower slopes the subcanopy and ground vegetation consists of kawakawa, *Macropiper excelsum*, kohekohe, and ferns such as *Arthropteris tenella*, *Asplenium bulbiferum*, *Blechnum filiforme*, and *Phymatosorus scandens* (Bell 1995, Newman 1990). On the higher slopes the subcanopy and groundcover is dominated by kiekie, *Freycinetia banksii*, which creates an unfavourable habitat for *L. pakeka* (Bell 1995). Most frogs occur below 200m a.s.l., and none were higher than 250m a.s.l. (Bell 1995, Bell & Bell 1994).

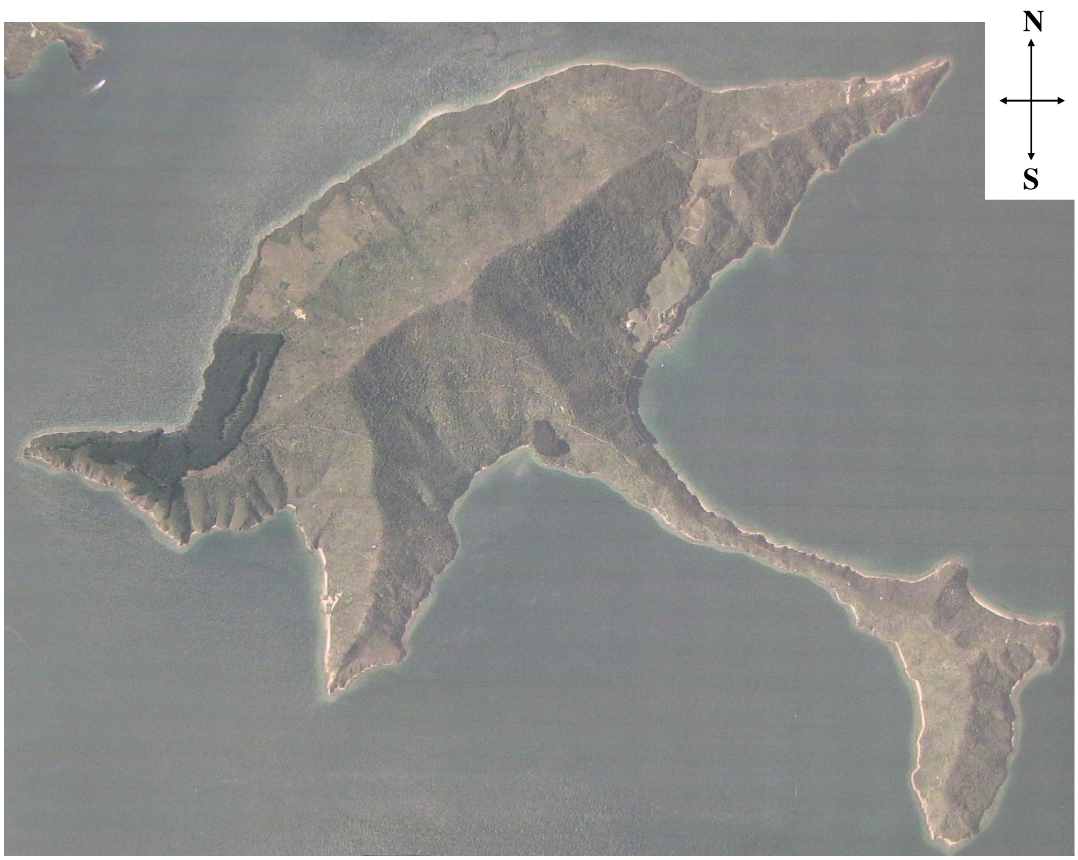

Figure 1.4: Maud Island is 309ha and rises to 365m a.s.l. This aerial photograph was provided courtesy of the Department of Conservation, Picton office.

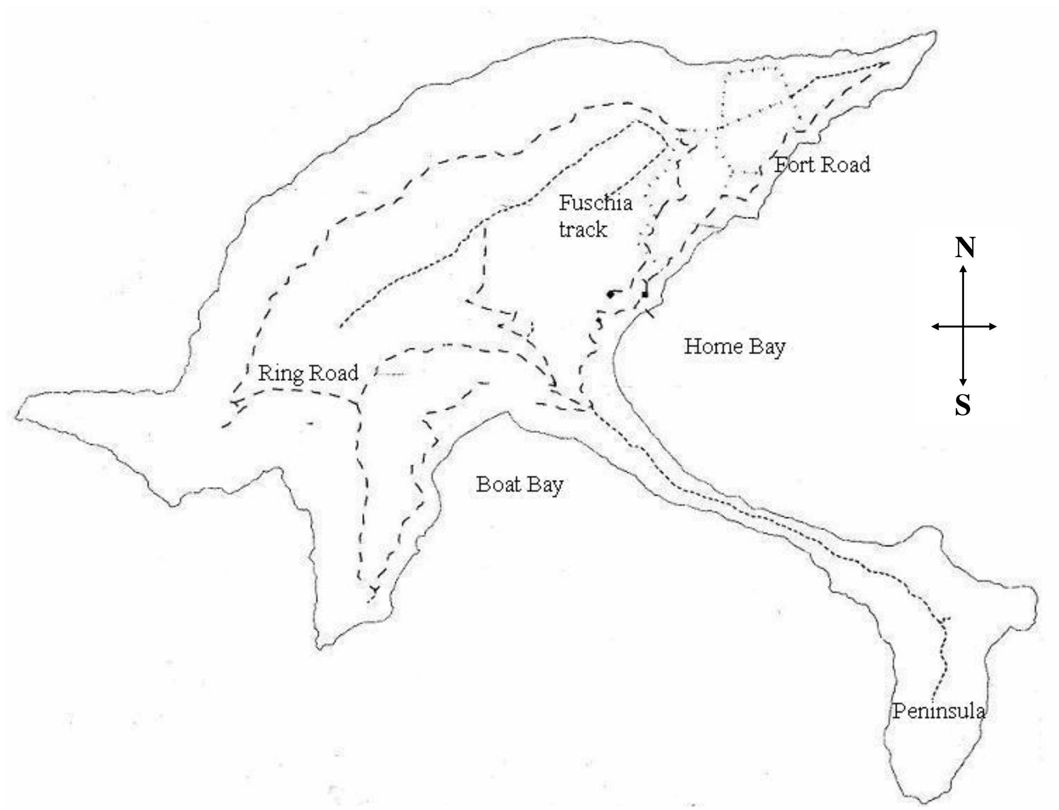

Figure 1.5: A map of Maud Island. The current study focused on the south-east face of Maud Island, around Home Bay. Of interest are Fuschia track and Fort Road. This map was provided courtesy of the Department of Conservation.

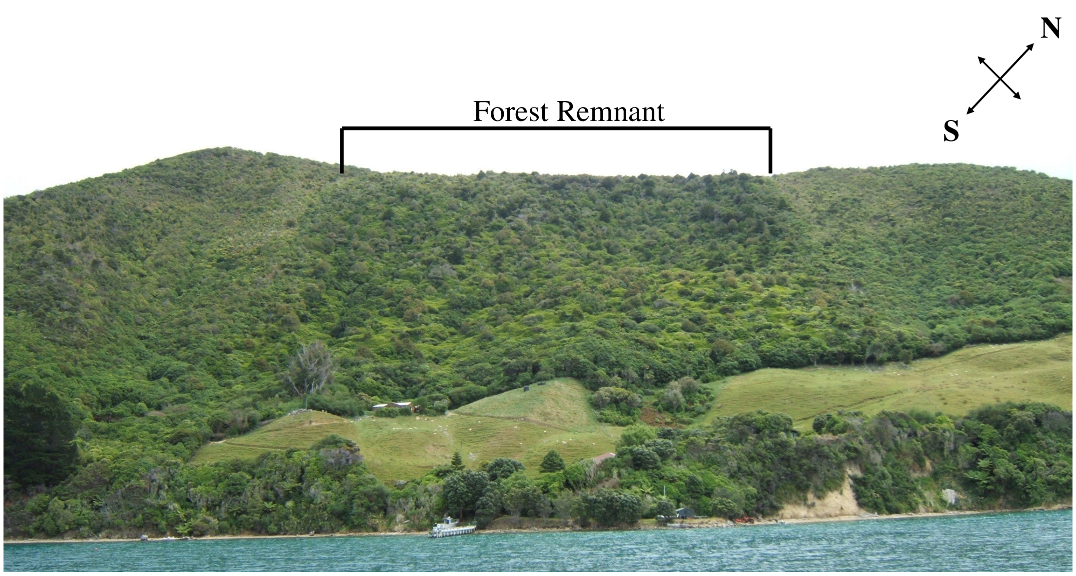

Figure 1.6: The current state of the south-east face of Maud Island around Home Bay. The forest remnant is still clearly visible despite regeneration of the forest.

1.3. The remnant population of *L. pakeka* on Maud Island

Populations of the *Leiopelma* species have been monitored in several ways, including using transects (Bell 1996), study grids (Bell 1996), and site occupancy modelling (Crossland *et al.* 2005). Long-term population study grids (12m by 12m) in the lower section of remnant forest have been used to monitor the remnant *L. pakeka* population on Maud Island since 1983 (Bell 1994, 1997b, Bell & Pledger 2001b). The grids are searched over five consecutive nights every year, and population estimates derived using mark-recapture analyses. Individual frogs are identified by unique toe-clip combinations. Population estimates remained stable over 1983-93 (Bell 1994, 1997b).

The *L. pakeka* population size was conservatively estimated at 19,000 (minimum number alive) in 1994, based on a survey across a 16ha area (Bell 1995, Bell & Bell 1994). The population size was re-estimated at 39,563 using the same survey data multiplied by a different emergence probability, based on improved statistical models using MARK (Bell & Pledger 2000). It is necessary to apply an emergence probability because the nocturnal *L. pakeka* does not come out every night, or, all at the same time. The frogs found in a search are, therefore, only a subset of those in the area.

The *L. pakeka* population on Maud Island appears to be growing and spreading out (Newman 1996). There are several anecdotal reports of frogs outside of the remnant, most of which have been within 50m from the edge. Bell (1995) saw *L. pakeka* in secondary forest adjacent to the remnant, and a frog was recently found approximately 100m into the north-east regenerating forest (S. Ward *pers. comm.*). *L. pakeka* has also moved down from the forest remnant into pastoral areas (Bell 1995, B. D. Bell and S. Ward *pers. comm.*), and a patch of regenerating forest (J. Germano *pers. comm.*). A frog was seen in regenerating scrub approximately 350m from the remnant prior to 1995 (D. Brown *pers. comm.*, per Bell 1995 & Newman 1996). Bell (1995) searched the area several times with no success. A frog has been seen twice in Rifleman Creek (S. Ward *pers. comm.*), and there are other sightings of *L. pakeka* along the Fort Road (C. Kelly & D. Gwynne *pers. comm.*).

1.4. The need for up-to-date population knowledge

Leiopelma pakeka is classified as "Vulnerable" according to the IUCN risk assessment database (IUCN *et al.* 2006), and "Nationally Endangered" by the New Zealand Threat Classification System (Hitchmough *et al.* 2007). *L. pakeka* has only been found on Maud Island, therefore, it is important to have up-to-date information on the population size and extent. The *L. pakeka* population size and distribution on Maud Island was conservatively investigated in 1994 (Bell 1995, Bell & Bell 1994). A re-estimation, based on the same survey, was much higher (B. D. Bell & S. Pledger *pers. comm.*). Anecdotal evidence indicates that the frogs are spreading out, which suggests population growth. Bell (1995) recommended that the current population size be investigated, further studies into distribution should explore population expansion, and that searches could be made for isolated frog populations. In 2004 the Native Frog Recovery Group also highlighted the need for current knowledge of the extent of the remnant *L. pakeka* population on Maud Island.

The forest habitat of Maud Island has been largely removed, so only a 15ha fragment remains. Habitat fragmentation has caused several amphibian populations to decline (Blaustein & Kiesecker 2002, Collins & Storfer 2003, Cushman 2006, Nyström *et al.*

2007, Young *et al.* 2001). It has been suggested that habitat destruction has a larger affect on terrestrial frogs, such as *L. pakeka* (Pineda & Halffter 2004). Species with limited dispersal abilities are negatively affected by habitat loss and fragmentation in the long-term (Cushman 2006). *L. pakeka* is such a species. Habitat destruction on Maud Island ceased over 35 years ago, and the vegetation has since been regenerating (Figure 1.6). Study of the *L. pakeka* population on Maud would therefore provide an interesting insight into the response of a long-lived amphibian species to natural habitat restoration. It is also important to determine that the population is still healthy and growing, given recent amphibian declines (see section 1.4.1. below).

1.4.1. Amphibian declines

Declines in amphibian populations have been noted since at least the 1990s (Alford *et al.* 2001, Houlahan *et al.* 2000, 2001). These declines span the globe, affecting Latin America and the Caribbean (Berger *et al.* 1998, IUCN *et al.* 2006, Young *et al.* 2001), North America (Bank *et al.* 2006), Europe (Carrier & Beebee 2003, Nyström *et al.* 2007), and Australia (Berger *et al.* 1998, Laurance 1996). One third (32%) of all amphibian species are now threatened, 43% are declining, and 165 species may already be extinct (IUCN *et al.* 2006, Stuart *et al.* 2004). Conservation of amphibian species is therefore important and studies that further the knowledge of frog management outcomes are significant.

In many cases the underlying causes of population decline remain a mystery (Stuart *et al.* 2004). Factors that have been implicated include over-exploitation (Collins & Storfer 2003, Young *et al.* 2001), habitat destruction (Blaustein & Kiesecker 2002, Collins & Storfer 2003, Young *et al.* 2001), and introduced species (Blaustein &

Kiesecker 2002, Collins & Storfer 2003, Young *et al.* 2001). Climate change, increasing ultraviolet radiation, and environmental pollution have also caused amphibian declines (Alford & Richards 1999, Blaustein & Kiesecker 2002, Collins & Storfer 2003, Young *et al.* 2001). Disease is one of the most commonly cited causes (Alford & Richards 1999, Blaustein & Kiesecker 2002, Carey 2000, Collins & Storfer 2003, Cullen & Owens 2002, Daszak *et al.* 2003, Young *et al.* 2001), and in particular chytrid fungus.

A pathogenic chytrid fungus, *Batrachochytrium dendrobatidis*, has caused amphibian population declines in the Americas (Berger *et al.* 1998, 1999, Bradley *et al.* 2002, Muths *et al.* 2003, Puschendorf *et al.* 2006), Hawaii (Beard & O'Neill 2005), Australasia (Berger *et al.* 1998, 1999), and Europe (Bosch *et al.* 2001). It is thought that the fungus originated in Africa and has spread through the trade of food, pharmaceuticals, and pets (Fisher & Gardner 2007). New Zealand frog populations declined in 1993-95 (Bishop 1999), and chytrid was found in the country in 1999 (Bishop 2000, Waldman *et al.* 2001). The fungus is thought to have caused population declines in *L. archeyi* from 1996-2001 in the Coromandel Peninsula (Bell 1999, 2004, Bell *et al.* 2004a).

Berger *et al.* (1999) stated that small clutch size and restricted range are factors which make frog populations vulnerable to decimation by disease - *L. pakeka* displays both these characteristics. *L. pakeka* exists in high densities on Maud Island (Bell 1995), and disease would probably spread rapidly if it entered the population.

1.5. Study objectives and thesis format

1.5.1. Aims and hypotheses

This study aimed to investigate the remnant *L. pakeka* population on Maud Island, by investigating the following aims and hypotheses:

1) To determine the current population size and distribution of *Leiopelma pakeka* in the forest remnant on Maud Island. It was hypothesised that:

   H_1: The *L. pakeka* population on Maud Island is growing, and the population size is now larger than the re-estimate of 39,563 (Bell & Pledger 2000).

2) To investigate population expansion of *L. pakeka*, by assessing the current distribution beyond the forest remnant. The hypotheses were:

   H_1: *L. pakeka* has spread out from the forest remnant, dispersing as far as possible into suitable habitat.

3) To examine the effect of weather conditions on *L. pakeka* emergence behaviour. The emergence of these nocturnal frogs is known to be positively related to weather variables, such as humidity, rainfall, and temperature (Bell 1978a, 1995, 1996, Bell *et al.* 1985, Newman 1990). *L. pakeka* has high rates of evaporative water loss (Cree 1985). Smaller frogs have a higher chance of desiccation in dry conditions, because they have a higher surface to volume ratio. The hypotheses were:

   H_1: The emergence behaviour of *L. pakeka* is positively affected by temperature, relative humidity, and rainfall.

   H_2: Smaller frogs are more likely to emerge during rainfall and high humidity.

4) To investigate the morphology of *Leiopelma pakeka* outside the forest remnant on the south-east face of Maud Island. The hypotheses were:

H_1: As distance from the forest remnant increases, the number of frogs found decreases. This lowered density may result in competitive release, leading to increased frog size with distance from the forest remnant.

H_2: Dispersal in *L. pakeka* may be carried out by subadults, as in other amphibians. The average size of frogs on the edges of distribution will therefore be smaller than in the remnant.

H_3: The frogs on the Fort Road are morphologically similar to the forest remnant *L. pakeka*, either because there is movement of individuals between the two areas, or the two 'populations' have not been separated long enough to differentiate.

1.5.2. Thesis format

There are five chapters in this thesis. This first chapter is an introduction to the study. The second addresses the forest remnant population size of *Leiopelma pakeka* (Aim 1). The third concentrates on the distribution of *L. pakeka* outside of the forest remnant, and addresses Aims 2 and 3. The fourth deals with the morphology of *L. pakeka* on the south-east face of Maud Island (Aim 4). The fifth and final chapter is a discussion of the findings. Chapters 2-4 have been written as separate scientific papers, therefore, there is some repetition of information and methodologies. A single reference list, at the end of this thesis, contains the literature cited from all five chapters.

1.5.3. Working with *Leiopelma pakeka*

There are several risks involved in working with native frogs. *L. pakeka* is a nationally endangered species, therefore, great care was taken to eliminate or minimise these risks. The most pressing risk is bringing disease onto the island, or spreading it between locations. Several hygiene precautions were taken to prevent disease risk. All gear was thoroughly cleaned and disinfected with an antiviral agent (Virkon® S – Antec International) before being taken into the field. Virkon® is effective against the chytrid fungus. Footwear and clothing was cleaned and disinfected between searching different areas, except on tracks accessible to the public. Frogs were handled using gloves (latex, non-powdered), which were changed between individuals unless they occurred together. The callipers and scale were cleaned between areas and search nights.

Another risk of working with the *Leiopelma* species is that emergent frogs can be trampled on at night, or crushed under retreat sites (Bell 1996). The greatest care was taken to ensure that no frogs were underfoot at night, and that stable footing was found to prevent falling or shifting rocks. To reduce the stress experienced by frogs, handling was kept to a minimum, and data was collected from frogs while in the field. No frogs were moved between areas.

This research was carried out under the following permits administered by the Department of Conservation: Maud Island Entry Permit (#19/06) (Appendix 7.2.1), Permit to conduct research on Maud Island frog (#NM-17358-RES) (Appendix 7.2.2). Approval was gained from the Animal Ethics committee of Victoria University of Wellington.

Chapter 2

The current population size of *Leiopelma pakeka* in its remnant forest habitat on Maud Island

2.1. Introduction

Leiopelma pakeka is a small terrestrial frog which has only been found in a 15ha remnant of native forest on Maud Island (Stephenson 1961). These frogs are classified as "Vulnerable" according to the IUCN risk assessment database (IUCN *et al.* 2006), and "Nationally Endangered" by the New Zealand Threat Classification System (Hitchmough *et al.* 2007).

A conservative estimate (minimum number alive) of *L. pakeka* population size was 19,312 in 1994 (Bell 1995, Bell & Bell 1994), based on an extensive survey across the forest remnant. The 16ha survey area included some regenerating forest, and was searched twice (Bell 1995, Bell & Bell 1994). The study found that elevation significantly affected the distribution of *L. pakeka* within the forest remnant. Most frogs were found in the lower half of the forest remnant, but none were recorded higher than 250m above sea level (a.s.l.) (Bell 1995, Bell & Bell 1994). The population size has been re-estimated at 39,563 using the same data, but analysed with improved statistical modelling and updated emergence probabilities (Bell & Pledger 2000). It is necessary to apply an emergence probability because the nocturnal *L. pakeka* does not come out every night, or, all at the same time. The frogs found in one search are, therefore, only a subset of those in the area.

L. pakeka on Maud Island has been monitored annually since 1983, by estimating population size on two 144m^2 grids in the lower section of forest (Bell 1994, 1997b, Bell & Pledger 2001b). Population estimates remained stable over 1983-93 (Bell 1994, 1997b). In recent years frogs have been recorded outside of the forest remnant, in regenerating forest and paddocks (Bell 1995, B. D. Bell & S. Ward *pers. comm.*). This expansion in distribution may be indicative of population growth.

This study aimed to determine the population size and distribution of *Leiopelma pakeka* in the forest remnant habitat on Maud Island in 2006. Given the reported expansion of *L. pakeka* range, the hypothesis was:

> H_1: The *L. pakeka* population on Maud Island is growing, and the population size is now larger than the re-estimate of 39,563 (Bell & Pledger 2000).

2.2. Methods

2.2.1. Study site

Maud Island is located in the Marlborough Sounds, New Zealand. *Leiopelma pakeka* occurs in a 15ha area of remnant forest on the south-east face of the island, between 90-300m above sea level (a.s.l.). (Figure 2.1). The 1994 population estimate was over an area of 16ha, including the remnant and some regenerating forest (Bell 1995). The current study also covered a 16ha area which included some regenerating forest to the north-east, to ensure that the two estimates were comparable.

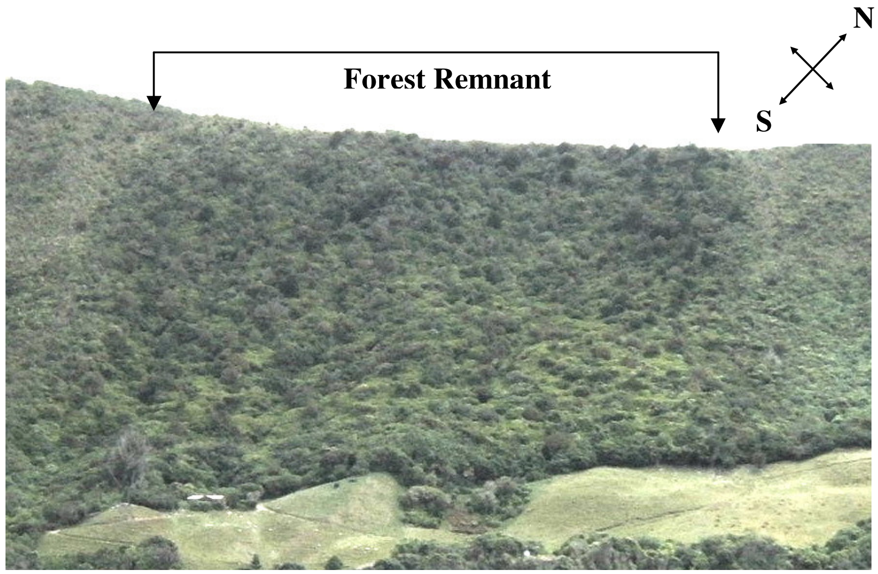

Figure 2.1: The 15ha forest remnant on the south-east face of Maud Island. The forest remnant edges are clearly visible by a change in vegetation. The remnant lies between 90-300m above sea level (a.s.l.), but most *Leiopelma pakeka* occur below 200m a.s.l. (Bell 1995).

2.2.2. Sampling design and data collection

The 16ha forest remnant was divided into five columns and five rows to ensure that surveying would cover the whole area (Figure 2.2). The five rows, based on elevation, were: 90-130m a.s.l., 130-170m a.s.l., 170-210m a.s.l., 210-250m a.s.l., and 250-300m a.s.l. (Figure 2.2). The five vertical columns were each 70m wide, and were measured from a 350m long baseline (bearing 010º) at 90m a.s.l. along the lower forest edge (Figure 2.2). Five 25m^2 plots (5m by 5m) were randomly placed in each of the 20 forest remnant sections between 90-250m a.s.l. (four elevational rows and five columns - see Figure 2.2). Few frogs occur above 250m a.s.l. (Bell 1995), so only six plots were searched in this area. The six plots were placed on three levels between 250-300m a.s.l., at 150m and 200m from the south-west remnant edge (Figure 2.2).

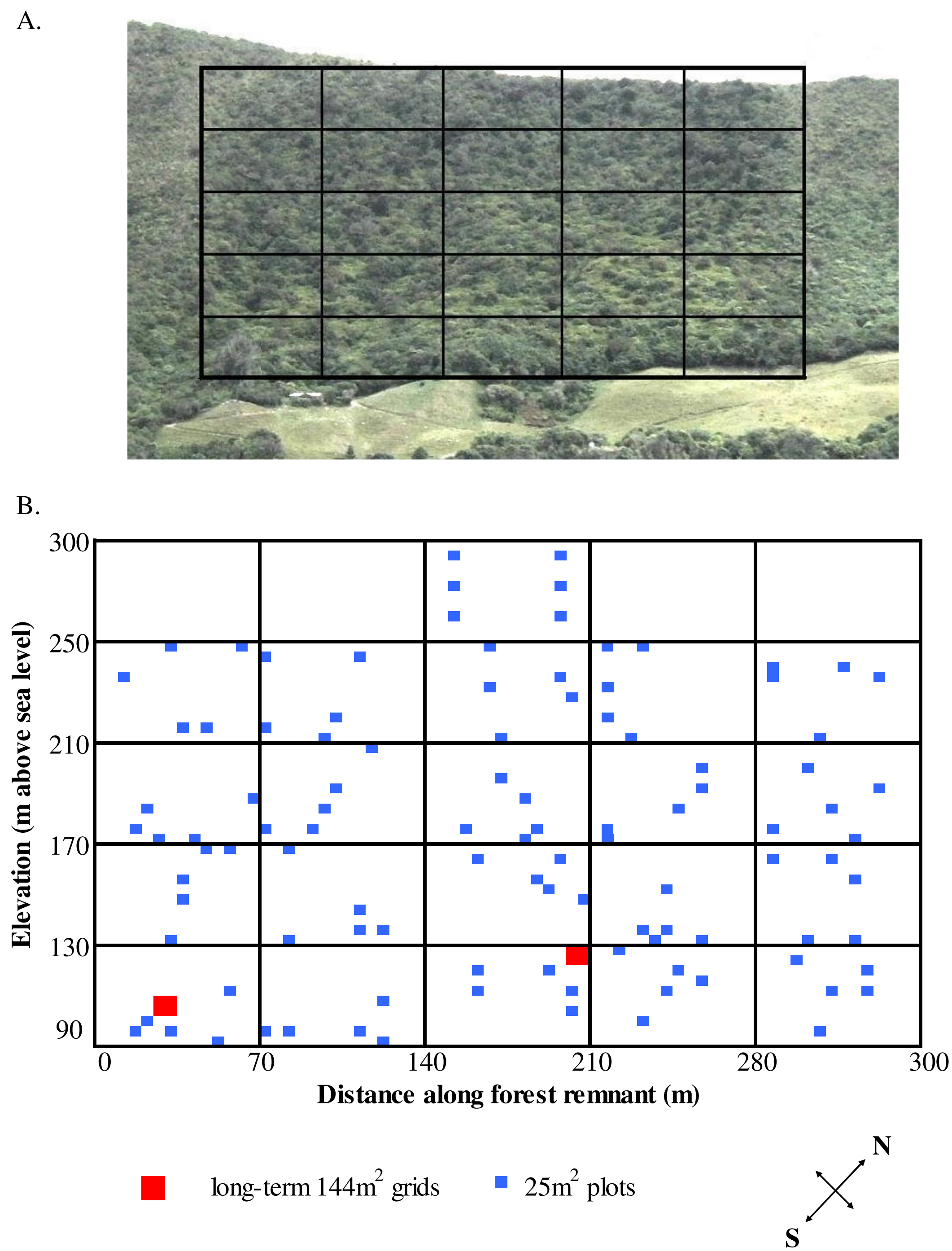

Figure 2.2: Sampling design: The 16ha study area (15ha forest remnant and some regenerating forest on the north-east) was divided into five rows and five columns (A). The five rows were each roughly 40m in elevation, and the five columns were each 70m wide (B). Five 25m^2 plots were randomly placed in each of the 20 sections below 250m a.s.l. Only six plots were placed between 250-300m a.s.l. in the middle of the forest remnant, because few frogs occur in this area (Bell 1995). In total, 106 plots were searched for *Leiopelma pakeka* (B). The two 144m^2 grids, on which population size is estimated annually, are shown in red in the lower figure.

Leiopelma pakeka is nocturnal, emerging at night from under rocks and vegetation (Bell 1978b, Newman 1977a). The 106 25m^2 plots were therefore searched carefully at night by torchlight. Only frogs which were fully emerged from their retreat sites were counted. Each plot was searched once, and it took six nights to cover all 106. The study took place from 29 June – 4 July 2006.

2.2.3. Statistical analyses

The population size of *Leiopelma pakeka* in the forest remnant was determined using a bootstrap method (as in Manly 1997). The numbers of frogs found in the 106 plots were each multiplied by one of 64 different emergence probabilities, chosen at random. This gave 106 different population estimates for a 25m^2 plot, and a population estimate for the total surveyed area was derived from these. The 106 plots covered an area of 2,650m^2. This was multiplied by area to cover the 16ha forest remnant. The whole process was repeated 10,000 times, and the average population estimate for the forest remnant determined. The statistical programme 'R' was used.

The 64 emergence probabilities were determined from two long-term population study grids (each 12m by 12m) in the lower forest remnant (Bell 1994, 1997b, Bell & Pledger 2001b). The population size on these 144m^2 grids is determined using mark-recapture analyses. The emergence probabilities were derived from the number of frogs found on the first night of searching, divided by the estimated population size. The 64 emergence probabilities are derived from searching the two grids over 1984-2004.

Unrealistically large plot population estimates were produced when emergence probabilities were extremely low, which had a disproportionate affect on results. To remedy this, the maximum $25m^2$ plot population estimate was capped at 27.625 frogs. This number was derived from an average of the conservative population estimates (92 and 227) and mean densities (0.6 - 1.6 frogs/m^2) of the two study grids (Bell 1994).

The effect of elevation on *L. pakeka* distribution within the forest remnant was investigated using regression and Kruskal-Wallis tests. Statistical analyses were conducted in SPSS (11.0 for Windows Students Version), and data were graphed in Microsoft Excel (2002).

2.3. Results

A total of 64 *Leiopelma pakeka* were captured in the 106 plots. The number of frogs found per plot ranged from 0 - 8, with an average of 0.512. The 10,000 population estimates for the 16ha forest remnant area ranged from 28,000 – 43,000 frogs (Appendix 7.3.2.). The average population estimate for the remnant was 34,499.26 frogs. The confidence intervals for the estimate were 29,975.73 and 39.195.11. The average density of frogs was 2,156.20 frogs/ha.

L. pakeka distribution in the forest remnant was significantly affected by elevation ($r = 0.348$, $p = 0.000$; Kruskal Wallis test for total and average frogs per elevational row $p = 0.034$). The majority (84.38%) of *L. pakeka* were between 90-170m above sea level (a.s.l.) (Table 2.1). The remainder (15.625%) were between 170-210m a.s.l. (Table 2.1). The number of frogs found in each plot was high between 90-170m a.s.l. (average 1 – 1.12 frogs per plot), low between 170-210m a.s.l. (average 0.4 frogs per plot), and none were found on plots higher than 210m a.s.l. (Table 2.1, Figure 2.3). Several frogs were seen outside of the plots between 210-250m a.s.l. A single frog was seen between 250m a.s.l. and 300m a.s.l., approximately 20m below the top of the forest remnant, but not in the six plots.

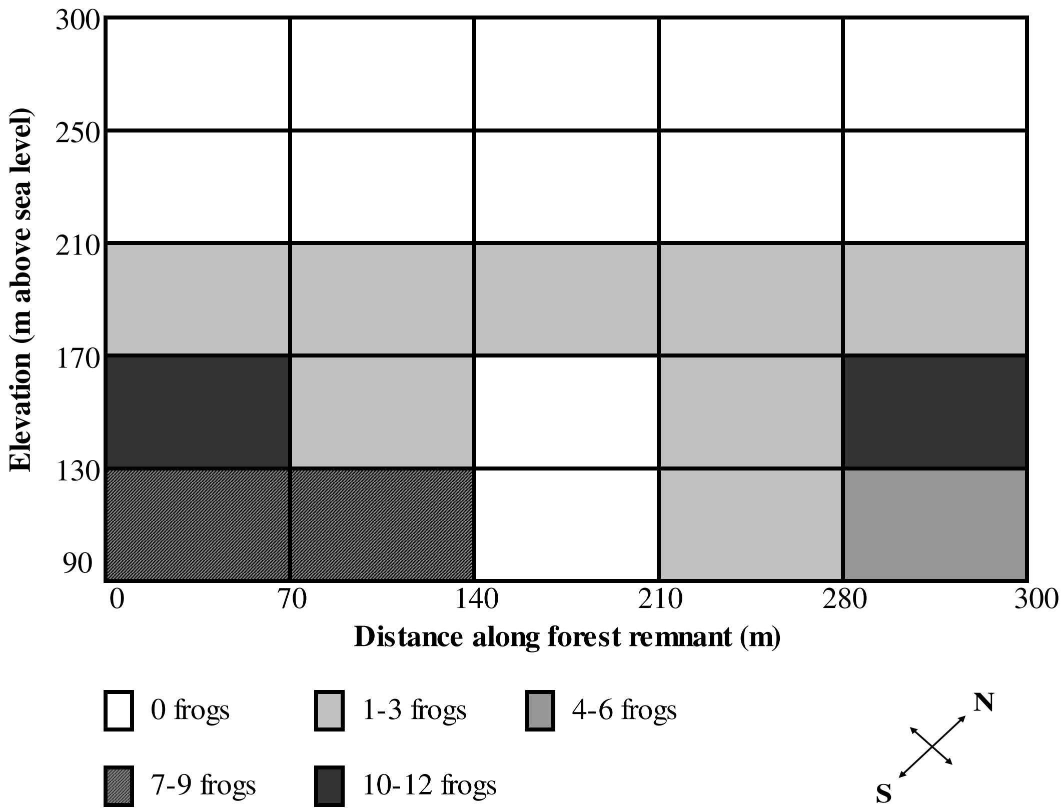

Figure 2.3: The total number of *L. pakeka* found in each section from the five plots searched. Elevation significantly affected the total number of frogs found. Most frogs were between 90-170m a.s.l., and the remainder were between 170-210m a.s.l. None were found in plots higher than 210m a.s.l.

2.4. Discussion

The *Leiopelma pakeka* population in the forest remnant on the south-east face of Maud Island appears to be growing. For at least twelve years now frogs have been observed in areas outside of the forest remnant (Bell 1995, B. D. Bell & S. Ward *pers. comm.*). The current study aimed, therefore, to investigate this possible population growth.

A total of 64 *L. pakeka* were found in 106 25m^2 plots across the 16ha forest remnant area. The population size was estimated to be 34,499 frogs, using the average of 10,000 population size estimates derived from a bootstrap method, and multiplying out by area to cover the full forest remnant. This is almost double the 1994 population size estimate of 19,312 individuals (Bell 1995, Bell & Bell 1994), however, it is less than the re-estimation of 39,563 derived from the same survey (Bell & Pledger 2000). The current study used the same emergence data as the re-estimation (Bell & Pledger 2000), and this partly explains the similarity in results. The 2000 figure falls outside of the 95% confidence intervals of the current estimate. The difference between the two estimates is probably reflective of methodology, and not an indication of a falling population size. The three population estimates are compared in Table 2.2.

Table 2.1: The three population estimates: the year of estimation, the extrapolation method, and the authors.
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Year	Frogs found	Estimated population size	Extrapolation method	Source
1994	170	19,312	Minimum number alive	Bell (1995), Bell & Bell (1994)
2006	170	39,563	Statistical modelling using MARK	Bell & Pledger (2000)
2006	64	34,499	Bootstrap analyses	Present study

The current estimate indicates that the *L. pakeka* population in the forest remnant has remained relatively stable over the past 12 years. This is supported by the stability of population estimates from the 144m^2 grids throughout 1983-96 (Bell 1994, 1997b). The *L. pakeka* population size may therefore have reached the carrying capacity of the forest remnant. Carrying capacity is “the number of individuals of a particular population that the environment can support" (Molles 2002). Further population growth would force the frogs to move outwards, explaining anecdotal reports of *L. pakeka* beyond the forest remnant.

All three population size estimates were based on two assumptions: that both the survey area, and 144m^2 grids, were representative of the forest remnant as a whole (Bell 1995). The current survey was designed to meet the first assumption. The second, however, is more problematic, as the grids were purposefully set in areas of higher frog density on the lower slopes (B. D. Bell *pers. comm.*). It is unknown whether population density influences the emergence behaviour of *L. pakeka*, but increased competition for limited resources could have an effect. It is likely that increased intraspecific competition in areas of high *L. pakeka* density decreases prey levels. More time would be required to gather sufficient food, and emergence would therefore increase. Increased intraspecific competition for space in areas of high *L. pakeka* density could alternatively result in lowered emergence, as frogs may need to spend more time occupying retreat sites in order to retain them.

The population estimate was extrapolated from a small number of captures, which introduces a large margin for error. The bootstrap method of randomly applying 64 different emergence probabilities to the 106 plot capture totals, and then taking the average of 10,000 different population estimates, should have minimised the introduced error. The population estimate was sensitive to the emergence probabilities used, and especially to low probabilities. Capping the maximum plot population size estimate at 27.625 frogs should have resolved this issue. The capping figure was derived from work on the two 144m^2 grids (Bell 1994) which occur in areas of high *L. pakeka* abundance, and therefore represent maximum frog densities. Higher local densities of *L. pakeka* in rocky areas have been found by Newman (1990) and (Bell 1994), but were probably not characteristic of the whole forest remnant. The maximum $25m^2$ plot population estimate was therefore considered to be realistic and representative of the forest remnant.

The average density of *L. pakeka* in the forest remnant was 2,156 frogs/ha, or 22 frogs/$100m^2$. *L. hamiltoni* on Stephens Island were found in comparable densities of 17-33/$100m^2$ (Newman 1990) – these frogs are very similar to *L. pakeka*, and it is argued that they are a single species (Holyoake *et al.* 1999, 2001). The similarity of density estimates is encouraging as it lends credibility to the current findings. Bell (1995) found the density of *L. pakeka* in the forest remnant to be 22-28 frogs/$100m^2$. The current density estimate is slightly lower, but still comparable. The current density estimate was for the entire 16ha forest remnant, but frogs were only found between 90-210m a.s.l. The 1994 study (Bell 1995, Bell & Bell 1994) also found that most frogs were below 200m a.s.l., in an area of approximately 8ha. If the calculation of the current estimate used an area of 8ha rather than 16ha, the density would double to 4,312 frogs/ha or 43 frogs/$100m^2$. The higher density estimate, however, does not indicate population growth, as the re-estimated population size based on the 1994 survey (Bell & Pledger 2000) has a comparable density of 49 frogs/$100m^2$ over 8ha.

Elevation significantly affected *L. pakeka* distribution in the forest remnant. All frogs were found below 210m a.s.l. This result was similar to Bell (1995) and Bell & Bell (1994), who found that 95% of *L. pakeka* were below 200m a.s.l. The majority (84%) of frogs occurred between 90-170m above sea level (a.s.l.), which again is comparable to Bell (1995), who found over 70% within these elevations. Both studies found more frogs between 130-170m a.s.l. than at 90-130m a.s.l. (Bell 1995), however, the difference was slight in this study. No frogs were on plots higher than 210m a.s.l., whereas the 1994 study found frogs up to 250m a.s.l. (Bell 1995). Frogs were seen outside of plots between 210-250m a.s.l., and this may indicate that the plots were too small or that more were needed. The elevational effects on *L. pakeka* distribution were attributed to the affects of habitat by Bell (1995) and Bell & Bell (1994). In the upper half of the forest remnant the forest canopy is lower, rocks are less abundant, and the habitat dry. It should be noted that the survey concentrated on the lower section of forest, and these elevational effects could therefore be an artefact of methodology. Only six plots in the centre of the forest remnant were searched above 250m a.s.l., and the lack of frogs found could reflect low search effort. The single frog seen in this area provides some support for this idea. This individual does not, however, provide evidence that *L. pakeka* is colonising the higher forest areas, as frogs were seen in the region in the 1970s (B. D. Bell *pers. comm.*). From personal observations there were no frogs to be seen in the upper areas - after searches, while walking from the tops of the transect lines to the summit, the ground was carefully surveyed and wider areas were eye-shine scanned.

No frogs were found on plots in the middle section of forest, below 170m a.s.l. This is known to be an area of high *L. pakeka* density (B. D. Bell *pers. comm.*), and one of the 144m^2 grids is situated there. Many frogs were seen, but none were found in the 25m^2 plots. Perhaps this indicates that the study plots were too small, or that more were needed. The two surveys (1994 and current), however, resulted in similar estimates of population size, when the same emergence data were used. This credits both techniques, and indicates that the current method is appropriate for accurately estimating population size of *L. pakeka* on Maud Island.

2.4.1. Conclusions and implications

Shaffer (1981) defined a minimum viable population as "the smallest isolated population having a 99% chance of remaining extant for 1,000 years despite the foreseeable effects of demographic, environmental and genetic stochasticity, and natural catastrophes." There is a general rule in conservation that a population size of 500 is the minimum for long-term sustainability (Franklin 1980). Others have suggested that the minimum population size needs to be between 5,000 (Lande 1995), to 10,000 (Thomas 1990) for long-term persistence, and to maintain genetic diversity. The estimated population size of *Leiopelma pakeka* on Maud Island was 34,499. This estimate is only a rough guide to the number of frogs in the forest remnant; however, this is well above the suggested minimum viable population size. Daugherty *et al.* (1981) found the *L. pakeka* population on Maud Island to have a high level of genetic diversity, which is encouraging as population growth and individual fitness are related to genetic diversity (Reed & Frankham 2003, Williams 2001). Genetic analyses could be carried out on the *L. pakeka* population of Maud Island, to determine the effective population size (the number of individuals breeding).

The current estimate indicates that the Maud Island remnant population of *L. pakeka* is large and stable. The carrying capacity of the forest remnant may therefore have been reached, and further population growth would then force the frogs to move outwards. Support for this exists in the reports of frogs outside of the forest remnant (Bell 1995, B.

D. Bell and S. Ward *pers. comm.*, D. Brown *pers. comm.*, per Bell 1995 & Newman 1996).

These findings are encouraging for the conservation of *L. pakeka*. This survey, which extensively covered the forest remnant, was completed in six nights – indicating that population-level monitoring of *L. pakeka* on Maud Island is feasible and cost-effective.

Chapter 3

Range expansion of the remnant *Leiopelma pakeka* population on Maud Island, New Zealand

3.1. Introduction

New Zealand is home to an archaic group of frogs, the Leiopelmatidae. There are seven identified *Leiopelma* species, three of which are known only from subfossil remains (Towns & Daugherty 1994, Worthy 1987ab). Of the four extant species, two have limited ranges in the North Island, and the remaining two species are larger and each limited to a single rodent-free island. *Leiopelma* species were previously widespread across New Zealand (Bell 1977, Bull & Whitaker 1975, Worthy 1987ab), but are thought to have declined when mammals, especially *Rattus exulans,* were brought into the country (Bell 1977, 1978ab, 1994, Bell *et al.* 1985, Towns & Daugherty 1994, Worthy 1987b).

Leiopelma pakeka is the largest extant species, and ranges in size from 11-50mm snout-vent length (Bell 1978b, King *et al. in press.*). These frogs are nocturnal, emerging at night from their daytime retreats to feed. The emergence behaviour of *L. pakeka* is affected by weather conditions, as these frogs have high rates of evaporative water loss (Cree 1985). High numbers emerge during wet nights (high humidity and rainfall), and fewer come out in colder temperatures (Bell *et al.* 1985). Smaller frogs are more likely to emerge in wet weather, because their high surface area to volume ratio means that they have a high chance of desiccation in dry conditions (Bell 1978a).

L. pakeka has only been found on Maud Island, where it was discovered in 1958 (Stephenson 1961). The frogs were probably distributed across the island before it was largely cleared for agricultural purposes under private ownership (Bell 1982, 1985b, Bell *et al.* 2004b). *L. pakeka* survived in a 15-hectare remnant of native forest, between 90-300m above sea level (a.s.l.), on the south-east face of the island. *L. pakeka* distribution is related to rocky substrate and forest canopy height and cover (Bell 1995, Bell & Bell 1994, Newman 1990). Most frogs occur in the lower half of the forest remnant (Bell 1995), which consists of kohekohe, *Dysoxylum spectabile*, and mahoe, *Melicytus ramiflorus* (Newman 1990, Bell 1995). Beyond 200m a.s.l. the habitat is dry and steep, and the forest canopy, consisting of hinau, *Elaeocarpus dentatus*, and kamahi, *Weinmannia racemosa*, is low (Bell 1995).

Habitat destruction on Maud Island ceased over 35 years ago. The native forest remnant was fenced off in 1965, and Maud Island became a reserve in 1975 (Appendix 7.1). Several amphibian populations across the world have declined due to habitat fragmentation (Blaustein & Kiesecker 2002, Collins & Storfer 2003, Cushman 2006, Nyström *et al.* 2007, Young *et al.* 2001). It has been suggested that habitat destruction has a larger affect on terrestrial frogs (Pineda & Halffter 2004). Cushman (2006) suggested that species with limited dispersal abilities are negatively affected by habitat loss and fragmentation in the long-term. *L. pakeka* is terrestrial and appears to have limited dispersal, occupying small home ranges over most of their long lives (Bell 1997a, King *et al. in press*, Newman 1990).

Since becoming a reserve, the vegetation across Maud Island has been regenerating naturally. Studies in America and Britain have found that habitat restoration can produce a rapid recovery of declining species (Brodman *et al.* 2006, Denton *et al.* 1997, Lehtinen & Galatowitsch 2001, Ries *et al.* 2001).

The *L. pakeka* population on Maud Island appears to be growing, and is spreading out from the forest remnant (Newman 1996). There are several anecdotal reports of frogs outside of the remnant, but most sightings have been within 50m. *L. pakeka* was recorded in secondary forest adjacent to the remnant over ten years ago (Bell 1995). A frog was recently found approximately 100m into the north-east regenerating forest (S. Ward *pers. comm.*). *L. pakeka* has also moved down from the remnant into pastoral areas (Bell 1995; B. D. Bell & S. Ward *pers. comm.*), a patch of regenerating forest (J. Germano *pers. comm.*), and a small rock wall.

L. pakeka has been sighted several times on Fort Road, approximately 300m from the forest remnant. A frog was seen in regenerating scrub approximately 350m from the remnant, prior to 1995 (D. Brown *pers. comm.*, per Bell 1995 & Newman 1996). Several searches failed to relocate this individual (Bell 1995). There have also been other sightings of *L. pakeka* along the Fort Road (C. Kelly & D. Gwynne *pers. comm.*).

L. pakeka is a terrestrial frog which does not require a water-body for any part of its life cycle, however, areas near creeks are likely to be rocky and damp, providing suitable habitat. Creeks could also provide a corridor of suitable habitat, along which *L. pakeka* could disperse to other areas. There are two creeks on the south-east face of Maud Island. Richard Henry Creek runs along the lower south-west edge of the remnant down to the beach. Rifleman Creek is to the north-east of the remnant, and runs from approximately 0-90m a.s.l. across Fort Road. A frog has been seen in Rifleman Creek twice (S. Ward *pers. comm.*).

The aim of this study was to investigate population expansion of *L. pakeka* on Maud Island, suggested by Bell (1995), by assessing their current distribution. The hypotheses were:

H_1: *L. pakeka* has spread out from the forest remnant, dispersing as far as possible into suitable habitat.

The affect of weather conditions on the emergence behaviour of *L. pakeka* was also investigated. It was expected that previous findings would be confirmed. The hypotheses were therefore:

H_2: The emergence behaviour of *L. pakeka* is positively affected by temperature, relative humidity, and rainfall.

H_3: Smaller frogs are more likely to emerge during rainfall and high humidity.

3.2. Methods

3.2.1. Study site and survey design

This study focused on the south-east face of Maud Island (Figure 3.1). The rest of the island appeared unsuitable for *Leiopelma pakeka*. It is also unlikely that frogs have crossed over the summit to the other side of the island, as *L. pakeka* is rare at higher elevations (Bell 1995, Chapter 2). Searches were limited to areas lower than 175m above sea level (a.s.l.), as most frogs in the forest remnant occur below this elevation. Regenerating forest and pastoral areas were searched for *L. pakeka*. The forest remnant boundaries were evident by a clear change in vegetation, and fence-posts remaining from 1965. The survey design is illustrated in Figure 3.1.

Areas below the remnant and along Fort Road were thoroughly searched as a whole. Below the remnant there were fields, a small patch of regenerating forest, and areas around Comalco Lodge, including a rock wall, wood, and rock piles (Figure 3.1). Rifleman Creek to the north-east of the remnant was searched from the spring above Fort Road down to the beach. Three rocky areas on Fort Road appeared highly suitable for frogs. These were approximately 350m, 425m and 475m from the forest remnant.

Regenerating forest was searched using two methods. The first method determined whether frogs had dispersed 50m from the forest remnant. A total of 18 short horizontal transect lines were searched along the north-east and south-west edges of the remnant (nine on each side). These stretched 50m into regenerating forest, and were approximately 25m apart. Frogs were found up to 50m out, so the survey was extended. The second method involved searching vertical transect lines through the regenerating forest. These were parallel to the remnant edges and set at 50m intervals. Six transect lines out to 300m from the remnant were used in the north-east regenerating forest. In the south-west regenerating forest bracken dominated the ground vegetation, and the forest canopy was low and patchy. Three transect lines were used to search this area, out to 150m from the remnant. The regenerating forest 50-100m from the remnant edge, higher than 125m a.s.l, included habitat and gradients that were impractical and dangerous for proper searching; therefore, this area was investigated using 50m long horizontal transects perpendicular to a rocky gully of suitable habitat (approximately 50-75m from remnant). Transects were 1m wide.

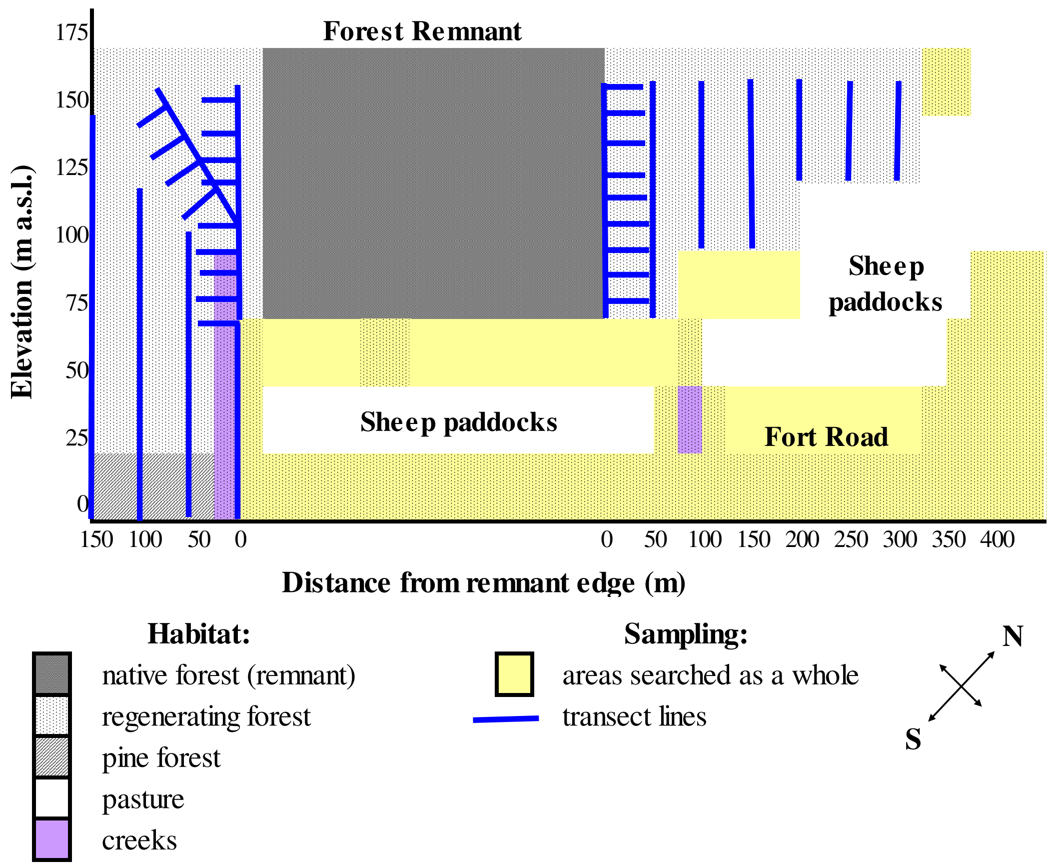


Figure 3.1: The south-east face of Maud Island. Elevation is on the y-axis, and distance from the forest remnant on the x-axis. Richard Henry Creek is in the south-west, and Rifleman Creek crosses Fort Road. Regenerating forest on either side of the remnant was surveyed using transect lines (blue). The remaining areas were searched as a whole (orange).

3.2.2. Data collection and analyses

Four visits were made to Maud Island: 23rd November – 9th December 2005, 14th March – 24th March, 14th April – 6th May, and 7th – 28th June 2006. Searches for emergent frogs were made at night using head torches, as described in Bell (1996). The ground was carefully searched for *L. pakeka*, and surrounding areas were eye-shine scanned using torches, as frogs can sometimes be seen from a distance using this method (Bell 1978a, Cree 1989, Crook 1973).

To prevent re-counting the same individual, frogs were held in numbered plastic bags until each search was complete. Bagged frogs were then returned to their original position, which had been temporarily marked with a numbered reflective garden peg. Handling of frogs was kept to a minimum.

Each area was searched at least three times, to minimise the possibility of missing frogs. Some searches were repeated due to low frog emergence, or dangerous weather conditions. Extra searches were made at the higher part of Rifleman Creek, and the rock wall behind Comalco Lodge (just below the south-west edge of the remnant). Frogs had not been found in these areas after three searches, yet reports indicated that they were present. It was also hoped that extra searches would provide insight into the detection probability of *L. pakeka*.

Leiopelma pakeka distribution was graphed using Microsoft Excel (2002). The data were classified into categories of distance from the forest remnant: 25m, 50m, 75m, 100m, and 350m (Fort Road). The 25m distance category included the horizontal transects along the north-east and south-west edges of the remnant, and pastoral areas and regenerating forest below the remnant. Detection probability was calculated as the proportion of times frogs were found, compared to the number of searches in that site. Detection probability was only determined for areas in which frogs were found. The effect of 'distance from the remnant' on 'the number of frogs found' was investigated using Spearman's correlation. An estimate of dispersed *L. pakeka* was calculated using the sum of the highest number of frogs found on a single search at each site, multiplied by an average emergence factor of 5.845 (Bell 1995), which corrected for those that remained submerged.

3.2.3. Habitat data

The habitat at each site was assessed by observation during the day. Features of interest were: slope, rock cover and size, habitat type, canopy cover and height, sub-canopy and ground cover, and leaf litter cover. Each habitat variable was ranked from 0-5, using the scheme in Table 3.1. For example, a ranking of 1 for habitat type refers to remnant native forest, and a ranking of 3 for rock size represents an area where the majority of rocks are 10-20cm wide. The affect of habitat on *Leiopelma pakeka* distribution was investigated using Kruskal-Wallis tests. Analyses were restricted to areas within 100m of the remnant, as few frogs were found further out. The 'presence of frogs at a site' was analysed because distance from the remnant significantly affected *L. pakeka* abundance.

Table 3.1: Habitat ranking table. Each habitat feature was ranked out of five, and the description of these is outlined below. For example, a ranking of 1 for habitat type refers to remnant forest, and a ranking of 3 for aspect indicates a steep slope.

Habitat feature	**Rank out of five for each feature**					
	0	**1**	**2**	**3**	**4**	**5**
Aspect	flat	gentle	medium	steep	very steep	vertical
Rock cover	0	1-20%	21-40%	41-60%	61-80%	81-100%
Rock size	-	<5cm	5.1-10cm	10.1-20cm	20.1-30cm	>30cm
Habitat type	-	remnant forest	regenerating forest	pine forest	shrubs	pasture
Canopy cover	0	1-20%	21-40%	41-60%	61-80%	81-100%
Canopy height (m)	0	<2m	2.1-4m	4.1-6m	6.1-8m	>8m
Sub-canopy cover	0	1-20%	21-40%	41-60%	61-80%	81-100%
Ground vegetation cover	0	1-20%	21-40%	41-60%	61-80%	81-100%
Leaf litter cover	0	1-20%	21-40%	41-60%	61-80%	81-100%

3.2.4. Meteorological data

Weather variables were collected from the meteorological station on the island (30m a.s.l.), recorded daily at 9am by the resident wardens. The measurements therefore encompassed the previous 24 hours. Weather variables of interest were: rainfall (mm), relative humidity (%), and minimum temperature (˚C). Relative humidity was determined from the wet and dry bulb thermometer temperatures (Linric Company's WebPsycH Psychrometric Calculator). Kruskal-Wallis tests were used to determine if weather differed significantly between research visits, or affected the presence of frogs on each search night. Spearman's correlation was used to investigate the effects of rainfall and relative humidity on the size of emergent frogs. Tibio-fibula length was used as an indication of frog size because this joint to joint measurement is not affected by soft tissue, unlike snout-vent length (Dewhurst 2003).

A negative relationship between frog size and weather variables was expected, as a higher number of smaller individuals should emerge during high rainfall and humidity (Bell 1978a), skewing the data set towards a lower average size of *L. pakeka*. All statistical analyses were carried out in SPSS (11.0 for Windows Students Version).

3.3. Results

3.3.1. Distributional range

The distribution and abundance of *Leiopelma pakeka* on the south-east face of Maud Island is shown diagrammatically in Figure 3.2. A total of 232 frogs were found. The majority (81%) were in regenerating forest: 136 in the north-east, 33 in the south-west, and 19 below the remnant. A single frog was found down Richard Henry Creek, in the south-west regenerating forest, and another 29 frogs were found in pastoral areas below the remnant, including fields and a rock wall behind Comalco Lodge. No frogs had moved further than 25m into pastoral areas. A total of 15 *L. pakeka* were found in a rocky area on Fort Road, roughly 350m from the remnant.

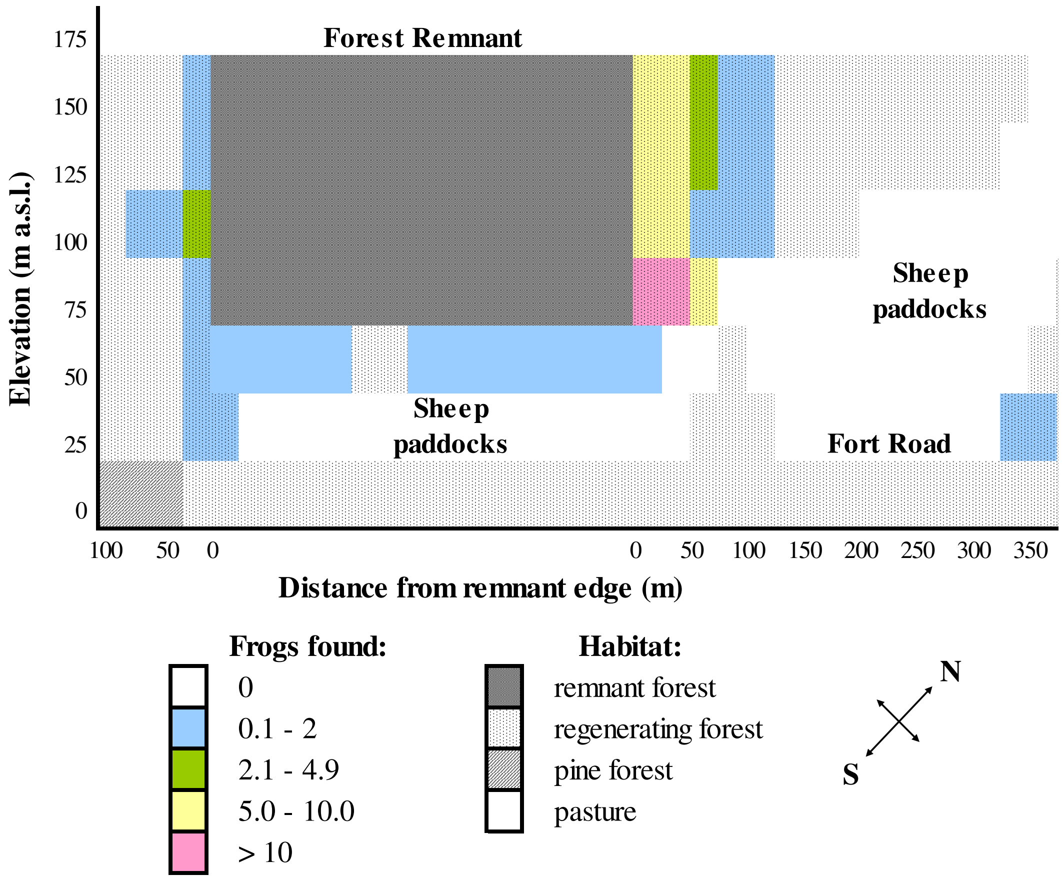


Figure 3.2: The distribution of *Leiopelma pakeka* outside of the forest remnant on the south-east face of Maud Island. Shaded areas represent the average numbers found. Frogs moved up to 100m into regenerating forest in the north-east, 75m into regenerating forest in the south-west, and up to 25m into fields. No frogs were found in areas of pine forest.

Most frogs were found within 50m of the remnant edge. In the north-east regenerating forest they were up to 100m out. *L. pakeka* captures declined significantly with distance from the remnant edge (r = -0.366, p = 0.000), as seen in Figure 3.3. Frogs found per night at each site ranged from 0 - 41. Using only the highest capture night for each site, there were at least 145 frogs. A conservative estimate of 847.525 frogs was derived using an average emergence factor of 5.845 (Bell 1995). Frogs were found at 21 of the 58 sites searched. The detection probability ranged from 0.2 to 1, with an average of 0.56 (Appendix 7.3.5).

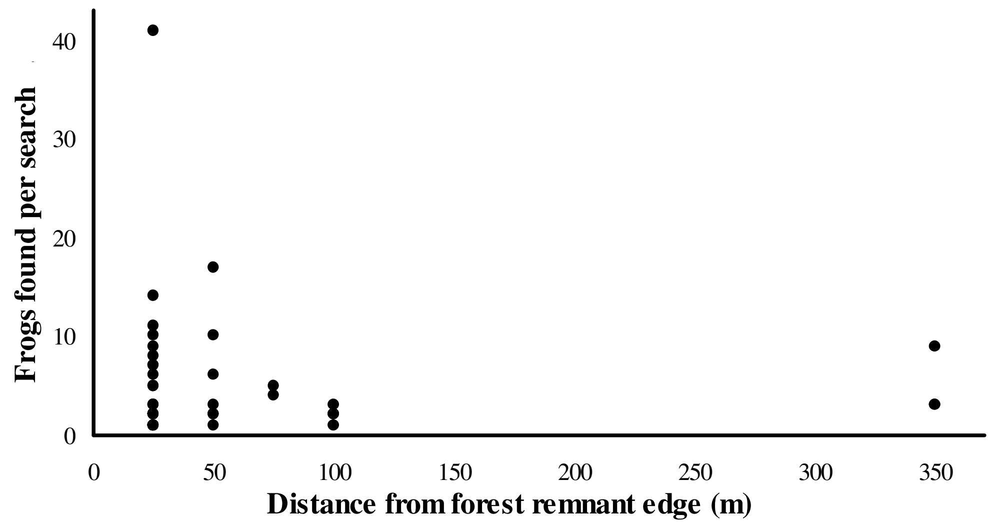


Figure 3.3: Scatterplot showing the significantly negative effect of distance from the forest remnant on the number of frogs found per search.

3.3.2. The effect of habitat on *L. pakeka* distribution

The presence of frogs at a site was significantly positively affected by rock cover ($p = 0.026$), canopy cover ($p = 0.009$), sub-canopy cover ($p = 0.022$), and leaf litter cover ($p = 0.005$). Frog presence was not significantly related to rock size ($p = 0.354$), aspect ($p = 0.065$), canopy height ($p = 0.089$), or ground cover ($p = 0.449$). Most frogs were found on soil (33.7%), rocks (23.4%), and leaf litter (28%). Another 11.4% were found on grass in pastoral areas – these were limited to rocky regions. Only 2.3% were in trees. Three frogs were discovered in unexpected places: a small hole in a mud bank (on Fort Road), among old broken glass bottles (down Richard Henry creek, previously a rubbish dump), and on top of a flattened area of bracken damp with rain under an open canopy (100m into north-east regenerating forest).

Habitat type significantly affected the presence of frogs at a site (p = 0.002). A total of 203 frogs were found in regenerating forest. Only 29 frogs were found in pastoral areas, all within 25m of the forest remnant. No frogs were found in the pine (*Pinus radiata*) forests on the lower elevations in the south-west of the island, although some of these areas were within 100m of the forest remnant edge. Frogs were found further into regenerating forest: up to 75m in the south-west, and 100m in the north-east (Figure 3.2). Habitat quality (forest canopy cover, moisture levels, and rocky substrate) appeared to be highest in the north-east regenerating forest, followed by the south-west regenerating forest, and lowest in pastoral areas. The north-east regenerating forest appeared fairly mature. In the south-west the canopy vegetation is shorter and sparser. Frogs did not disperse more than 100m into regenerating forest alongside the remnant, where bracken becomes abundant. A single frog was found in a small patch of bracken in the north-east regenerating forest. This was on a wet night, and the bracken was damp with rain.

3.3.3. The effect of weather on emergence behaviour

Relative humidity and minimum temperature (p = 0.000) differed significantly between the four research visits, which were: 23rd November – 9th December 2005, 14th March – 24th March, 14th April – 6th May, and 7th – 28th June 2006. Rainfall, however, did not differ significantly between research visits (p = 0.467). Relative humidity was highest in April-May, followed by November-December, and lowest in June. Minimum temperature was highest in March, followed by April-May, and lowest in June. Frog emergence was not significantly affected by rainfall (p = 0.144), relative humidity (p = 0.508), or minimum temperature (p = 0.452). The size of emergent frogs (tibio-fibula length) was significantly positively correlated with relative humidity (r^2 = 0.006, p = 0.003), but not rainfall (r^2 = 0.058, p=0.619), as shown in Figure 3.4.

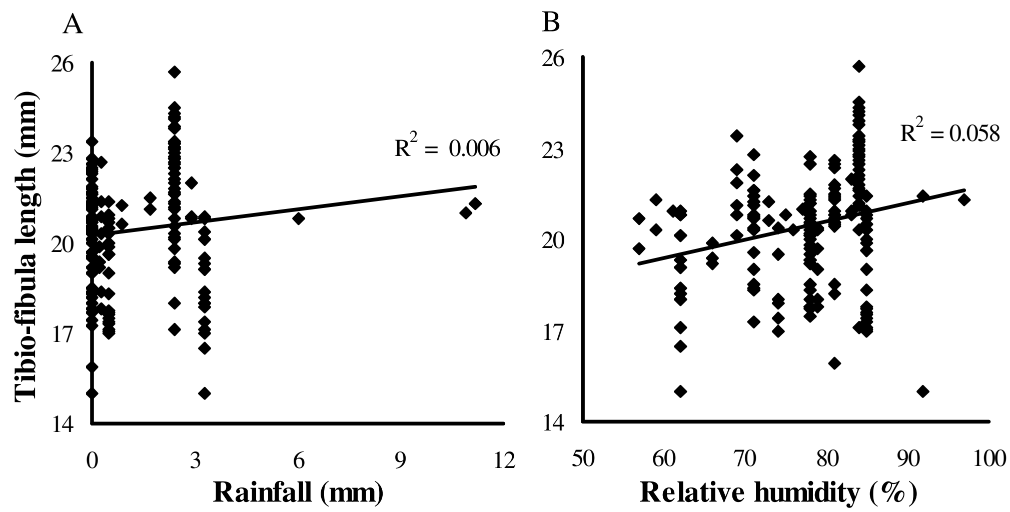


Figure 3.4: Scatter plot of frog size (tibio-fibula length) versus A) rainfall (mm) and B) relative humidity (%). Both relationships were positive, but only humidity had a significant effect ($p<0.05$).

3.4. Discussion

3.4.1. Distribution of *Leiopelma pakeka* outside the forest remnant

The *Leiopelma pakeka* remnant population on the south-east face of Maud Island appears to be growing. Frogs have been found outside of the forest remnant since 1989 (B. D. Bell *pers. comm.*). Population estimates for the forest remnant remained stable over 1994-2006 (Chapter 2). Population estimates for two 144m^2 study grids were also stable from 1983 – 1996 (Bell 1997a). Molles (2002) defines carrying capacity as “the number of individuals of a particular population that the environment can support.”

The carrying capacity of the forest remnant may have been reached, and further population growth would then force *L. pakeka* to move outwards.

Range expansion in *L. pakeka* was confirmed by this study. *L. pakeka* has mainly dispersed within 50m of the forest remnant, although they have moved up to 100m out. The frogs found 100m out were in the north-east regenerating forest on Fuschia track (approximately 165m above sea level (a.s.l.)), and one was near the lower fence line. A frog was found 100m along Fuschia track in 2005, when rocks were overturned during a school trip hunt for insects (S. Ward *pers. comm.*). *L. pakeka* numbers declined significantly with distance from the forest remnant, as would be expected if population growth is forcing range expansion. Frogs were in the fields just below the remnant in 1989 (B. D. Bell *pers. comm.*), and since then, they have not moved further than 25m into pastoral areas. This slow spread outwards may be indicative of population growth.

It should be noted that initial observations were focused on the forest remnant. It is possible, therefore, that *L. pakeka* have always occurred in the areas where they were found during the current study. These findings are considered to be representative of range expansion, however, because *L. pakeka* numbers declined significantly with distance from the forest remnant

At least 145 frogs were found outside the forest remnant. This number excludes multiple searches to avoid including possible recaptures of single frogs. The number of frogs found in a search represents a subset for the area as night-time emergence in *L. pakeka* is variable. Frogs do not emerge every night, or all at the same time. It was necessary to multiply the number of frogs found by an emergence probability, to better understand how many *L. pakeka* were in an area. The estimate of *L. pakeka* outside of the remnant, adjusted for emergence, was 847 frogs. This is a rough estimate, to be taken as a guide only, as emergence behaviour may be affected by population density, habitat quality, and food reserves, all of which could differ between areas.

Creeks provide damp, rocky habitat that appears suitable for *L. pakeka*. It was thought that *L. pakeka* would disperse down these corridors of good habitat, to other areas of regenerating forest. A single frog was discovered down Richard Henry Creek 32m below the lower forest remnant edge. No frogs were found in Rifleman Creek, or the regenerating forest along the shoreline.

All anecdotal sightings of frogs were confirmed, except those in Rifleman Creek. If frogs were in the area, the average detection probability of 0.56 indicates that they should have been found. *L. pakeka* is very cryptic, remaining immobile for prolonged periods (Bell 1985b), and frogs were missed on three searches at four sites where they did occur. The large areas involved in this study make it possible that some frogs were missed. Habitat type may also affect the detection probability of *L. pakeka* in an area. In the current study it was harder to find frogs in tall grass than in regenerating forest.

The furthermost movement of *L. pakeka* has occurred in regenerating forest. Studies in America and Britain have shown that declining species can rapidly recovery after habitat restoration (Brodman *et al.* 2006, Denton *et al.* 1997, Lehtinen & Galatowitsch 2001, Ries *et al.* 2001). After habitat restoration in northwest Indiana, amphibians increased from seven species to ten, and from 14 to 172 populations (Brodman *et al.*

2006). Habitat-sensitive butterfly species richness increased by up to five times in restored roadside prairies in Iowa (Ries *et al.* 2001). Newly created ponds in Britain were colonised within two years by natterjack toads (*Bufo calamita*), and over 65% of populations provided with new ponds stabilised or increased in number (Denton *et al.* 1997). This suggests that habitat restoration is an extremely important factor in the recovery of endangered species.

3.4.2. Fort Road frogs

A total of 15 *Leiopelma pakeka* were found on Fort Road. Frogs were located on the bank along Fort Road and in greater numbers below the path (Figure 3.5). This region looks similar to a photo in Bell (1995) of where a frog was seen on Fort Road over twelve years ago. *L. pakeka* may therefore have inhabited the area since prior to 1995.

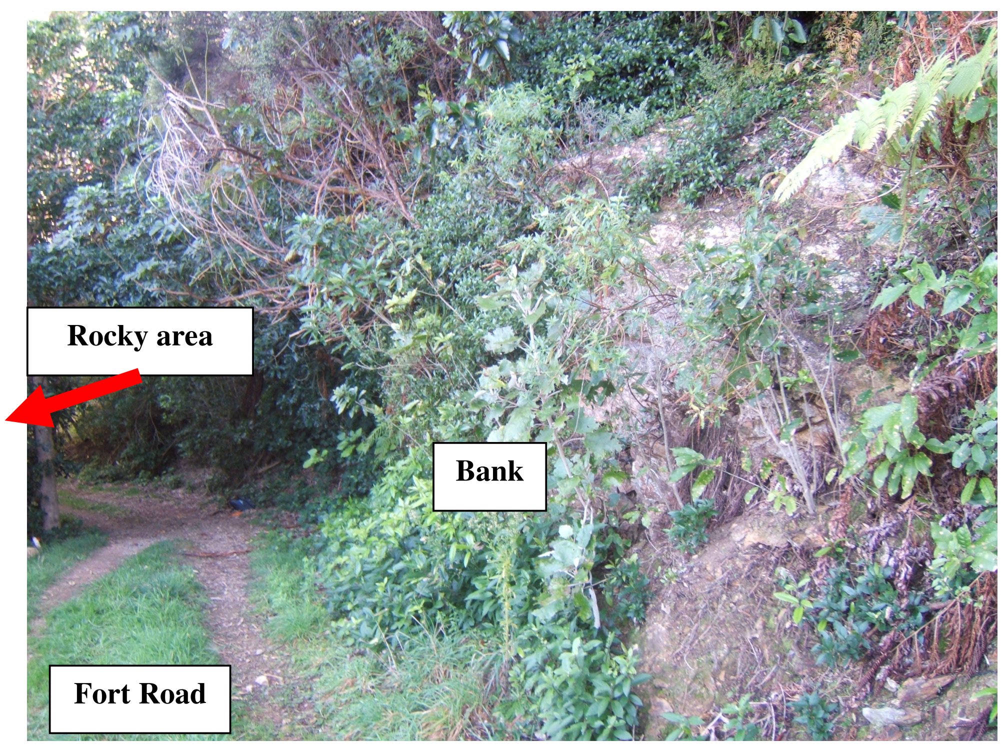


Figure 3.5: The habitat of the Fort Road frogs. They can be found on the bank to the right of the photo, or in greater numbers in a rock area off the path, to the left.

There are at least nine individuals in the area, as this many were found on one search night. The frogs could number 52.605 individuals using the emergence probability of Bell (1995). A population estimate could be determined using photographic identification (Beausoleil *et al.* 2004, Bradfield 2004, Newman 1977a, 1990), and mark-recapture analyses.

The Fort Road frogs could either be a relict population previously undetected, a colony dispersed from the forest remnant, or may even have arrived in the area through human activity. *L. pakeka* was probably previously distributed across Maud Island (Bell 1982, 1985b, Bell *et al.* 2004b), and it is possible that frogs have remained undetected on Fort Road due to extremely low numbers. Bell (1995) searched the Fort Road but failed to relocate the frog seen earlier, possibly due to low abundance or density. The lack of frogs found between the two areas in the current study supports the idea of a relict population. The two sightings of frogs in Rifleman Creek provides some support the idea that the frogs dispersed to this region, however, it is not known if *L. pakeka* disperses across distances. Much of the limited knowledge on dispersal in *L. pakeka* is derived from translocated populations, where frogs have moved up to 26m (Bell *et al.* 2004, Trewenack *et al. in press.*). Translocated *L. hamiltoni moved* 70m (Tocher & Brown 2004) – this species is very similar to *L. pakeka* (Holyoake *et al.* 1999, 2001). These large movements occurred in translocated populations, and may therefore not be indicative of natural dispersal behaviour. No frog has yet been found to have moved larger distances, such as the 350m between the forest remnant and the Fort Road. These frogs occupy small home ranges for most of their lives (Bell 1994, 1997a, Bell *et al.* 2004b, King *et al. in press*, Newman 1990), and it may be unlikely that *L. pakeka* naturally moved between the two areas. The origin of the Fort Road frogs could possibly be determined using genetic analyses.

3.4.3. The effect of habitat on *Leiopelma pakeka* distribution

Habitat type significantly affected the presence of *Leiopelma pakeka* at a site and dispersal. Almost seven times as many frogs occurred in regenerating forest than in pastoral areas. Frogs were also found much further into regenerating forest than pastoral areas. Bracken may also be a limiting factor in *L. pakeka* dispersal, as only a single frog was found in bracken in the current study. This shrub-like plant creates a dry environment, which may not be suitable habitat for *L. pakeka*. The extent to which *L. pakeka* distribution is limited by bracken is unknown, as other *Leiopelma* species are known to inhabit areas with bracken (Stephenson & Stephenson 1957).

No frogs were found in the pine (*Pinus radiata*) forests on the lower elevations in the south-west of the island. Pine trees could create an unsuitable habitat, possibly by making the environment too dry for *L. pakeka*. This is supported by the absence of *L. hochstetteri* in areas where pine trees were close to the stream flow (Douglas 1997). At this point in time, *L. pakeka* has probably not dispersed to these areas. In the future pine trees could have a limiting affect on frog distribution; however, this is unlikely as it has been found that *L. hochstetteri* can inhabit pine forest (Crossland *et al.* 2005).

The movement of *L. pakeka* appeared to be related to the quality of the habitat, with frogs found furthermost into the north-east regenerating forest, followed by the south-west and the least into pastoral areas. Habitat quality (forest canopy cover, moisture levels, and rocky substrate) appeared to be highest in the north-east regenerating forest, followed by south-west regenerating forest, and lowest in pastoral areas. Habitat quality is known to affect the abundance of many species, including *Rana aurora aurora* and *Triturus helveticus* (Chan-McLeod 2003, Denoël & Lehmann 2006, Wilcox & Murphy 1985).

Frog presence at a site was also significantly affected by canopy, sub-canopy, and ground cover. Canopy height did not significantly affect frog presence. In contrast, Bell and Bell (1994), found canopy height to have the largest influence of the four within the forest remnant. Leaf litter cover also significantly and positively affected frog presence at a site. This relationship may arise because abundant leaf litter will increase the moisture levels of the habitat, which is important for frogs. Dense canopy cover provides a stable microclimate, and so probably has a larger influence on *L. pakeka* distribution than leaf litter. The previously established habitat effects on *L. pakeka* distribution were within the forest remnant. The differences found here may therefore be due to the inclusion of different habitat types.

Almost one quarter of the frogs were found on rocks. Rock cover significantly affected frog presence at a site, as found in other studies (Bell 1995, Bell & Bell 1994, Newman 1990). In pastoral areas, frogs were limited to areas with rocky substrate. Rock size did not affect frog distribution. The opposite was expected, as larger rocks should provide better shelter. In this study, 34% of frogs were found on soil. This does not necessarily reflect a relationship between frog presence at a site and soil substrate, as these individuals were probably moving over their home range in search of food.

3.4.4. The effect of weather on *Leiopelma pakeka* emergence behaviour

Emergence in *Leiopelma* species has been found to be positively related to weather variables, such as humidity, rainfall, and temperature (Bell 1978a, 1995, 1996, Bell *et al.* 1985, Newman 1990). Emergence was not significantly affected by any of the weather variables in the current study. A relationship could have been masked by analysing frog presence instead of abundance, as some frogs may emerge regardless of weather conditions. Frog presence was analysed because the data was collected during a distributional study, which would distort the results of analyses using abundance data.

The size of emergent frogs was significantly positively correlated with relative humidity, although the opposite was expected. Smaller frogs have a higher surface area to volume ratio than large frogs, and therefore experience higher rates of water loss. They should have emerged in higher numbers during wet conditions, resulting in a decreased average frog size. Other studies have found that smaller frogs are overlooked during night searches (Bell 1978ab), and from personal observations, it was much harder to see small frogs during rainfall or when the ground was wet. The positive relationship between frog size and humidity may, therefore, have been a factor of observer bias towards larger individuals.

3.4.5. Conclusions

Range expansion has occurred in the remnant *L. pakeka* population on the south-east face of Maud Island. There are at least 145 frogs outside the forest remnant, and up to 847 if corrected for emergence. *L. pakeka* has mainly dispersed within 50m of the remnant, although they have moved up to 100m into regenerating forest. Habitat type significantly affected the distance moved by frogs. The range expansion is probably due to population growth forcing frogs out from the remnant. The only frogs found in an isolated pocket away from the remnant were on Fort Road. These were probably in the area prior to 1995, and could be another remnant population. This study presents a minimum estimate for the range of *L. pakeka* on Maud Island. There could also be other pockets of distribution on the island, where *L. pakeka* has remained undetected.

Habitat type and rock, canopy, subcanopy, ground and leaf litter cover all affected the presence of frogs at a site. Habitat type also significantly affected the distance that frogs moved out from the remnant. These findings are relevant to the conservation of *Leiopelma*, especially when considering habitat restoration or translocation sites. In particular, translocation sites should be in remnant or regenerating native forest. When considering sites for translocation or restoration, it would be advisable to take into account areas with the following attributes: high rock cover, high canopy cover, high subcanopy cover, and high leaf litter.

Leiopelma pakeka was probably distributed over the whole of Maud Island before the vegetation was cleared (Bell 1982, Bell *et al.* 2004b). The range expansion is therefore a recovery from habitat fragmentation. Amphibians are thought to be especially susceptible to habitat fragmentation (Wind 2000). It has been suggested that species with limited dispersal are affected by habitat fragmentation in the long term (Cushman 2006). This range expansion is therefore especially encouraging.

Chapter 4

The morphology of *Leiopelma pakeka* in the remnant population on Maud Island

4.1. Introduction

"Measurements of frogs can provide information on age, sex, condition, growth-rate and inter-population differences" stated Bell (1996) in reference to the Leiopelmatidae. The *Leiopelma* are small frogs found only in New Zealand, and are considered to be archaic because they possess several primitive morphological traits (Bell 1982, Bull & Whitaker 1975, Green & Cannatella 1993, Stephenson 1952, 1960, 1961). The largest of the four extant species, *Leiopelma pakeka*, survived in a 15ha forest remnant on Maud Island in the Marlborough Sounds. No other populations of this species have been found to date.

A translocated population of *L. pakeka* in Boat Bay on Maud Island subsequently became larger and heavier than frogs in the forest remnant (Bell 1982, 1995, Dewhurst 2003). These size differences may be indicative of phenotypic plasticity (Dewhurst 2003), which is when the morphology of an organism can be significantly affected by certain environmental factors (Thain & Hickman 2001). These factors can include microclimatic variables (Nunney & Cheung 1997, Yost 1987), food quality and reserves (Ford & Seigel 1989, Madsen & Shine 1993, Morey & Reznick 2000, Pfennig *et al.* 1991), habitat (Fjellheim *et al.* 1995, Laurila & Kujasalo 1999, Pfennig *et al.* 1991, Reylea 2001ab, Sumner *et al.* 1999, Trussell 1997, 2000), and population structure

(Bohlin *et al.* 2002, Branch 1975, Dash & Hota 1980, Denno & Roderick 1992, Hoare *et al*. 2006, Imre *et al.* 2005, Jenkins *et al*. 1999, Kira *et al.* 1953, LeBerg & Smith 1993, Moore *et al*. 2007, Ostfeld & Canham 1995, Palmblad 1968, Semlitsch & Caldwell 1982, Skogland 1983). The size increase in translocated *L. pakeka* is thought to have arisen through intraspecific competitive release (Bell 1995, Bell *et al.* 2004b). Low population density can release individuals from intraspecific competition, as there are comparatively more resources per animal. Competitive release can lead to increased growth-rates and size. *Notophthalmus viridescens dorsalis* salamanders, for example, experienced rapid growth as a result of decreased density (Harris 1987). Significantly higher growth-rates were seen in descendant iguanas from a translocated population of *Cyclura cychlura inornata*, where density was lower (Knapp 2001). Translocated tuatara, *Sphenodon guntheri*, increased in weight and length, possibly due to decreased density (Nelson *et al.* 2002). Competitive release positively affected relative size at metamorphosis in *Hyla gratiosa* tadpoles (Travis 1984).

The *L. pakeka* population on Maud Island appears stable (Bell 1994, 1997b, Chapter 2), and frogs have been spreading out from the forest remnant into regenerating forest and pastoral areas. In Chapter 3 the distribution and range expansion of the remnant population of *Leiopelma pakeka* on Maud Island was established, the results of which are summarised here. *L. pakeka* has generally dispersed within 50m of the remnant. The distance moved varied between habitats. Frogs were found 100m into regenerating forest on the north-east side of the remnant, 75m into regenerating forest on the south-west side, and 25m into pastoral areas below the remnant. The number of frogs found declined significantly with increasing distance from the forest remnant. A number of animals were also found approximately 350m from the remnant, on the Fort Road.

These frogs may have been in the area for over ten years (Bell 1995, Newman 1996), and the origin of this colony is unknown. They could be a remnant population, have dispersed there naturally, or through human agency.

L. pakeka is known to occupy small home ranges (Bell 1997a, King *et al. in press*, Newman 1990), and the dispersal behaviour of these frogs is not well known. The largest known movements have been documented in translocated populations: 26m in Boat Bay on Maud Island (Bell *et al.* 2004, Trewenack *et al. in press.*), and 70m in *L. hamiltoni* on Stephens Island (dispersal back to the source location) (Tocher & Brown 2004). *L. pakeka* is very similar to *L. hamiltoni*, and it has been argued that they are a single species (Holyoake *et al.* 1999, 2001). It is clear, therefore, that these frogs possess the ability to disperse reasonable distances. In both cases the translocated frogs were adults (Brown 1994, Bell 1994), however these movements may not be representative of natural disperal behaviour. In many amphibians, juveniles are the dispersive life-history stage (deMaynadier & Hunter 1999, Jameson 1956, Roble 1979). Cushman (2006) stated that "in amphibians, population connectivity is predominantly effected through juvenile dispersal." Adult *L. pakeka* are known to occupy home ranges (Bell 1997a, King *et al. in press*, Newman 1990), so if a dispersive life stage exists it may be in younger, and therefore smaller, frogs.

This study aimed to investigate the morphology of *Leiopelma pakeka* outside the forest remnant. The hypotheses were:

H_1: As distance from the forest remnant increases, the number of frogs found decreases (Chapter 3). This lowered density may result in competitive release, leading to increases in frog size with distance from the forest remnant.

H_2: Dispersal in *L. pakeka* may be carried out by subadults, as in other amphibians. The average size of frogs on the edges of distribution will therefore be smaller than in the remnant.

H_3: The frogs on the Fort Road are morphologically similar to the forest remnant *L. pakeka*, either because there is movement of individuals between the two areas, or the two 'populations' have not been separated long enough to differentiate.

4.3. Methods

4.2.1. Study site, survey design and *Leiopelma pakeka* distribution

The study site was the south-east face of Maud Island in the Marlborough Sounds. Regenerating forest covers the slopes on either side of the remnant and along the shoreline. Below the remnant are pastoral areas and some regenerating forest. Data used in this study were collected during a survey assessing the distribution of *L. pakeka* outside of the forest remnant on Maud Island. This is summarised here, for a more detailed description please see Chapter 3.

Searches for frogs were limited to areas below 175m above sea level (a.s.l.) as most occur between 90-200m a.s.l. (Bell 1995, Chapter 2). In the forest remnant sufficient frogs were found in the initial surveys at lower elevations and 165m a.s.l. on the north-east side, therefore, the search area was not extended. Regenerating forest covered the slopes on the south-west side down to the beach and on the north-east side to 90-135m a.s.l. Transect lines were used to focus searches in the regenerating forest. The remaining south-east face was searched as thoroughly as possible. Regenerating forest along the vertical edges of the remnant was searched using 18 transect lines (50m long, 25m apart). Transect lines parallel to the edges were also used to search further out (six in the north-east and three in the south-west). On the Fort Road two main areas were searched. The first was from a spring below the remnant edge to the bottom of Rifleman Creek. The second was a rocky area in regenerating forest, further along the Fort Road, roughly 350m from the remnant.

Searches for these nocturnal animals were made at night using torches (head lamps), as described in Bell (1996). The ground was carefully searched, and wider areas were also eye-shine scanned. To minimise the possibility of missing frogs each area was searched at least three times. Frogs were placed in numbered plastic bags until each search was complete, to enable accurate estimation of numbers. After collecting morphological data, frogs were returned to the exact location where they were found, this was temporarily marked with a numbered reflective garden peg. Fresh gloves were used when handling frogs.

The distribution of *L. pakeka* on the south-east face of Maud Island is shown diagrammatically in Figure 4.1, below. Most frogs were within 50m of the remnant. In regenerating forest they were further out – 75m on the south-west and 100m on the north-east. Frogs were also found on Fort Road, roughly 350m from the remnant.

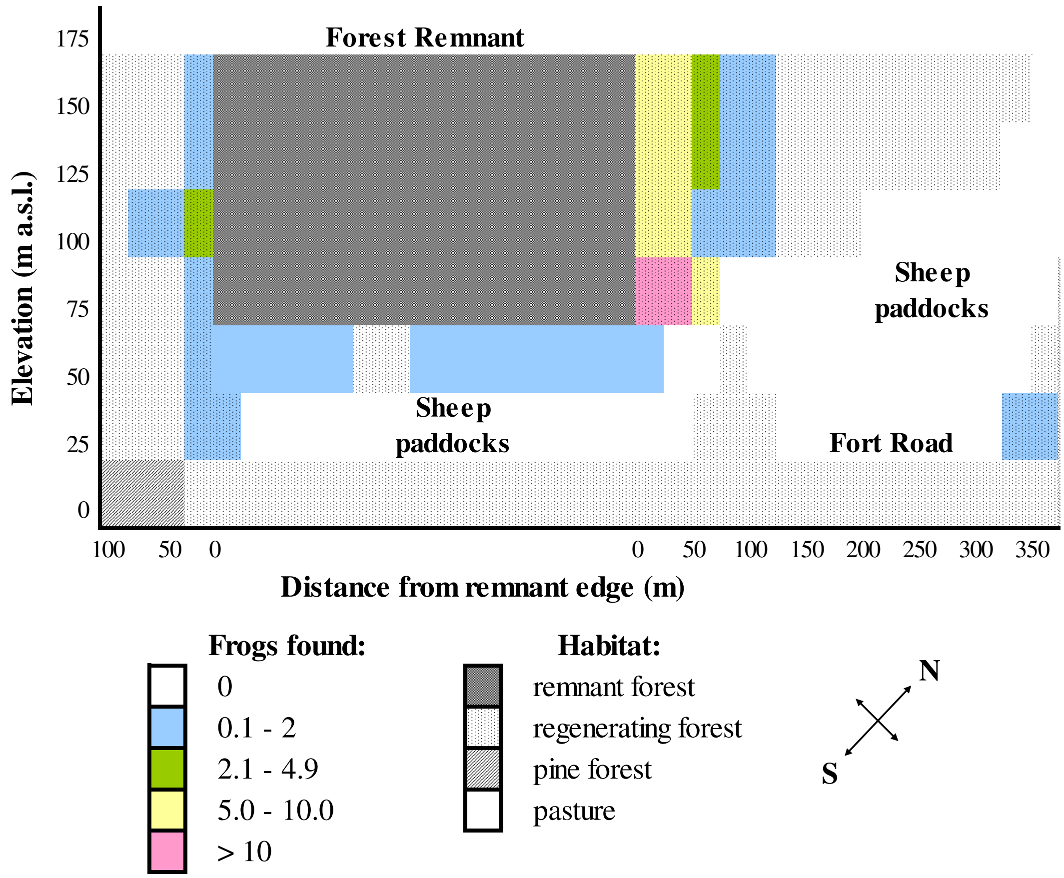
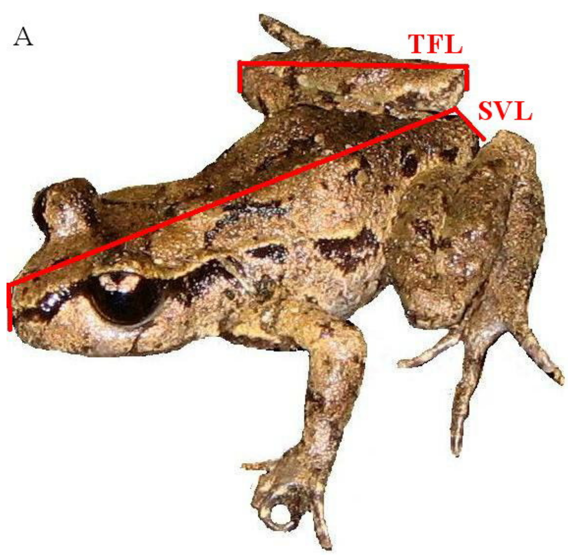


Figure 4.1: The distribution of *L. pakeka* on the south-east face of Maud Island. Habitat type is also shown. Most frogs were found within 50m of the remnant edge. Frogs were found up to 100m into regenerating forest on the north-east side.

4.2.2. Study species and data collected

Leiopelma pakeka ranges in size from 10mm (Bell 1978b) to 51mm (B. D. Bell *pers. comm.*) snout-vent length. Growth continues throughout their lives, although it slows down with age (Bell 1997b). There are several size and age classes into which frogs can be divided (Bell 1978b). In this case the frogs were divided into these four size classes based on snout-vent length: less than a year old (<15mm), juveniles (15-35mm), "male" (mature males and immature females, 35-43mm), and mature females (>43mm). *L. pakeka* is almost always brown, although colour intensity and patterning vary between individuals (Bell 1978b, 1982, Bell *et al.* 1998a) – these are, however, fixed in each frog and do not change over time (Stephenson 1961).

The following data were collected from each frog: colour intensity, pattern, girth, weight, snout-vent length, and tibio-fibula length. Colour categories were: light, light-medium, medium, medium-dark, and dark. Pattern categories were: uniform, uniform-mottled, mottled, mottled-patterned, and patterned. Girth ranged from 1 (very thin) to 5 (very fat). Weight was measured using a hand-held digital scale (Diamond Series A04 Professional-mini Pocket Scale) accurate to 0.1g. Dial callipers (accurate to 0.1mm) were used to measure snout-vent length and tibio-fibula length (Figure 4.2). Snout-vent length was measured from the tip of the snout to the cloacal opening, and tibio-fibula length from the mid-leg joint to the lower tibiatarsal joint**.** The body condition index of Dewhurst (2003) was used [log(weight)/log(snout-vent length)]. Colour, pattern, snout-vent length, and tibio-fibula length are shown in Figure 4.2.



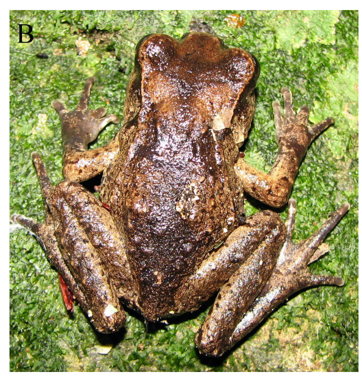


Figure 4.2: The various colour and pattern variations of *L. pakeka*: light to dark (A-C), patterned (A), mottled (B), and uniform (C). The physical measurements, shown in A, were taken with callipers (SVL = snout-vent length; TFL = tibio-fibula length).

4.2.3. Data analyses

To avoid including an individual twice, any frogs with similar morphology found on different nights within the same area were excluded. Similar morphology was defined as: measurements within 0.2mm, and colour intensity and patterning within one category. The morphology of dispersing versus forest remnant frogs was investigated using Spearman's correlation – the variables were distance from the remnant edge, and frog size (snout-vent length, tibio-fibula length, weight, girth, and body condition index). The distance categories were: forest remnant, 25m, 50m, 75m, and 100m from the remnant edge. The 25m category included the transect lines from the remnant edges, and areas below the remnant. The morphology of Fort Road and forest remnant frogs was compared using non-parametric Kruskal-Wallis tests. This was done by comparing the frogs found on Fort Road to those in the remnant and surrounding areas. Statistical analyses were conducted using SPSS (11.0 for Windows Students Version), and data were graphed using Microsoft Excel (2002).

4.3. Results

4.3.1. Morphology of dispersing *Leiopelma pakeka*

Data were collected for 180 *L. pakeka* in and around the forest remnant. The frogs were found as follows: six in the forest remnant, 131 at 25m, 31 at 50m, six at 75m, and six at 100m. Two frogs were smaller than 15mm (11.35mm and 14mm), and were excluded from statistical analyses because they would disproportionately affect results.

Distance from the forest remnant had a small but significantly positive affect on the weight ($r = 0.268$, $p = 0.000$), girth ($r = 0.146$, $p = 0.046$), and condition index (r = 0.270, p = 0.000) of *Leiopelma pakeka*. Figure 4.3 shows that distance had a significant effect on average snout-vent length and tibio-fibula length, with both increasing with distance out to 75m from the remnant, and decreasing at 100m. Distance out to 75m significantly positively affected snout-vent length (r = 0.187, p = 0.014), and tibio-fibula length (r = 0.0135, p = 0.077).

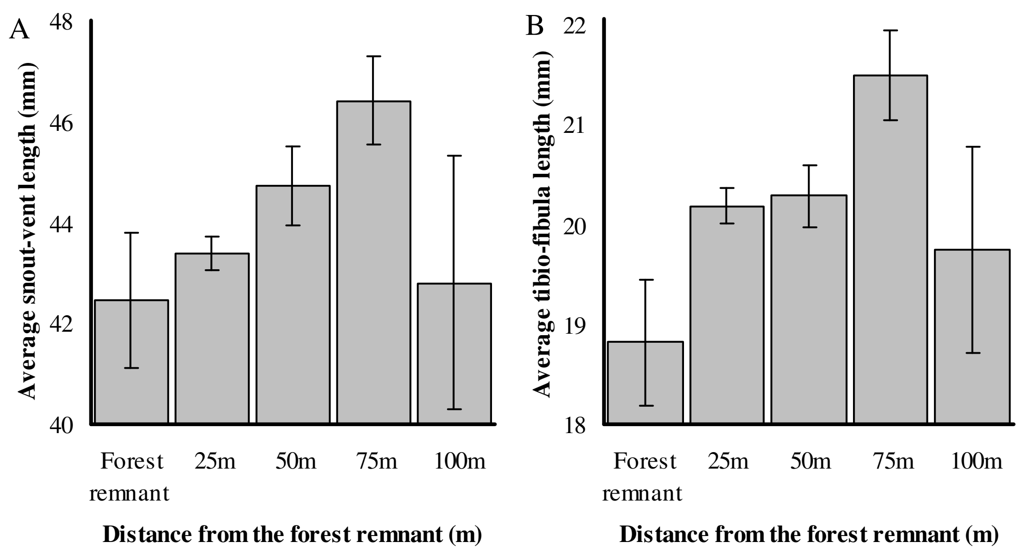


Figure 4.3: The average snout-vent length (A) and tibio-fibula length (B) (± one standard error) of frogs found at various distances from the remnant forest edge. In both cases, the size of frogs increased with distance to 75m, then decreased at 100m. Sample sizes were: 6 in the forest remnant, 131 at 25m, 31 at 50m, 6 at 75m, and 6 at 100m.

Two forest remnant *L. pakeka* were notably lethargic and no information was taken from either. Both of these frogs were watched until they recovered and moved to retreat sites. Another remnant frog had two oval patches coloured yellow/orange on its ventral surface above the hind legs, although it appeared otherwise healthy and energetic. Damage was seen in 20 remnant frogs, including scarring (4), a frosted eye (1), missing toes (9), and a missing hand (1). One had the three inner toes on the right hand joined.

4.3.2. Forest remnant versus Fort Road frogs

Information was collected from 189 *Leiopelma pakeka* (excluding possible recaptures): nine on Fort Road and 180 from the forest remnant area. The two areas did not differ significantly with regards to colour intensity (p = 0.122). Most of the Fort Road frogs were light-medium brown (77.78%), and the rest were light (11.11%) and medium (11.11%). The remnant frogs were similar, most of them were light-medium intensity brown (20.56% light, 23.33% light-medium, and 40.56% medium). Darker frogs were found only in the remnant forest (medium-dark 8.33% and dark brown 7.22%).

There was a statistically significant difference in patterning of *L. pakeka* between the two areas (p = 0.000). The majority (88.89%) of Fort Road frogs were patterned and the rest were mottled-patterned. One third of the remnant population was mottled, and of the rest, patterned frogs were slightly more prevalent (22.78%) than mottled-patterned (20%). Only a quarter of the remnant *L. pakeka* population were uniform (15.56%), and uniform-mottled (8.89%).

In both populations most of the frogs found were larger than 35mm snout-vent length. The two populations did not differ significantly with regards to size (p = 0.280). Slightly more of the Fort Road *L. pakeka* were mature males/immature females (55.56%) than mature female (44.44%), whereas the remnant population held double the number of mature females (63.89%) than mature males/immature females (31.11%). The two smaller size classes (<35mm snout-vent length) were only represented in the remnant population (3.89% juveniles and 1.11% first year class).

The forest remnant *L. pakeka* were, on average, larger than the Fort Road frogs, as seen in Figures 4.3-4. These differences were not statistically significant ($p > 0.05$). The largest frogs found in each area were 51mm snout-vent length in the remnant, and 46.2mm on the Fort Road. The remnant frogs had a wider size range than the Fort Road for all measurements (Figures 4.4-5) – but this may due to a larger sample size. Fort Road frogs showed the characteristic bimodal distribution in snout-vent length frequency graphs (demonstrated in Bell 1978a, Newman 1990), peaking within both mature male/immature female and mature female size classes (Figure 4.4). The remnant *L. pakeka* population did not show the bimodal snout-vent length distribution, although the graph levelled-off somewhat at the mature male/immature female size class.

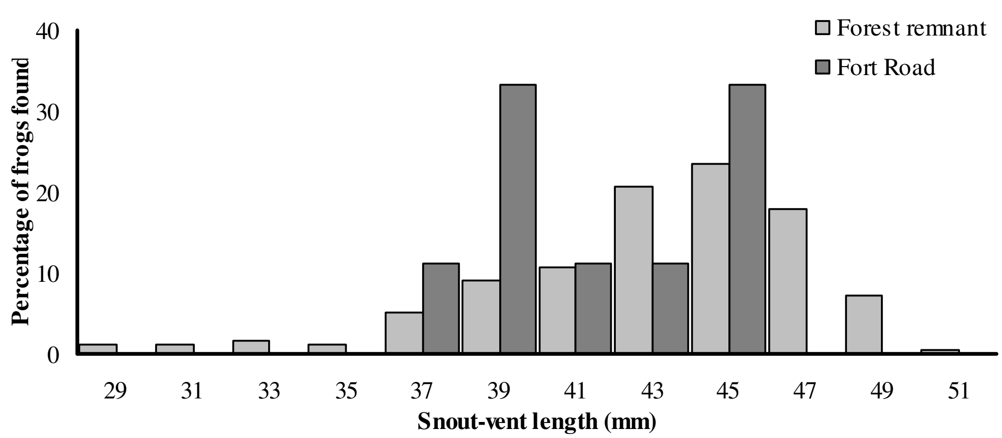


Figure 4.4: Snout-vent length ranges for the forest remnant and Fort Road *Leiopelma pakeka*. The x-axis shows snout-vent length (2mm increments). The Fort Road frogs, which were all adults, show the characteristic bimodal distribution, peaking at both "male" (35 - 43mm) and female (>43mm) size classes. The largest frog in the remnant was 51mm, and 46.2mm on the Fort Road. Nine frogs were found on the Fort Road and 180 frogs in the forest remnant area.

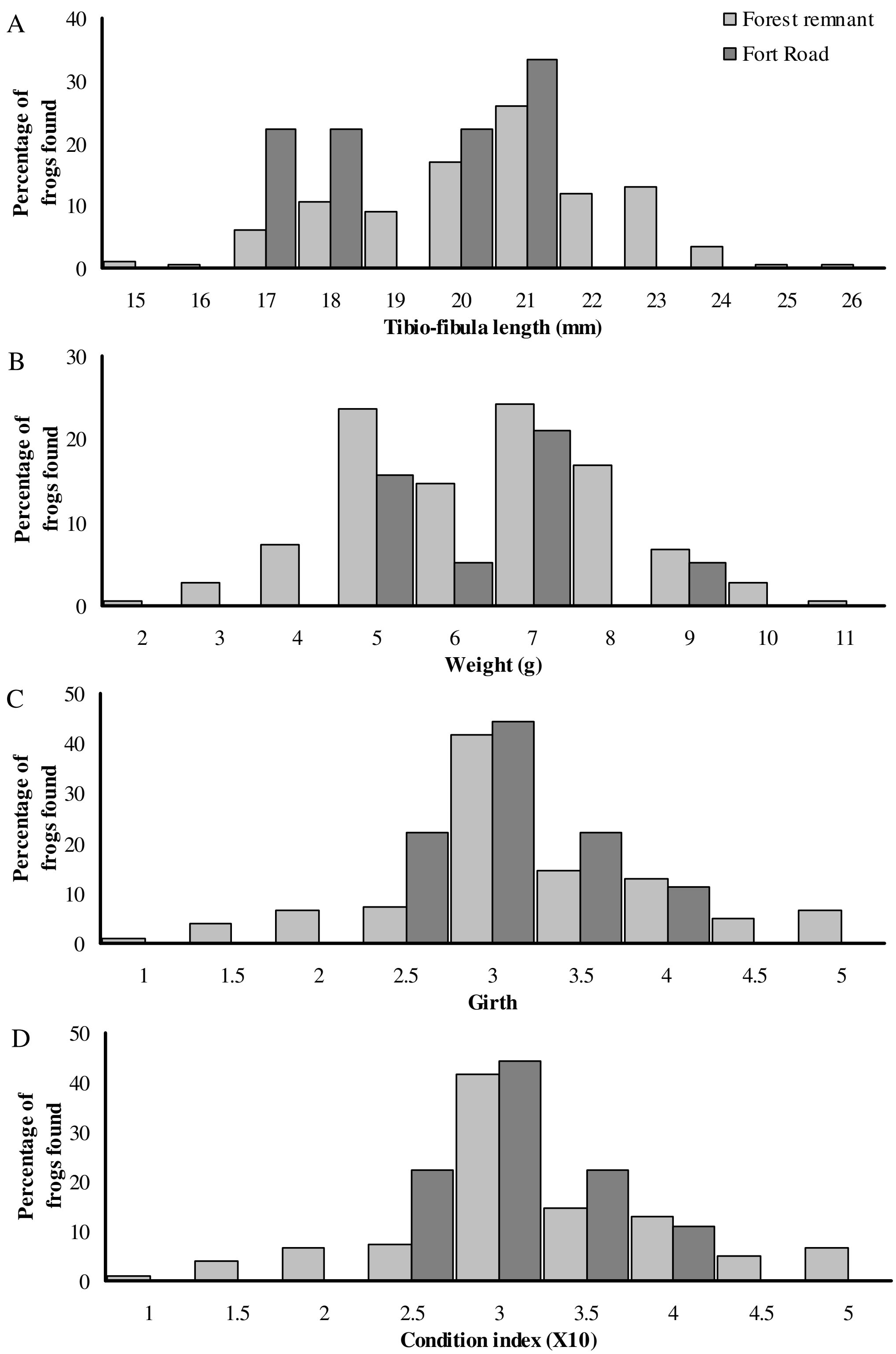


Figure 4.5: Physical measurement ranges for forest remnant (180 frogs) and Fort Road (nine frogs) *Leiopelma pakeka*: A) tibio-fibula length, B) weight, C) girth, and D) condition index. Girth ranged from 1 (very thin) to 5 (very fat). The ranges of all measurement were wider in remnant frogs.

4.4. Discussion

4.4.1. Morphology of dispersing *Leiopelma pakeka*

The majority of *Leiopelma pakeka* found during the current study were large. Almost all (95%) frogs were larger than 35mm snout-vent length, although snout-vent lengths did range from 11.35 - 51mm. Smaller individuals could have been overlooked as other studies have found that these are missed during night searches (Bell 1978ab). The bias of the sample towards large frogs could also arise because the population may be near, or at, the carrying capacity of the forest remnant. The resulting high density of large *L. pakeka* may negative affect the emergence behaviour of smaller individuals. It is also possible that these findings reflect the actual population structure in the forest remnant, as strong competition could result in high juvenile mortality. High competition in the densely populated forest remnant may prevent large frogs from gaining enough food or having sufficiently large home ranges – therefore promoting adult dispersal.

The largest individual was 51mm snout-vent length, which is the upper limit of the size range (B. D. Bell *pers. comm.*). Females grow larger than males (Bell 1978ab), and snout-vent length frequency graphs usually show a bimodal distribution (Bell 1978a, Newman 1990). The frequency graph (Figure 4.4) levelled off somewhat at the mature male/immature female size class; however, this study did not find the characteristic bimodal snout-vent length distribution. The number of mature females found was more than double that of mature males/immature females. If this data were representative of the *L. pakeka* population of Maud Island there may be reason for alarm, especially as parental care of young is carried out by the male. The bias towards large, and presumably female, frogs may therefore result in a small effective population size, potentially diminishing genetic diversity (Reed & Frankham 2003). It is probable, however, that smaller frogs were missed.

The size of *Leiopelma pakeka* increased significantly with distance from the forest remnant, to 75m from the edge. This is an indication of intraspecific competitive release. The larger size in *L. pakeka* translocated to Boat Bay was attributed to intraspecific competitive release (Bell 1995, Bell *et al.* 2004b). Dewhurst (2003) also found higher growth rates (snout-vent length versus weight, and tibio-fibula length versus weight) in translocated *L. pakeka* compared to the source population.

At 100m from the forest remnant both snout-vent length and tibio-fibula length of *L. pakeka* decreased. This could be evidence of juvenile dispersal, as seen in many other amphibians (Cushman 2006, deMaynadier & Hunter 1999, Jameson 1956, Roble 1979). The small sample size creates uncertainty in this statement, and therefore more research is needed into the dispersal of *L. pakeka*. The decrease in frog size at 100m from the forest remnant could also be due to environmental factors. *L. pakeka* density declined with distance from the remnant, where competition could decrease and food availability increase. It is unlikely that food type or quality changed, as all sites were in the same general area. Habitat quality appeared to decline further out from the remnant, the exception was the nearby 25m distance category, which included pastoral areas. Population density determines the level of intraspecific competition, which can affect individual body condition (Hoare *et al*. 2006, Moore *et al*. 2007), growth-rate (Bohlin *et al.* 2002, Harris 1987, Ostfeld & Canham 1995, Semlitsch & Caldwell 1982), weight (Jenkins *et al*. 1999, LeBerg & Smith 1993), and size (Branch 1975, Imre *et al.* 2005). Perhaps frog size at 100m from the remnant was restricted by some environmental factor other than population density. The development and morphology of phenotypically plastic organisms can be affected by habitat (Fjellheim *et al.* 1995, Laurila & Kujasalo 1999, Pfennig *et al.* 1991, Reylea 2001ab, Sumner *et al.* 1999, Trussell 1997, 2000), quantity and quality of food (Ford & Seigel 1989, Madsen & Shine 1993, Morey & Reznick 2000, Pfennig *et al.* 1991), and microclimate (Nunney & Cheung 1997, Yost 1987). At 100m from the forest remnant the habitat quality declined noticeably. The forest canopy became lower and sparser, and ground vegetation consisted largely of bracken. Lower habitat quality probably results in decreased prey availability, and an inhospitable microclimate for *L. pakeka*. These factors may have limited size in frogs at 100m from the remnant.

Weight, girth, and condition index were all high, indicating that the frogs are in good health. These variables are affected by food reserves and water retention (Bell 1994, 1996). *Leiopelma* species hydrate quickly, and can increase in weight up to 29% (Cree 1985) – weather can therefore have a large impact on frog morphology. The variable weather conditions over the study period do not appear to have affected the results, as a relationship between morphology and distance from the remnant was still found. Large size (snout-vent and tibio-fibula lengths) was another indication of good health – the values are much higher than the average tibio-fibula length (16.1mm) found by Bell (1978ab). The size increases may lead to higher fitness. Dewhurst (2003) suggested that large females may produce eggs with more yolk reserves, enabling hatchlings to metamorphose at a larger size. These size increases may however be an artefact of including frogs which had dispersed and were larger, whereas earlier studies (Bell 1978a,b) were focused on the forest remnant.

These frogs are highly cryptic. Their brown colouration and darker patterning provide camouflage against backgrounds of rock, soil, leaf litter, and trees. It is important to determine whether the frogs found in the current study are comparable morphologically to those found in previous studies. A difference would suggest either a change in the population, or observer sampling bias. One third of the frogs were mottled, and another 43% were mottled-patterned and patterned. Bell *et al.* (1998a) found that 33% of frogs were uniform, 38% mottled, and 29% patterned. Bell (1995) found that one third were mottled, but approximately half were uniform. Significant differences in patterning have been found between study grids within the remnant (Bell 1995), so perhaps pattern is highly variable.

Almost 85% of *Leiopelma pakeka* near the forest remnant were light to medium brown. Within this, 40% were medium brown, a result similar to Bell (1978a). Bell (1978a) found slightly more medium brown frogs despite a fairly equal representation of the three colour intensities (light, medium, and dark). Bell *et al.* (1998a), however, found that 60% of frogs were medium-dark to dark brown, 25% were medium brown, and only 16% were light to light-medium brown. Other studies have found that higher numbers of dark frogs are found during the day than at night, and it has therefore been suggested that frogs lighten upon emergence, or appear so under bright torchlight (Bell 1978a). Bell (1995) explained this trend by suggesting that darker frogs are easier to see during the day. All three studies (Bell 1995, 1978a, and current) involved only night searches, so these suggestions are not relevant, and cannot explain why different colour intensity ratios were found between studies. Green colouration has been reported in *L. pakeka* in the forest remnant on Maud Island (Bell 1995), and in young captive bred frogs (Bell 1978ab). Captive bred juveniles have been coloured green, red-brown, and grey-brown (Bell 1978b). Only brown *L. pakeka* were found during the current study – a similar result to that of Bell (1978ab), who also did not find any green frogs on Maud Island.

4.4.2. Forest remnant versus Fort Road frogs

Forest remnant *L. pakeka* were generally larger than those on the Fort Road. The remnant held the largest frog, which was almost 5mm bigger than any on the Fort Road. Size ranges were wider in the remnant than on Fort Road for snout-vent length, tibio-fibula length, weight, girth, and condition index. Smaller *L. pakeka* were only found in the remnant, and this accounts for the lower end of the size range. In the remnant, twice as many mature females were found as mature males/immature females (64% and 30% respectively). Of the nine Fort Road frogs, five were in the mature male/immature female size range and four in the mature female category. Remnant frogs probably reached larger sizes because a higher proportion of big frogs were found. The size structure of the two sites was otherwise similar, with most frogs in the adult range (<35mm). Fort Road *Leiopelma pakeka* were not morphologically distinct from the forest remnant frogs in any variable other than patterning. Pattern appears highly variable within populations, and a poor indicator of morphological differentiation.

There is a possibility that frogs from the two areas are morphologically distinct, and that these findings are an artefact of the methodology. The remnant data set is large (180), and should therefore be considered robust. On the Fort Road, however, only nine frogs were found after possible recaptures were excluded. Real differences could be masked by removing these possible recaptures. If recaptures are included, over-representation may skew the data set, and create differences where there are none. *L. pakeka* is extremely cryptic, and smaller frogs are often missed in night searches (Bell 1978a). Of the frogs found, half as many were in the 35-43mm snout-vent length range than over 43mm, indicating that smaller frogs may have been missed.

Inter-population size differences have been found in *L. archeyi* (Bell *et al.* 1998b), *L. hochstetteri* (Newman & Towns 1985), and *L. pakeka* (Bell 1982, 1995, Bell *et al.* 2004b, Dewhurst 2003). If the remnant and Fort Road frogs consisted of two separate populations, morphological differences could possibly have been found between the areas. They are only 350m apart, however, and some inter-movement of individuals could occur. In other amphibians, individuals can move between sub-populations 13km apart (Smith & Green 2005). Fort Road frogs may belong to a subpopulation, with sufficient immigration of frogs from the forest remnant to prevent morphological differentiation between the areas. It is unlikely, however, that frogs move freely between the Fort Road and forest remnant. *L. pakeka* is known to occupy a small home range over their lifespan (Bell 1994, 1997a, Bell *et al.* 2004b, King *et al. in press*, Newman 1990). It is unlikely that they would leave their home range to travel toward increasingly unfamiliar chemosignals, which they are known to avoid (Lee & Waldman 2002, Waldman & Bishop 2004). No frogs were found in the area between the remnant and Fort Road, even though it contains suitable habitat. The distance between these two areas is approximately 350m, and excluding Fort Road, *L. pakeka* has only been found up to 100m from the remnant. There are, however, two anecdotal reports of a frog in Rifleman Creek, which is between the remnant and Fort Road area, although it is much closer to the latter. These frogs could inhabit the area and have evaded detection in the current study, or represent dispersing individuals. In both cases, complete separation of the Fort Road and forest remnant frogs is rendered improbable.

4.4.2. Conclusions

L. pakeka size increased with distance from the remnant, possibly from decreased density and intraspecific competitive release. All frogs outside of the remnant were larger than those found inside, and there was limited evidence of juvenile dispersal. More research is needed into the dispersal behaviour of *L. pakeka*, to determine the extent of movement and the life stage in which it occurs. Fort Road frogs were morphologically similar to forest remnant *L. pakeka,* and possibly consist of a subpopulation with limited movement of individuals between the two areas. Future research could investigate the population structure using genetic analyses. Overall, the remnant *Leiopelma pakeka* population on the south-east face of Maud Island appears healthy.

Chapter 5

Concluding summary and discussion

5.1. Summary of chapters 2-4

The current study aimed to determine the population size and distribution of the remnant population of *Leiopelma pakeka* on the south-east face of Maud Island. The relationships between frog distribution and emergence to habitat and weather variable were also investigated, as was the morphology of dispersing individuals. The main findings are outlined below. Please refer to chapters 2-4 for more information.

The remnant population of *Leiopelma pakeka* on Maud Island is large, estimated at 34,499 from the current study. This is comparable to the estimate of 39,563 based on a survey in 1994 (Bell & Pledger 2000), disproving the hypothesis that the population size is now larger than the re-estimate. The *L. pakeka* population in the forest remnant appears to have remained stable over 1994-2006, and is supported by the similarity of population estimates from the 144m^2 grids throughout 1983-96 (Bell 1994, 1997b). This indicates that the *L. pakeka* population in the forest remnant may have reached carrying capacity.

Range expansion of the *L. pakeka* remnant population was confirmed by the current study, with 232 frogs found outside the forest remnant. *L. pakeka* has mainly dispersed within 50m of the forest remnant, although they have moved up to 100m out. There was limited evidence of juvenile dispersal in *L. pakeka*, with frogs at 100m decreasing in size. It should be noted that initial observations were focused on the forest remnant. There is a possibility, therefore, that frogs always occurred in the areas where they were found during the current study. The findings of the current study are, however, considered to be representative of range expansion for the following reasons.

1. *L. pakeka* numbers declined significantly with distance from the forest remnant
2. There was evidence of competitive release in *L. pakeka* as distance from the forest remnant increased, with the size (snout-vent length, and tibio-fibula length, weight, girth, and condition index) of frogs increasing up to 75m out.

A further 15 *L. pakeka* were found on Fort Road, roughly 350m from the remnant. These frogs appear to have inhabited the area for at least twelve years. At least nine different individuals were found, but it is likely that the colony is much larger than this. The Fort Road frogs were not morphologically distinct from forest remnant *L. pakeka*. They could either be a subpopulation separate from the forest remnant, with sufficient flow of individuals to prevent morphological differentiation, or a population which has not been separated from the forest remnant long enough to differentiate.

The current study presents a minimum estimate for the range of *L. pakeka* on Maud Island. There could be other pockets of distribution on the island, where *L. pakeka* has remained undetected. The presence of *L. pakeka* on the other faces of Maud Island is unlikely given the dry state of the habitat and the rarity of frogs near the summit. There is a small chance that they have crossed the summit, however, as a frog was found approximately 20m from the top vegetation line in the current study. The rest of Maud Island was investigated to determine areas of habitat suitable for *L. pakeka*. The most suitable areas were along Rifleman Creek, and a rocky gully that runs between the Ring

Road and the Boat Bay track. The rocky gully is the first along the Boat Bay track past the site of the translocated *L. pakeka* population. Rifleman Creek and the rocky gully were searched at least three times at night for emergent frogs and none were found.

Habitat type affected the presence of *L. pakeka* at a site, with important factors being vegetation type, canopy cover, sub-canopy cover, rock cover, and leaf litter cover. The extent of dispersal appeared to be positively related to habitat quality, with the farthest movement occurring in the most mature regenerating forest. Weather did not significantly affect *L. pakeka* emergence, contrary to the findings of other studies (Bell 1978a, 1995, 1996, Bell *et al.* 1985, Newman 1990). There was a significantly positive correlation between relative humidity and the size of emergent frogs.

The size range of *L. pakeka* has been extended by 1mm in the current study. A large frog, approximately 52mm snout-vent length, was found 20m from the top vegetation line in the forest remnant. This was the only frog seen higher than 250m above sea level, and was photographed because it appeared to be quite large. The frog can be seen in Figure 5.1, below. The frog was measured to be at least 52mm snout-vent length using a ruler. The exact length of the frog is unknown as the frog was found during the population estimate survey, and the appropriate measuring equipment had not been taken on the search. This is a pity and a personal lesson to always be prepared for any unexpected events.

Figure 5.1: The frog found 20m from the top vegetation line in the forest remnant. A ruler was placed alongside the frog to determine the snout-vent length, which appeared to be 52mm. (Unfortunately the photograph is slightly blurry, but the length of the frog is still apparent)

5.2. Methodological concerns regarding chapters 2-4

There were several methodological concerns in the current study. These are described below, and solutions are suggested.

With regards to the population estimate, future research could include several surveys of the forest remnant area. In some areas frogs were seen, but did not occur in the plots, such as higher than 210m above sea level. This could be remedied by using more plots (e.g. 50 or 100 per elevational band), or larger search areas (e.g. 10m by 10m plots). The bootstrap analysis of the data was designed to correct for this introduced error, and I would recommend using this analysis again. Site-occupancy modelling (the level of occupancy of a species in an area) has been used in *L. hochstetteri* (Crossland *et al.*

2005), and would also be appropriate for analysing the distributional patterns of *L. pakeka* within the forest remnant.

With regards to the distributional study, the large search areas increased the chance of overlooking frogs. I would suggest that smaller search areas be used in future studies, such as randomly placed 10m by 10m grids throughout the survey areas. In retrospect, this is the method that I would have used, searching these grids in the same way as the two long-term study grids of B. D. Bell. I would recommend visiting each 100m^2 grid once, and searching each area over several nights (for example, two grids in a section per night). It was also difficult and time-consuming to remove all the markers set up for the distributional survey at the end of the study. I would recommend removing all markers after each search is complete, as was done in the population estimate survey.

An effect of weather conditions on frog emergence was not found, however, the weather during the first research visit in November-December 2005 was fairly dry and very few frogs were found. Not much data was gained during that visit, as it was the pilot study. The research period was also much longer than initially planned, taking nine weeks after the pilot study as opposed to the proposed three. Part of the reason for this was due to some changes in the research approach. In future, I would suggest that research involves a pilot study testing several methodologies.

5.3. Recommendations for future study

1. The Fort Road frogs should be monitored, as this area is along a regularly used track (a likely introduction point for disease). One way of achieving this would be to

include the Fort Road area in the annual monitoring programme, in addition to the two 144m^2 grids in the forest remnant (Bell 1994, 1997b). The number of frogs could be determined using mark-recapture analyses (individual frogs could be identified using photographs as in Beausoleil *et al.* (2004), Bradfield (2004), and Newman (1977a, 1990)).

2. The distributional study should be repeated in 10 years time, as this is probably sufficient time for *L. pakeka* to disperse further. The search areas should be extended, and the rocky gully on Boat Bay track should be searched to determine whether translocated frogs have dispersed there.
3. Research into the phenotypic plasticity of these frogs should be conducted to determine the environmental factors that affect frog size. This should be coupled with research into the habitat variables that affect *L. pakeka* distribution.
4. Dispersal in *L. pakeka* should be further investigated, and research should focus on subadults as other studies have found that this is the dispersive life stage (Cushman 2006, deMaynadier & Hunter 1999, Harrison 1992, Jameson 1956, Roble 1979).
5. Further genetic analyses could be carried out on the *L. pakeka* population of Maud Island. Possible areas of interest would be whether the *L. pakeka* population on Maud Island has experienced a bottleneck, and determining the effective population size (the number of individuals breeding).

5.4. Conservation of amphibians

Leiopelma pakeka is one of four remaining species of an extremely archaic group of frogs. These possess several morphological traits that are considered to be primitive, including amphicoelous vertebrae, nine presacral vertebrae (versus eight in other frogs), and the retention of tail-wagging muscles in adults (please see Bell 1982, Bull & Whitaker 1975, Green & Cannatella 1993, Stephenson 1952, 1960, 1961). They are therefore categorised as either a sister or basal group to other living anurans (Cannatella & Hillis 1993, Feller & Hedges 1998, Ford & Cannatella 1993, Gao & Wang 2001, Green & Cannatella 1993, Green *et al.* 1980, 1989, Hay *et al.* 1995, Hillis *et al.* 1993, Kluge & Farris 1969, Noble 1955, Roelants & Bossuyt 2005, Stephenson *et al.* 1972, Worthy 1986, 1987a). In addition to their taxonomic importance, they have recently been ranked number 58 on an EDGE (Evolutionarily Distinct and Globally Endangered) list of the top 100 amphibian species which need to be prioritised for conservation (www.edgeofexistence.org).

Declines in amphibian populations around the world have been noted since at least the 1990s (Alford *et al.* 2001, Houlahan *et al.* 2000, 2001). One third (32%) of all amphibian species are now threatened, 43% are declining, and 165 species may already be extinct (IUCN *et al.* 2006, Stuart *et al.* 2004). These declines span the globe, affecting North America (Bank *et al.* 2006), Europe (Carrier and Beebee 2003, Nyström *et al.* 2007), Australasia (Berger *et al.* 1998, Laurance 1996), Latin America and the Caribbean (Berger *et al.* 1998, IUCN *et al.* 2006, Young *et al.* 2001). Further knowledge of successful management of rare amphibian species, such as *Leiopelma pakeka*, is therefore particularly relevant.

The forest habitat of Maud Island, where *L. pakeka* survived, was largely removed, so that only a 15-hectare fragment remained (Bell 1982, 1985b, Bell *et al.* 2004b). Several amphibian populations have declined due to habitat fragmentation (Blaustein & Kiesecker 2002, Collins & Storfer 2003, Cushman 2006, Nyström *et al.* 2007, Young *et* *al.* 2001). It has been suggested that habitat destruction has a larger effect on terrestrial frogs (Pineda & Halffter 2004), and that species with limited dispersal abilities are negatively affected by habitat loss and fragmentation in the long-term (Cushman 2006). *L. pakeka* is terrestrial and may have limited dispersal, as they are known to occupy small home ranges over most of their long lives (Bell 1997a, King *et al. in press*, Newman 1990).

Habitat destruction on Maud Island ceased over 35 years ago, and since then the vegetation has been regenerating naturally. The range expansion of *L. pakeka* is likely to represent a return to the original distribution – frogs were probably found across Maud Island before it was cleared (Bell 1982, 1985b, Bell *et al.* 2004b). The current study shows that K-selected species can recover and increase with minimal management. The furthermost movement occurred in regenerating forest. Studies in America and Britain have shown that habitat restoration can produce a rapid recovery of declining species (Brodman *et al.* 2006, Denton *et al.* 1997, Lehtinen & Galatowitsch 2001, Ries *et al.* 2001).

Disease is of particular concern for the Maud Island frog, as pathogens may spread quickly due to the high *L. pakeka* densities. *L. pakeka* has a very restricted range and small clutch size (Bell 1978ab), both of which may make them vulnerable to decimation by disease (Berger *et al.* 1999). *Batrachochytrium dendrobatidis*, in particular, has caused amphibian populations to decline across the globe (Beard & O'Neill 2005, Berger *et al.* 1998, 1999, Bosch *et al.* 2001, Bradley *et al.* 2002, Muths *et al.* 2003, Puschendorf *et al.* 2006). Chytrid was found in New Zealand in 1999 (Bishop 2000, Waldman *et al.* 2001), and probably caused declines in native *L. archeyi* populations in the Coromandel Peninsula over 1996-2001 (Bell 1999, 2004, Bell *et al.* 2004a).

Symptoms of chytrid infection include lethargy and sitting unexposed during the day (Berger *et al.* 1999, Nichols *et al.* 2001). Three frogs were found in the current study, which were of concern. Two *L. pakeka* found in the forest remnant were notably lethargic, and were observed until they had recovered, and moved to a retreat site. Another frog had two yellow/orange coloured oval patches on the ventral surface above the hind legs – appearing otherwise energetic and healthy. It is however unlikely that disease has reached the remnant *L. pakeka* population for the following reasons:

1. No dead or obviously ill frogs were found during the current study, and no emergent frogs were found during the day, which is a symptom of chytrid infection (Berger *et al.* 1999, Nichols *et al.* 2001).
2. The population appears to be stable.
3. Snout-vent length, tibio-fibula length, weight, girth, and condition index of the frogs were all high, indicating that they are in good health.
4. Strict hygiene protocols are maintained.

Several translocations have established additional populations of *L. pakeka* on predator-free islands and in Wellington (Bell 1985b, 1994, Bell & Pledger 2001a, Bell *et al.* 2004b, Dewhurst 2003, J. Germano *pers. comm.*, Lukis & Bell 2007, Tocher & Pledger 2005). These populations will ensure the survival of *L. pakeka* if disease or some other catastrophe endangered the frogs on Maud Island.

5.5. Conclusions

All four aims of the current study were fulfilled. The *Leiopelma pakeka* population size in the forest remnant was estimated at 34,499, indicating that the frogs are doing well. They were found to have moved up to 100m into regenerating forest, which is very encouraging as it indicates population growth. Dispersing frogs were found to increase in size with distance from the forest remnant, out to 75m. This may be an indication of competitive release, as density of *L. pakeka* decreased further from the forest remnant. At 100m, however, frogs were slightly smaller, indicating that some environmental factor is limiting size.

A colony of frogs was found on Fort Road, approximately 350m from the remnant. These may have inhabited the area since prior to 1994, and this is again an encouraging sign that the *L. pakeka* population on Maud Island is healthy. The frogs on Fort Road were morphologically similar to those in the forest remnant.

Habitat type had a significant effect on *L. pakeka* distribution – important variables were rock, canopy, sub-canopy, and leaf litter cover. There was a significantly positive correlation between relative humidity and the size of emergent frogs; however weather variables did not affect the number of *L. pakeka* emerging.

Overall, these findings indicate that the Maud Island frog population is healthy and increasing. The population size may have reached the carrying capacity of the forest remnant, and frogs are dispersing into surrounding areas. This is particularly encouraging given the global significance and conservation value of the species.

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7. Appendices

7.1. Maud Island history

Obtained from Maud Island resident Department of Conservation staff.

<u>A brief summary of significant events on Maud Island</u>

Pre-European
- Clear evidence of Maori occupation. Te Rauparaha raided the Pelorus Sound in 1828.

1867
- Crown grants ownership of Maud Island to John Gibson.

1899-1914
- Various changes of ownership, with signficant clearance of the forest.

1914
- Sold to P. E. (Percy) Mills.

1942
- Maud Island occupied by defence forces during World War Two, and a naval gun emplacement established.

1945-55
- Wekas introduced to Maud Island.

1958
- Hamiltons frog 'discovered' on Maud Island - identified by E. M. Stephenson in 1961 (although an unusual frog on the Island was noted as early as 1940 by P. E. Mills).

1965
- The remaining bush area (c.15 ha) fully fenced off under a private agreement between the owner (E. J. Robb) and the Department of Internal Affairs.

1968
- The Wildlife Branch of the Department of Internal Affairs approached the Lands & Survey Department requesting purchase of the Island as a Reserve. No funds were available.

1969
- The Island was sold to E. J. T. (Jack) Shand.

1970
- The fenced-off bush area was made a Private Scenic Reserve.

1971
- Jack Shand gifted the bush to the Crown as a Reserve for Preservation of Flora and Fauna.

1972
- Jack Shand gifted a further c.67 ha of land (above the 'ring-road') as an addition to the Reserve.

1973
- *Pinus radiata* plantations established under a Farm Forestry Grant (Planting ceased by 1975).

1974
- First two kakapo transferred to the Island.

1975
- Remainder of Island offered to the Crown by Jack Shand and purchased for $78,000 with the assistance of the Royal Forest and Bird Protection Society. Gazetted a Nature Reserve.
- A wide variety of exotic plants planted on Island including apple, pear, cherry, oat, crabapple, sunflower, flax, toetoe, *Coprosma repens,* currants, raspberry, guava and grape as potential kakapo food.

1977
- Mike Meads introduces giant wetas *Deinacrida rugosa* from Mana Island.
- Public access revoked by changing status of remaining Sounds Foreshore areas.

1979
- The Shands leave the Island, and the Wildlife Service establish a regular staff presence on the Island.

1980
- Netting enclosures constructed in the bush to protect the frogs.
- Transfer of two little spotted kiwi to Maud Island.

1980-1
- Colin Ogle conducts vegetation survey.

1982
- Stoats first seen on Maud Island.
- Remaining kakapo and kiwi removed, saddlebacks wiped out by stoats.
- Designation changed to Scientific Reserve.

1983
- Eight stoats removed by August, no more seen for several years.
- First approved management plan completed.

1984
- Six takahe introduced.
- Selwyn Bucknell becomes first Resident Officer.
- Translocation of 100 frogs from forest remnant to Boat Bay bush.

1985
- First summer holiday programme public visits conducted.

1987
- Department of Conservation inherits responsibility for management of the Island.

1989
- *Hoplodactylus stephensi* (a rare gecko) discovered on Maud Island (previously known only from Stephens Island).
- Kakapo reintroduced.
- Old homestead pulled down, Comalco Lodge constructed.

1990
- Kakapo aviaries constructed.
- Stoat sighted on Island. Trapping operation eventually captures 8 stoats in the period to July 1993.

1991
- Selwyn Bucknell retires, replaced by Dave Crouchley.
- Gideon Climo becomes second permanent staff member on Island (specialising in kakapo).
- Pest and Weed Contingency Plan becomes operational.

1993
- The last stoat is removed from the Island.

1994

- E. Bell completes MSc on habitat preferences and ecology of Maud Island frogs. Estimates population to be c.19,000.
- Frogs genetically distinct from Stephens Island frogs and therefore a species endemic to Maud Island.

1996

- Brian Paton replaces Dave Crouchley as the resident officer.

1997

- 300 Frogs transferred to Motuara Island in the Queen Charlotte Sound.

2000

- Generator ex Stephens lighthouse installed at bottom generator shed.

2001

- All breeding female Kakapo removed to Codfish Island.
- Big drought – main water spring dries up for 5 months.
- July - Bottom house alterations completed.
- December Paton family move off the island.

2002

- Steve Ward starts as caretaker.
- More Kakapo removed to Codfish – 5 birds left.
- February – ring road reopened after several years blocked by slip at Milktree.
- March – New main generator installed.

2003

- February – 1 x male stoat caught in Boat Bay trap.
- March – 1 x weasel caught in peninsula trap.
- May, last of Kakapo removed from Maud.
- June Kakapo team pull out from Maud operation.
- Last of sheep removed from west side paddocks.

2004

- March – 1st of the local cluster schools overnight trips.

2005

- May – DOC 200 traps installed on mainland and shoreline trap lines. Rats confirmed on Tennyson Islands.
- June – 100 frogs translocated from Maud to Long Island.

2006

- March – New quarantine room built at Lodge.
- April – Mouse found at bottom house.
- September – 30 frogs collected and translocated to Karori Sanctuary.

7.2. Permits

7.2.1. Maud Island Entry Permit (#19/06)

Department of Conservation
Te Papa Atawhai

(NELCO-22740)

Maud Island
Entry Permit
Tom Shand Scientific Reserve

Pursuant to S59(1) Reserves Act 1977, and subject to the conditions contained in this Permit:

Jacqui le Roux *[Permit Holder]*
15 Tattenhall Grove, *[Address]*
Churton Park
Wellington
04 477 9933

Permit No 19/06
Date Issued 7/3/06
Is authorised to enter Tom Shand Scientific Reserve

For the following purpose(s):
Frog Study Scientific Work

Period of Permit 13/3/06 to 13/9/06

Vessel Name/Type/Description: DOC approved boat.

Special Conditions: Notification of trip dates & field assistants name at least 2 weeks before each trip to be sent to DOC & Maud Island

Names of Other Party Members:
1 field assistant

Conditions of Permit

1. This permit is not transferable; it must be carried, and produced on demand.
2. You enter the island at your own risk. The **permit holder** will be liable for all costs incurred by the department for search and rescue, pollution, introduction of pests, damage, fire-fighting, or other loss as a result of the use of this permit.
3. The **permit holder** shall ensure that:
   - access and landings occur only as agreed to with the resident officer (ph 03 576 5233);
   - he reports to the resident officer immediately on arrival and shall adhere to all instructions given by that officer with respect to conduct on the island. No wildlife shall be handled other than as may be approved by that officer;
   - all clothing and stores are clean and free of seeds or other plant material; footwear must be thoroughly clean and dry;
   - all stores are sealed on packing or are re-packed on day of departure. All stores shall be unpacked only in a designated (rodent-proof) area;
   - no fires are lit, cooking is confined to the accommodation buildings and smoking occurs only in the immediate house environs—and in dry weather shall not occur at all;
   - no animals, or firearms are brought onto the island;
   - no plants, wildlife, soil, rocks, or historic sites are damaged, removed, or disturbed;
   - all rubbish accumulated during the visit is removed.
4. Committing any offence or breach of these conditions will cancel this permit.
5. This permit may be revoked or varied at any time.

Signed: .... (signature) .... (signature)

Roy Grose **Permit holder**
Commissioner **Date:**

R. Cox Acting Area Manager

Maud Island is special, being home to endangered species and historic sites.
Help protect the island from animal/plant pests, and from fire.
DIAL 111 TO REPORT FIRES & OTHER EMERGENCIES

7.2.2. Permit to conduct research on Maud Island frog

Department of Conservation
Te Papa Atawhai

PERMIT TO CONDUCT RESEARCH ON MAUD ISLAND FROG

Authority No	NM-17358-RES
Pursuant to:	Section 53 of the Wildlife Act 1953
The Permittees:	Jacqueline Le Roux, Heather Murray and Gemma Bowker-Wright, Victoria University, PO Box 600, Wellington
Authorised to:	conduct research on the native frog *Leiopelma pakeka*
For the purpose of:	better understanding of the population size and dispersal of this frog
Subject to the conditions below.	
Period of Permit:	1 October 2005 to 30 June 2006

The Permittees shall:

1. obtain separate authority for entry to the island.
2. conduct research on Maud Island consistent with the research proposal submitted in August 2005 – File NHT 05-06-08 and subject to the following conditions:
   - not commence work on the island until someone from the department has provided a full briefing and ensured that the permittees are familiar with the terrain and competent to carry out the work with regard to their personal safety and the welfare of the frogs.
   - ensure that research activity within frog habitat is done with care to avoid disturbance to vegetation or the substrate. The substrate may, however, be carefully disturbed outside of the core forest remnant and off fixed transects for the purpose of establishing whether frogs are present.
   - mark transects with flagging tape and reflective tape – ensuring that all tape is removed at the end of the research.
   - handle frogs consistent with best practice, including hygiene protocols that involve the use of new sterile gloves and sterilised equipment for each transect.
   - frogs encountered on transects may be held prior to weighing and measuring but are not to be removed from the transect.

Nelson/Marlborough Conservancy
Private Bag 5, 186 Bridge Street Nelson, New Zealand
Telephone 03-546 9335, Fax 03-548 2805

3. ensure that no fauna, flora (or parts thereof), soil, rocks or minerals are removed from the islands.

4. provide the department with a report at the termination of this permit and a copy of any subsequent publications arising from this work.

This authority may be revoked or varied at any time by the Conservator, Nelson/Marlborough Conservancy.

D.L. Hayes. 10/10/05.

David Hayes
Acting Conservator

Date

7.3. Raw data

7.3.1. Population survey data

Elevation (m a.s.l.)	Vertical column (distance from south-west remnant edge)	Plot number	Frogs found	Date of search
90-130	0-70m	1	1	2/07/2006
90-130	0-70m	2	6	2/07/2006
90-130	0-70m	3	0	2/07/2006
90-130	0-70m	4	0	2/07/2006
90-130	0-70m	5	1	2/07/2006
90-130	70-140m	6	2	2/07/2006
90-130	70-140m	7	1	2/07/2006
90-130	70-140m	8	0	2/07/2006
90-130	70-140m	9	2	2/07/2006
90-130	70-140m	10	4	2/07/2006
90-130	140-210m	11	0	29/06/2006
90-130	140-210m	12	0	29/06/2006
90-130	140-210m	13	0	29/06/2006
90-130	140-210m	14	0	29/06/2006
90-130	140-210m	15	0	29/06/2006
90-130	210-280m	16	0	29/06/2006
90-130	210-280m	17	0	29/06/2006
90-130	210-280m	18	0	29/06/2006
90-130	210-280m	19	0	29/06/2006
90-130	210-280m	20	3	29/06/2006
90-130	280-350m	21	1	1/07/2006
90-130	280-350m	22	0	1/07/2006
90-130	280-350m	23	3	1/07/2006
90-130	280-350m	24	2	1/07/2006
90-130	280-350m	25	0	1/07/2006
130-170	0-70m	26	0	2/07/2006
130-170	0-70m	27	2	2/07/2006
130-170	0-70m	28	2	2/07/2006
130-170	0-70m	29	8	2/07/2006
130-170	0-70m	30	0	2/07/2006
130-170	70-140m	31	1	2/07/2006
130-170	70-140m	32	1	2/07/2006
130-170	70-140m	33	0	2/07/2006
130-170	70-140m	34	0	2/07/2006

Elevation (m a.s.l.)	Vertical column (distance from south-west remnant edge)	Plot number	Frogs found	Date of search
130-170	70-140m	35	0	2/07/2006
130-170	140-210m	36	0	29/06/2006
130-170	140-210m	37	0	29/06/2006
130-170	140-210m	38	0	29/06/2006
130-170	140-210m	39	0	29/06/2006
130-170	140-210m	40	0	29/06/2006
130-170	210-280m	41	0	29/06/2006
130-170	210-280m	42	0	29/06/2006
130-170	210-280m	43	1	29/06/2006
130-170	210-280m	44	0	29/06/2006
130-170	210-280m	45	2	29/06/2006
130-170	280-350m	46	4	1/07/2006
130-170	280-350m	47	2	1/07/2006
130-170	280-350m	48	2	1/07/2006
130-170	280-350m	49	2	1/07/2006
130-170	280-350m	50	1	1/07/2006
170-210	0-70m	51	0	3/07/2006
170-210	0-70m	52	0	3/07/2006
170-210	0-70m	53	0	3/07/2006
170-210	0-70m	54	0	3/07/2006
170-210	0-70m	55	1	3/07/2006
170-210	70-140m	56	0	3/07/2006
170-210	70-140m	57	0	3/07/2006
170-210	70-140m	58	1	3/07/2006
170-210	70-140m	59	2	3/07/2006
170-210	70-140m	60	0	3/07/2006
170-210	140-210m	61	0	30/06/2006
170-210	140-210m	62	0	30/06/2006
170-210	140-210m	63	0	30/06/2006
170-210	140-210m	64	0	30/06/2006
170-210	140-210m	65	1	30/06/2006
170-210	210-280m	66	0	30/06/2006
170-210	210-280m	67	0	30/06/2006
170-210	210-280m	68	0	30/06/2006
170-210	210-280m	69	1	30/06/2006
170-210	210-280m	70	1	30/06/2006
170-210	280-350m	71	1	1/07/2006
170-210	280-350m	72	1	1/07/2006
170-210	280-350m	73	0	1/07/2006
170-210	280-350m	74	0	1/07/2006

Elevation (m a.s.l.)	Vertical column (distance from south-west remnant edge)	Plot number	Frogs found	Date of search
170-210	280-350m	75	1	1/07/2006
210-250	0-70m	76	0	3/07/2006
210-250	0-70m	77	0	3/07/2006
210-250	0-70m	78	0	3/07/2006
210-250	0-70m	79	0	3/07/2006
210-250	0-70m	80	0	3/07/2006
210-250	70-140m	81	0	3/07/2006
210-250	70-140m	82	0	3/07/2006
210-250	70-140m	83	0	3/07/2006
210-250	70-140m	84	0	3/07/2006
210-250	70-140m	85	0	3/07/2006
210-250	140-210m	86	0	30/06/2006
210-250	140-210m	87	0	30/06/2006
210-250	140-210m	88	0	30/06/2006
210-250	140-210m	89	0	30/06/2006
210-250	140-210m	90	0	30/06/2006
210-250	210-280m	91	0	30/06/2006
210-250	210-280m	92	0	30/06/2006
210-250	210-280m	93	0	30/06/2006
210-250	210-280m	94	0	30/06/2006
210-250	210-280m	95	0	30/06/2006
210-250	280-350m	96	0	1/07/2006
210-250	280-350m	97	0	1/07/2006
210-250	280-350m	98	0	1/07/2006
210-250	280-350m	99	0	1/07/2006
210-250	280-350m	100	0	1/07/2006
250-30	140-210m	101	0	4/07/2006
250-30	140-210m	102	0	4/07/2006
250-30	140-210m	103	0	4/07/2006
250-30	140-210m	104	0	4/07/2006
250-30	140-210m	105	0	4/07/2006
250-30	140-210m	106	0	4/07/2006

7.3.2. Histogram of 10,000 population estimates derived from bootstrap analyses

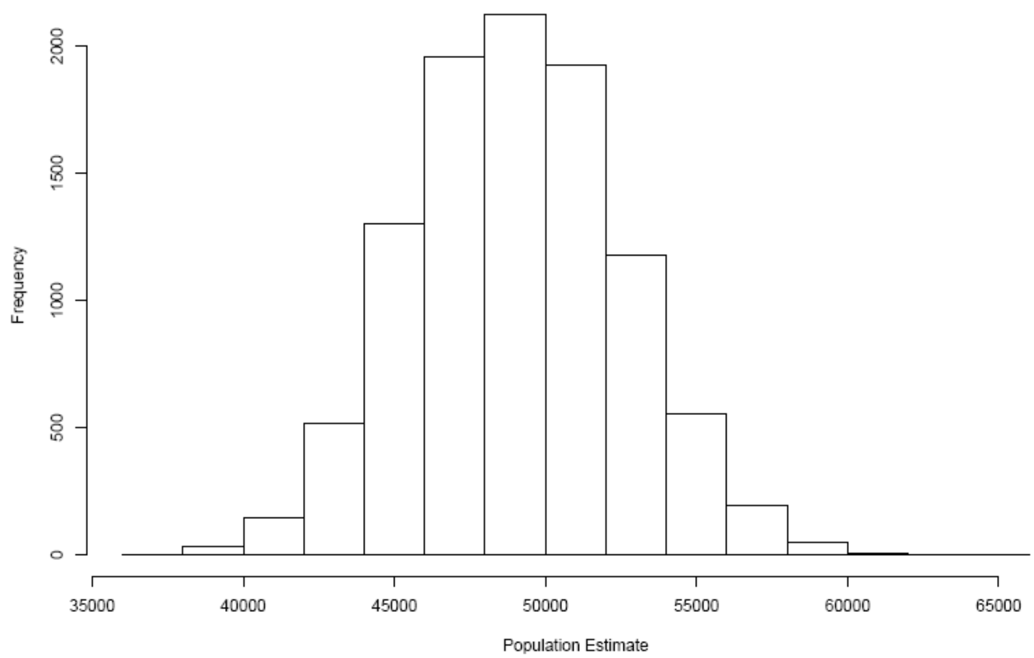

Figure 7.1: Histogram of 10,000 population estimates for the 16ha forest remnant area.

7.3.3. Distributional survey results

Location	Distance from remnant edge (m)	Elevation (m above sea level)	Dates	Frogs found
Northern regenerating forest	25	100-125	19/03/2006	0
Northern regenerating forest	25	100-125	20/03/2006	41
Northern regenerating forest	25	125-150	19/03/2006	0
Northern regenerating forest	25	125-150	13/06/2006	7
Northern regenerating forest	25	125-150	14/06/2006	8
Northern regenerating forest	25	150-175	19/03/2006	0
Northern regenerating forest	25	150-175	30/04/2006	14
Northern regenerating forest	25	150-175	4/05/2006	11
Northern regenerating forest	25	150-175	13/06/2006	0
Northern regenerating forest	25	150-175	14/06/2006	6
Northern regenerating forest	50	100-125	14/04/2006	17
Northern regenerating forest	50	100-125	26/04/2006	0
Northern regenerating forest	50	100-125	28/04/2006	10
Northern regenerating forest	50	100-125	30/04/2006	2
Northern regenerating forest	50	125-150	14/04/2006	2
Northern regenerating forest	50	125-150	30/04/2006	0
Northern regenerating forest	50	125-150	12/06/2006	0
Northern regenerating forest	50	150-175	30/04/2006	3
Northern regenerating forest	50	150-175	4/05/2006	6
Northern regenerating forest	50	150-175	12/06/2006	0
Northern regenerating forest	50	150-175	14/06/2006	1
Northern regenerating forest	100	125-150	14/04/2006	0
Northern regenerating forest	100	125-150	9/06/2006	0
Northern regenerating forest	100	125-150	11/06/2006	1
Northern regenerating forest	100	150-175	14/04/2006	0
Northern regenerating forest	100	150-175	4/05/2006	2
Northern regenerating forest	100	150-175	9/06/2006	3
Northern regenerating forest	100	150-175	11/06/2006	0
Northern regenerating forest	100	150-175	14/06/2006	2
Northern regenerating forest	150	125-150	16/04/2006	0
Northern regenerating forest	150	125-150	8/06/2006	0
Northern regenerating forest	150	125-150	9/06/2006	0
Northern regenerating forest	150	150-175	16/04/2006	0
Northern regenerating forest	150	150-175	8/06/2006	0

Location	Distance from remnant edge (m)	Elevation (m above sea level)	Dates	Frogs found
Northern regenerating forest	150	150-175	9/06/2006	0
Northern regenerating forest	200	125-150	16/04/2006	0
Northern regenerating forest	200	125-150	8/06/2006	0
Northern regenerating forest	200	125-150	9/06/2006	0
Northern regenerating forest	200	150-175	16/04/2006	0
Northern regenerating forest	200	150-175	8/06/2006	0
Northern regenerating forest	200	150-175	9/06/2006	0
Northern regenerating forest	250	150-175	16/04/2006	0
Northern regenerating forest	250	150-175	9/06/2006	0
Northern regenerating forest	250	150-175	10/06/2006	0
Northern regenerating forest	300	150-175	16/04/2006	0
Northern regenerating forest	300	150-175	9/06/2006	0
Northern regenerating forest	300	150-175	10/06/2006	0
Southern regenerating forest	25	25	19/04/2006	1
Southern regenerating forest	25	25	27/04/2006	0
Southern regenerating forest	25	25	28/04/2006	0
Southern regenerating forest	25	100-125	14/03/2006	0
Southern regenerating forest	25	100-125	16/03/2006	0
Southern regenerating forest	25	100-125	17/03/2006	0
Southern regenerating forest	25	100-125	18/03/2006	0
Southern regenerating forest	25	100-125	23/03/2006	1
Southern regenerating forest	25	125-150	23/06/2006	5
Southern regenerating forest	25	125-150	25/06/2006	2
Southern regenerating forest	25	125-150	26/06/2006	5
Southern regenerating forest	25	150-175	23/06/2006	0
Southern regenerating forest	25	150-175	25/06/2006	0
Southern regenerating forest	25	150-175	26/06/2006	3
Southern regenerating forest	25	50-75	18/03/2006	0
Southern regenerating forest	25	50-75	19/04/2006	2
Southern regenerating forest	25	50-75	21/04/2006	1
Southern regenerating forest	25	50-75	22/04/2006	1
Southern regenerating forest	25	50-75	2/05/2006	0
Southern regenerating forest	25	75-100	14/03/2006	1
Southern regenerating forest	25	75-100	16/03/2006	0
Southern regenerating forest	25	75-100	17/03/2006	0
Southern regenerating forest	25	75-100	18/03/2006	0
Southern regenerating forest	25	75-100	22/03/2006	2
Southern regenerating forest	25	75-100	23/03/2006	0

Location	Distance from remnant edge (m)	Elevation (m above sea level)	Dates	Frogs found
Southern regenerating forest	50	0-25	19/04/2006	0
Southern regenerating forest	50	0-25	27/04/2006	0
Southern regenerating forest	50	0-25	28/04/2006	0
Southern regenerating forest	50	25-50	19/04/2006	0
Southern regenerating forest	50	25-50	27/04/2006	0
Southern regenerating forest	50	25-50	28/04/2006	0
Southern regenerating forest	50	50-75	23/04/2006	0
Southern regenerating forest	50	50-75	2/05/2006	0
Southern regenerating forest	50	50-75	6/05/2006	0
Southern regenerating forest	50	75-100	23/04/2006	0
Southern regenerating forest	50	75-100	2/05/2006	0
Southern regenerating forest	50	75-100	6/05/2006	0
Southern regenerating forest	75	125-150	16/03/2006	5
Southern regenerating forest	75	125-150	17/03/2006	0
Southern regenerating forest	75	125-150	18/03/2006	0
Southern regenerating forest	75	125-150	21/03/2006	4
Southern regenerating forest	75	125-150	23/03/2006	0
Southern regenerating forest	75	150-175	16/03/2006	0
Southern regenerating forest	75	150-175	17/03/2006	0
Southern regenerating forest	75	150-175	23/03/2006	0
Southern regenerating forest	100	0-25	20/04/2006	0
Southern regenerating forest	100	0-25	21/04/2006	0
Southern regenerating forest	100	0-25	2/05/2006	0
Southern regenerating forest	100	100-125	23/04/2006	0
Southern regenerating forest	100	100-125	2/05/2006	0
Southern regenerating forest	100	100-125	6/05/2006	0
Southern regenerating forest	100	25-50	20/04/2006	0
Southern regenerating forest	100	25-50	21/04/2006	0
Southern regenerating forest	100	25-50	2/05/2006	0
Southern regenerating forest	100	50-75	23/04/2006	0
Southern regenerating forest	100	50-75	2/05/2006	0
Southern regenerating forest	100	50-75	6/05/2006	0
Southern regenerating forest	100	75-100	23/04/2006	0
Southern regenerating forest	100	75-100	2/05/2006	0
Southern regenerating forest	100	75-100	6/05/2006	0
Southern regenerating forest	150	0-25	20/04/2006	0
Southern regenerating forest	150	0-25	21/04/2006	0
Southern regenerating forest	150	0-25	2/05/2006	0

Location	Distance from remnant edge (m)	Elevation (m above sea level)	Dates	Frogs found
Southern regenerating forest	150	100-125	23/06/2006	0
Southern regenerating forest	150	100-125	25/06/2006	0
Southern regenerating forest	150	125-150	23/06/2006	0
Southern regenerating forest	150	125-150	25/06/2006	0
Southern regenerating forest	150	150-175	23/06/2006	0
Southern regenerating forest	150	150-175	25/06/2006	0
Southern regenerating forest	150	150-175	26/06/2006	0
Southern regenerating forest	150	25-50	20/04/2006	0
Southern regenerating forest	150	25-50	21/04/2006	0
Southern regenerating forest	150	25-50	2/05/2006	0
Southern regenerating forest	150	50--75	23/06/2006	0
Southern regenerating forest	150	50--75	25/06/2006	0
Southern regenerating forest	150	50--75	26/06/2006	0
Southern regenerating forest	150	75-50	23/06/2006	0
Southern regenerating forest	150	75-50	25/06/2006	0
Regenerating forest below remnant	25	75-100	25/04/2006	10
Regenerating forest below remnant	25	75-100	26/04/2006	2
Regenerating forest below remnant	25	75-100	28/04/2006	7
Field below middle of remnant	25	75-100	5/05/2006	9
Field below middle of remnant	25	75-100	8/06/2006	2
Field below middle of remnant	25	75-100	9/06/2006	0
Field below middle of remnant	25	75-100	10/06/2006	1
Field below n-e remnant edge	25	75-100	8/06/2006	1
Field below n-e remnant edge	25	75-100	9/06/2006	0
Field below n-e remnant edge	25	75-100	10/06/2006	0
Field below n-e remnant edge	25	75-100	11/06/2006	1
Field below lower regenerating forest	50	50-75	27/11/2005	0
Field below lower regenerating forest	50	50-75	28/11/2005	0

Location	Distance from remnant edge (m)	Elevation (m above sea level)	Dates	Frogs found
Field below lower regenerating forest	50	50-75	23/04/2006	0
Field below lower regenerating forest	50	50-75	24/04/2006	0
Field below lower regenerating forest	50	50-75	25/04/2006	0
Field below lower regenerating forest	50	50-75	29/11/2005	0
Field next to lodge	25	75-100	10/06/2006	3
Field next to lodge	25	75-100	11/06/2006	0
Field next to lodge	25	75-100	12/06/2006	3
Rock Wall behind lodge	25	75-100	14/04/2006	0
Rock Wall behind lodge	25	75-100	15/04/2006	0
Rock Wall behind lodge	25	75-100	16/04/2006	0
Rock Wall behind lodge	25	75-100	17/04/2006	0
Rock Wall behind lodge	25	75-100	18/04/2006	0
Rock Wall behind lodge	25	75-100	19/04/2006	0
Rock Wall behind lodge	25	75-100	21/04/2006	1
Rock Wall behind lodge	25	75-100	22/04/2006	2
Rock Wall behind lodge	25	75-100	24/04/2006	1
Rock Wall behind lodge	25	75-100	25/04/2006	0
Rock Wall behind lodge	25	75-100	29/04/2006	1
Rock Wall behind lodge	25	75-100	6/05/2006	1
Rock Wall behind lodge	25	75-100	7/06/2006	1
Rock Wall behind lodge	25	75-100	8/06/2006	0
Rock Wall behind lodge	25	75-100	9/06/2006	0
Rock Wall behind lodge	25	75-100	11/06/2006	0
Rock Wall behind lodge	25	75-100	12/06/2006	0
Rock Wall behind lodge	25	75-100	13/06/2006	0
Rock Wall behind lodge	25	75-100	14/06/2006	0
Rock Wall behind lodge	25	75-100	15/06/2006	1
Rock Wall behind lodge	25	75-100	16/06/2006	0
Rock Wall behind lodge	25	75-100	17/06/2006	0
Rock Wall behind lodge	25	75-100	18/06/2006	0
Rock Wall behind lodge	25	75-100	20/06/2006	1
Field next to lower Richard Henry Creek	50	25-50	20/04/2006	0
Field next to lower Richard Henry Creek	50	25-50	27/04/2006	0

Location	Distance from remnant edge (m)	Elevation (m above sea level)	Dates	Frogs found
Field next to lower Richard Henry Creek	50	25-50	2/05/2006	0
Fort Road	350	0-25	15/06/2006	0
Fort Road	350	0-25	16/06/2006	0
Fort Road	350	0-25	17/06/2006	0
Fort Road	350	25-50	15/06/2006	0
Fort Road	350	25-50	16/06/2006	0
Fort Road	350	25-50	17/06/2006	0
Fort Road	350	25-50	15/06/2006	3
Fort Road	350	25-50	16/06/2006	3
Fort Road	350	25-50	17/06/2006	0
Fort Road	350	25-50	21/06/2006	9
Fort Road	350	50-75	15/06/2006	0
Fort Road	350	50-75	16/06/2006	0
Fort Road	350	50-75	17/06/2006	0
Fort Road	>400	25-50	15/06/2006	0
Fort Road	>400	25-50	16/06/2006	0
Fort Road	>400	25-50	17/06/2006	0
Rifleman Creek	250	0-25	16/06/2006	0
Rifleman Creek	250	0-25	17/06/2006	0
Rifleman Creek	250	0-25	18/06/2006	0
Rifleman Creek	250	25-50	24/03/2006	0
Rifleman Creek	250	25-50	17/04/2006	0
Rifleman Creek	250	25-50	18/04/2006	0
Rifleman Creek	250	25-50	25/04/2006	0
Rifleman Creek	250	25-50	26/04/2006	0
Rifleman Creek	250	25-50	28/04/2006	0
Rifleman Creek	250	25-50	4/05/2006	0
Rifleman Creek	250	25-50	16/06/2006	0
Rifleman Creek	250	25-50	17/06/2006	0
Rifleman Creek	250	25-50	18/06/2006	0
Rifleman Creek	300	25-50	27/11/2005	0
Rifleman Creek	300	25-50	28/11/2005	0
Spring above Rifleman Creek	100	75-100	26/04/2006	0
Spring above Rifleman Creek	100	75-100	28/04/2006	0
Spring above Rifleman Creek	100	75-100	4/05/2006	0

Location	Distance from remnant edge (m)	Elevation (m above sea level)	Dates	Frogs found
Spring above Rifleman Creek	100	75-100	14/06/2006	0
Spring above Rifleman Creek	100	75-100	15/06/2006	0
Regenerating forest along shoreline	250	0-25	28/04/2006	0
Regenerating forest along shoreline	250	0-25	1/05/2006	0
Regenerating forest along shoreline	250	0-25	2/05/2006	0

7.3.4. Detection probabilities of sites from distributional survey

Detection probabilities of sites where frogs were found: number of searches when frogs were found divided by total number of searches in that site.

Location	Distance (m) from remnant edge	Elevation (m above sea level)	Total searches	Searches when frogs were found	Detection probability
North-east regenerating forest	50	100-125	4	3	0.75
North-east regenerating forest	50	125-150	3	1	0.33
North-east regenerating forest	50	150-175	4	3	0.75
North-east regenerating forest	100	125-150	3	1	0.33
North-east regenerating forest	100	150-175	5	3	0.60
North-east regenerating forest	0-50	100-125	2	1	0.50
North-east regenerating forest	0-50	125-150	3	2	0.67
North-east regenerating forest	0-50	150-175	5	3	0.60
South-west regenerating forest	75	125-150	5	2	0.40
South-west regenerating forest	0-50	25-50	3	1	0.33
South-west regenerating forest	0-50	50-75	5	3	0.60
South-west regenerating forest	0-50	75-100	6	2	0.33
South-west regenerating forest	0-50	100-125	5	1	0.20
South-west regenerating forest	0-50	125-150	3	3	1.00
South-west regenerating forest	0-50	150-175	3	1	0.33
Regenerating forest below remnant	0-50	75-100	3	3	1.00
Field next to lodge	0-50	75-100	3	2	0.67
Field below middle of remnant	0-50	75-100	4	3	0.75
Field below north-east remnant edge	0-50	75-100	4	2	0.50
Rock wall behind lodge	0-50	75-100	24	8	0.33
Fort Road	350	25-50	4	3	0.75

7.3.5. Morphology of frogs

SVL is snout-vent length, and TFL is tibio-fibula length. Colour: light (L), medium-light (LM), medium (M), medium-dark (MD), and dark (D). Pattern: uniform (U), uniform/mottled (UM), mottled (M), mottled/patterned (MP), patterned (P). Girth is subjectively assessed on a scale of one (very thin) to five (very fat).

Distance = distance from forest remnant edge.

NE = north-east.

SW = south-west.

Elevations are approximate.

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
Remnant Forest	0	150	30-Apr	L	M	0.17	3	11.4	5.8	-
Remnant Forest	0	150	30-Apr	LM	MP	4.2	3	38.5	17.7	-
Remnant Forest	0	150	30-Apr	M	M	5.42	3	39.4	17.3	-
Remnant Forest	0	150	30-Apr	LM	MP	8.11	4	45.5	20.5	-
Remnant Forest	0	150	30-Apr	LM	M	6.73	3	44.1	19.6	-
Remnant Forest	0	150	30-Apr	M	M	8.17	2	44.8	20.5	-
NE regenerating forest	25	100	20-Mar	LM	P	2.15	4	30.3	17.1	-
NE regenerating forest	25	100	20-Mar	M	P	3.96	3	42.5	20.3	-
NE regenerating forest	25	100	20-Mar	M	P	5.04	3	44	21.4	-
NE regenerating forest	25	100	20-Mar	M	UM	4.55	3	44.4	22	-
NE regenerating forest	25	100	20-Mar	LM	MP	5.87	3	46.4	23.2	-
NE regenerating forest	25	100	20-Mar	LM	MP	5.33	4.5	42.5	21.6	-
NE regenerating forest	25	100	20-Mar	M	P	4.32	3	38.7	20.8	-
NE regenerating forest	25	100	20-Mar	M	UM	5.03	1.5	47.7	22.5	-
NE regenerating forest	25	100	20-Mar	M	M	6.53	4	47.5	22.8	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
NE regenerating forest	25	100	20-Mar	D	M	5.62	3	47.4	23.1	-
NE regenerating forest	25	100	20-Mar	LM	U	4.6	2	44.9	21.6	-
NE regenerating forest	25	100	20-Mar	LM	UM	4.94	3	44.9	22.8	-
NE regenerating forest	25	100	20-Mar	M	M	5.24	3.5	46.7	22.9	-
NE regenerating forest	25	100	20-Mar	MD	U	5.36	3.5	47	22.7	-
NE regenerating forest	25	100	20-Mar	M	M	6.77	3	49	23.1	-
NE regenerating forest	25	100	20-Mar	M	M	5.01	3	45	21.2	-
NE regenerating forest	25	100	20-Mar	M	UM	4.43	2	46.4	22.5	-
NE regenerating forest	25	100	20-Mar	M	MP	5.24	3	46	22.6	-
NE regenerating forest	25	100	20-Mar	M	P	4.94	1	47.2	23.4	-
NE regenerating forest	25	100	20-Mar	M	M	3.76	2	31.5	21.1	-
NE regenerating forest	25	100	20-Mar	M	M	4.52	2	43.3	21.8	-
NE regenerating forest	25	100	20-Mar	LM	UM	5.03	1.5	46.6	21.7	-
NE regenerating forest	25	100	20-Mar	M	MP	3.68	3	43.8	22.1	-
NE regenerating forest	25	100	20-Mar	M	P	4.76	2.5	44.6	23	-
NE regenerating forest	25	100	20-Mar	M	MP	5.25	2.5	48.8	23.3	-
NE regenerating forest	25	100	20-Mar	L	P	4.84	3.5	45.1	23.4	-
NE regenerating forest	25	100	20-Mar	M	MP	5.16	1	47.9	24.2	-
NE regenerating forest	25	100	20-Mar	L	UM	5.66	3.5	45	22.5	-
NE regenerating forest	25	100	20-Mar	M	P	4.8	2	45.3	23.3	-
NE regenerating forest	25	100	20-Mar	MD	UM	5.28	1.5	47.3	23.8	-
NE regenerating forest	25	100	20-Mar	M	UM	6.13	3.5	46.6	22.3	-
NE regenerating forest	25	100	20-Mar	M	P	5.67	3	48.2	23.9	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
NE regenerating forest	25	100	20-Mar	M	M	6.6	4.5	46.7	24.3	-
NE regenerating forest	25	100	20-Mar	D	U	6.23	3.5	48.8	25.7	-
NE regenerating forest	25	100	20-Mar	M	UM	5.41	2	50.1	24.1	-
NE regenerating forest	25	100	20-Mar	M	P	4.93	3	50.3	24.5	-
NE regenerating forest	25	100	20-Mar	M	M	5.86	2	48.9	23.2	-
NE regenerating forest	25	100	20-Mar	MD	MP	5.69	3	47.8	23.3	-
NE regenerating forest	25	100	20-Mar	LM	MP	7.46	4.5	49.8	23.9	-
NE regenerating forest	25	100	15-Apr	M	M	6.65	2	47	22.9	-
NE regenerating forest	25	100	13-Jun	MD	U	7.22	3	45.2	21.1	-
NE regenerating forest	25	100	13-Jun	MD	U	7.34	3	44.3	20.9	-
NE regenerating forest	25	100	14-Jun	M	U	5.78	3	38.9	18	-
NE regenerating forest	25	100	14-Jun	LM	P	5.2	3	39.7	18.4	-
NE regenerating forest	25	125	13-Jun	D	U	5.17	3	40.1	19	-
NE regenerating forest	25	125	13-Jun	M	U	4.78	2.5	37.6	18	-
NE regenerating forest	25	125	13-Jun	M	U	4.69	2.5	36.6	17.8	-
NE regenerating forest	25	125	13-Jun	M	M	7.9	3	44	20.3	-
NE regenerating forest	25	125	13-Jun	M	U	6.26	3	40.8	19.7	-
NE regenerating forest	25	125	13-Jun	MD	U	7.93	3	46.6	20.4	-
NE regenerating forest	25	125	14-Jun	M	P	5.27	4	40.7	17.1	-
NE regenerating forest	25	125	14-Jun	LM	P	4.67	3	46.4	18.2	-
NE regenerating forest	25	125	14-Jun	M	M	6.3	3	43.4	19.1	-
NE regenerating forest	25	125	14-Jun	M	P	6.18	3	41.6	20.1	-
NE regenerating forest	25	125	14-Jun	LM	M	6.61	3	36.1	18	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
NE regenerating forest	25	125	14-Jun	MD	U	7.47	3	44.8	20.1	-
NE regenerating forest	25	125	14-Jun	L	P	6.2	3	40.4	19.1	-
NE regenerating forest	25	125	14-Jun	M	M	8.21	3.5	46.7	20.8	-
NE regenerating forest	25	150	30-Apr	M	MP	5.1	4	38.8	17.5	-
NE regenerating forest	25	150	30-Apr	L	M	4.4	3	38	17	-
NE regenerating forest	25	150	30-Apr	LM	U	5.59	3	41.2	19	-
NE regenerating forest	25	150	30-Apr	LM	M	4.38	2.5	38.5	17.4	-
NE regenerating forest	25	150	30-Apr	L	U	7.28	3.5	43.9	19.7	Toe loss: right forelimb 2nd inner
NE regenerating forest	25	150	30-Apr	M	M	3.88	1.5	38.1	18.3	-
NE regenerating forest	25	150	30-Apr	LM	M	3.89	2	38.7	17.8	-
NE regenerating forest	25	150	30-Apr	L	P	4.51	2.5	38.2	17.6	-
NE regenerating forest	25	150	30-Apr	LM	M	6.13	2.5	44	20	-
NE regenerating forest	25	150	30-Apr	LM	MP	8.03	3	45.8	20.3	-
NE regenerating forest	25	150	30-Apr	LM	UM	6.51	3	44.5	19.9	-
NE regenerating forest	25	150	30-Apr	LM	M	6.15	4	42.4	19.6	-
NE regenerating forest	25	150	30-Apr	LM	M	6.76	3	46.8	20.7	-
NE regenerating forest	25	150	4-May	LM	U	3.47	3	34.5	17.3	-
NE regenerating forest	25	150	4-May	LM	M	7.26	4	44.2	19	-
NE regenerating forest	25	150	4-May	M	M	7.58	4.5	44.8	19.5	-
NE regenerating forest	25	150	4-May	M	M	6.94	3	43.5	20.8	-
NE regenerating forest	25	150	4-May	L	U	6.11	3	44.4	20.1	-
NE regenerating forest	25	150	4-May	LM	U	6.18	3	42	20.3	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
NE regenerating forest	25	150	4-May	LM	M	4.25	3	37	18.9	-
NE regenerating forest	25	150	4-May	M	U	5.87	3	41.8	19.6	-
NE regenerating forest	25	150	4-May	L	M	7.58	3	43.5	21.6	Left eye pupil frosted
NE regenerating forest	25	150	4-May	M	M	7.14	2.5	47.4	22.1	-
NE regenerating forest	25	150	4-May	L	P	8.33	3.5	47	20.1	-
NE regenerating forest	25	150	14-Jun	M	MP	4.27	2.5	37.3	18	-
NE regenerating forest	25	150	14-Jun	LM	P	4.03	3	35.2	16.5	-
NE regenerating forest	25	150	14-Jun	L	P	5.89	3	41.2	19.3	-
NE regenerating forest	25	150	14-Jun	MD	P	7.46	4	44.3	20.9	-
NE regenerating forest	25	150	14-Jun	L	P	8.32	3	46.5	20.3	-
NE regenerating forest	50	100	14-Apr	M	M	2.87	3	32.5	15.9	-
NE regenerating forest	50	100	14-Apr	L	MP	5.83	4	39.4	18.5	-
NE regenerating forest	50	100	14-Apr	M	M	6.51	3.5	41.1	18.2	-
NE regenerating forest	50	100	14-Apr	M	P	7.3	3.5	45.4	21.4	-
NE regenerating forest	50	100	14-Apr	LM	MP	8.5	3.5	45.5	21.4	-
NE regenerating forest	50	100	14-Apr	LM	MP	7.75	4	44	20.5	-
NE regenerating forest	50	100	14-Apr	M	MP	7.47	3.5	46.5	20.7	-
NE regenerating forest	50	100	14-Apr	M	MP	8.06	4.5	45.3	20.8	-
NE regenerating forest	50	100	14-Apr	LM	M	8.06	4.5	46	20.8	-
NE regenerating forest	50	100	14-Apr	MD	MP	7.23	5	42.8	20.6	-
NE regenerating forest	50	100	14-Apr	L	UM	9.49	5.5	48.3	20.5	-
NE regenerating forest	50	100	14-Apr	L	P	8.84	5.5	47	21.3	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
NE regenerating forest	50	100	14-Apr	LM	MP	7.77	3.5	48.7	22.5	-
NE regenerating forest	50	100	14-Apr	L	P	9.26	4	48.3	22.4	-
NE regenerating forest	50	100	14-Apr	M	MP	9	5	47.8	21.5	-
NE regenerating forest	50	100	14-Apr	MD	MP	8.69	3	49.6	22.6	-
NE regenerating forest	50	100	14-Apr	M	M	8.46	2.5	49.3	21.8	-
NE regenerating forest	50	100	28-Apr	D	U	6	3	41.8	17.8	-
NE regenerating forest	50	100	28-Apr	LM	P	5.59	3	39.1	17.8	-
NE regenerating forest	50	100	28-Apr	M	M	4.51	2.5	39.1	18.4	-
NE regenerating forest	50	100	28-Apr	M	M	9.35	5	47.5	20.3	-
NE regenerating forest	50	100	28-Apr	LM	M	6.77	3	44.7	20.6	-
NE regenerating forest	50	100	28-Apr	M	M	7.54	3	47.3	20.8	-
NE regenerating forest	50	100	28-Apr	LM	MP	8.19	3	47.9	21.4	-
NE regenerating forest	50	100	28-Apr	LM	M	9.82	3	51	22.7	-
NE regenerating forest	50	100	28-Apr	M	M	10.2	5	47.8	22	-
NE regenerating forest	50	100	28-Apr	L	P	8.84	3.5	47.1	21.3	-
NE regenerating forest	50	100	30-Apr	LM	M	3.22	4	34.2	17.1	-
NE regenerating forest	50	100	30-Apr	LM	MP	7.62	3	43.6	20	-
NE regenerating forest	50	125	14-Apr	M	MP	6.95	2.5	47.2	21.7	-
NE regenerating forest	50	125	14-Apr	L	P	7.55	5	47.2	20.9	-
NE regenerating forest	50	150	30-Apr	L	P	6.76	4.5	42.8	20.8	-
NE regenerating forest	50	150	30-Apr	M	M	6.83	3	45.4	21.4	-
NE regenerating forest	50	150	4-May	LM	M	7.05	3	45.4	20.7	-
NE regenerating forest	50	150	4-May	L	MP	5.88	3.5	38.5	18.4	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
NE regenerating forest	50	150	4-May	L	P	7.46	3	45.1	21.6	-
NE regenerating forest	50	150	4-May	M	MP	7.3	3.5	45	20.5	-
NE regenerating forest	50	150	4-May	L	P	7.85	3	44.4	21.4	-
NE regenerating forest	50	150	4-May	L	P	10.3	5	48.4	22.8	Scarring on right side & inner forelimb
NE regenerating forest	50	150	14-Jun	M	UM	7.07	3	45	20.1	-
NE regenerating forest	100	150	4-May	L	MP	8.64	3	47.1	22.1	-
NE regenerating forest	100	150	4-May	LM	MP	7.65	3	45.5	20.8	-
NE regenerating forest	100	150	9-Jun	M	U	6.71	3	42.9	20.3	Found o bracken squashed down, open overhead, & very damp
NE regenerating forest	100	150	9-Jun	M	UM	8.88	3.5	46.4	21.3	Toe loss: right forelimb outer
NE regenerating forest	100	150	9-Jun	M	P	9.45	4	46	21.8	-
NE regenerating forest	100	150	14-Jun	MD	MP	2.72	3	30.7	15	-
NE regenerating forest	100	150	14-Jun	M	MP	7.4	3.5	44.3	20.8	-
SW regenerating forest	25	50	22-Mar	M	P	7.78	4	43.1	21.2	-
SW regenerating forest	25	50	22-Mar	MD	M	8.1	4	45.7	21.5	-
SW regenerating forest	25	50	19-Apr	L	M	0.27	5	14	6.7	-
SW regenerating forest	25	50	19-Apr	M	M	2.67	4	29.4	15	-
SW regenerating forest	25	50	21-Apr	M	MP	10.6	5	48.8	21.3	-
SW regenerating forest	25	50	22-Apr	M	MP	10.2	4.5	48.9	21.7	-
SW regenerating forest	25	50	6-May	M	M	10.5	5	47.8	21.2	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
SW regenerating forest	25	125	21-Mar	M	MP	7.06	4	42.9	20.9	-
SW regenerating forest	25	125	21-Mar	MD	UM	8.48	4.5	45.1	20.8	-
SW regenerating forest	25	125	23-Mar	D	UM	7.09	4	42.5	20.3	-
SW regenerating forest	25	125	23-Jun	MD	U	12.1	3	43.9	17.7	-
SW regenerating forest	25	125	23-Jun	D	U	6.5	3	42.5	19	-
SW regenerating forest	25	125	23-Jun	M	UM	8.9	3.5	45.2	22.4	-
SW regenerating forest	25	125	23-Jun	D	M	8.89	3	41.7	21.7	-
SW regenerating forest	25	125	26-Jun	MD	U	7.14	2.5	45.8	20	-
SW regenerating forest	25	125	26-Jun	L	P	5.84	2.5	40.5	19.2	-
SW regenerating forest	25	125	26-Jun	M	U	6.7	2.5	43.7	19.4	-
SW regenerating forest	25	125	26-Jun	LM	U	8.4	3	45.9	20.6	-
SW regenerating forest	25	125	26-Jun	L	M	8.59	3.5	44.4	21.2	-
SW regenerating forest	25	150	26-Jun	M	U	4.32	2.5	46.4	17.7	-
SW regenerating forest	25	150	26-Jun	M	M	6	3	37.7	18.5	-
SW regenerating forest	25	150	26-Jun	D	U	5.41	1.5	42.4	20.7	-
SW regenerating forest	50	25	19-Apr	LM	UM	9.92	5.5	48.4	21.4	Found sitting in bottom of broken glass bottle among other rubbish in Richard Henry Creek - formerly a rubbish dump.
SW regenerating forest	75	125	21-Mar	L	UM	6.01	3	43.5	18.3	-
SW regenerating forest	75	125	21-Mar	LM	P	7.91	5	42.1	20.5	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
SW regenerating forest	75	125	21-Mar	MD	M	7.64	3	44.2	20.6	-
SW regenerating forest	75	125	21-Mar	MD	UM	7.87	1.5	46.2	22	-
SW regenerating forest	75	125	16-Mar	L	U	7.2	3	45.9	21.1	-
SW regenerating forest	75	125	16-Mar	LM	MP	4.93	2	42.5	20.1	-
SW regenerating forest	75	125	16-Mar	L	P	7.83	4	47.2	21.9	-
SW regenerating forest	75	125	16-Mar	L	P	7.76	3	48.5	23.4	-
SW regenerating forest	75	125	16-Mar	L	P	7.46	3.5	48.2	22.3	-
Field below NE remnant edge	25	75	4-May	L	U	5.34	3	40.8	19	-
Field below NE remnant edge	25	75	4-May	LM	U	3.79	3	37.3	18.3	-
Field below NE remnant edge	25	75	4-May	M	M	7.34	4	44.8	21.1	-
Field below NE remnant edge	25	75	8-Jun	M	M	5.26	2	41.9	19.7	-
Field below NE remnant edge	25	75	11-Jun	M	P	7.13	3	44.4	21.3	-
Field below remnant centre	25	75	5-May	L	MP	5.63	3.5	40.1	17.5	-
Field below remnant centre	25	75	5-May	LM	M	8.18	4	46.4	20.9	Toe loss: right forelimb outer toe
Field below remnant centre	25	75	5-May	M	M	5.18	2	41.1	20	-
Field below remnant centre	25	75	5-May	M	MP	6.89	3.5	44	19.7	-
Field below remnant centre	25	75	5-May	LM	M	6.79	3.5	45	19.5	-
Field below remnant centre	25	75	5-May	L	P	6.56	3	43	20.5	-
Field below remnant centre	25	75	5-May	LM	M	6.52	3	42.6	20.1	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
Field below remnant centre	25	75	5-May	L	P	10.4	5	49.4	22.5	Toe loss: left forelimb 2nd outer, left hind limb 2nd inner. Sitting on top of a clump of grass (1 foot off ground)
Field below remnant centre	25	75	5-May	L	P	6.93	3	43.8	20.5	-
Field below remnant centre	25	75	8-Jun	M	P	7.06	4	44.3	19.4	Toe loss (clipped?): right forelimb 2nd outer, right hindlimb mid, left forelimb 2nd inner
Field below remnant centre	25	75	8-Jun	M	MP	8.03	3	45.4	20.7	-
Field below remnant centre	25	75	10-Jun	L	P	5.41	3	41.1	18.5	-
Field next to lodge	25	75	10-Jun	LM	M	6.59	4	40.8	18.5	Left foot had 3 inner toes joined into a stump
Field next to lodge	25	75	10-Jun	LM	M	8.23	3.5	43.9	20.3	-
Field next to lodge	25	75	10-Jun	M	U	8.12	3.5	46.3	20.4	Toe loss: right forelimb 2nd inner
Field next to lodge	25	75	12-Jun	D	P	5.39	3	40	19.2	-
Field next to lodge	25	75	12-Jun	D	U	7.38	4.5	45	19.9	-
Field next to lodge	25	75	12-Jun	M	U	4.25	1.5	42.4	19.4	-
Regenerating forest below remnant	25	75	25-Apr	D	U	7.76	3	45.3	20.6	-
Regenerating forest below remnant	25	75	25-Apr	D	P	5.01	3	38.4	18	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
Regenerating forest below remnant	25	75	25-Apr	LM	M	5.47	3	41.6	19.4	-
Regenerating forest below remnant	25	75	25-Apr	L	P	6.45	3	44.5	19.3	-
Regenerating forest below remnant	25	75	25-Apr	D	M	7.57	4	43.6	20.2	-
Regenerating forest below remnant	25	75	25-Apr	MD	M	7.25	3.5	44.1	19.8	-
Regenerating forest below remnant	25	75	25-Apr	MD	M	6.51	3	44.1	20.8	-
Regenerating forest below remnant	25	75	25-Apr	LM	U	8.71	3.5	48.2	21.3	-
Regenerating forest below remnant	25	75	25-Apr	M	U	5.39	3	40.7	19.2	-
Regenerating forest below remnant	25	75	25-Apr	M	MP	7.23	3	44.3	20.1	-
Regenerating forest below remnant	25	75	26-Apr	M	M	4.78	3	37.3	17.3	-
Regenerating forest below remnant	25	75	26-Apr	LM	U	8.87	3.5	49.2	21.7	-
Regenerating forest below remnant	25	75	28-Apr	M	M	5.34	4	39.2	17.8	-
Regenerating forest below remnant	25	75	28-Apr	L	MP	6.79	3	45.6	20.9	-
Regenerating forest below remnant	25	75	28-Apr	M	M	6.97	3	43.2	20.2	-
Regenerating forest below remnant	25	75	28-Apr	M	MP	7.44	3	45.1	21	-
Regenerating forest below remnant	25	75	28-Apr	LM	P	6.64	3	46.7	21.5	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
Regenerating forest below remnant	25	75	28-Apr	M	M	7.71	4.5	43.4	20.3	-
Regenerating forest below remnant	25	75	28-Apr	M	P	6.94	3	44.6	21.4	-
Regenerating forest below remnant	25	75	29-Apr	LM	UM	5.46	5	39.2	17.3	-
Regenerating forest below remnant	25	75	29-Apr	L	P	8.01	5	46.1	21.1	-
Regenerating forest below remnant	25	75	30-Apr	M	M	5.63	5	39.6	17.1	-
Regenerating forest below remnant	25	75	30-Apr	L	MP	8.02	4	45.2	21	-
Regenerating forest below remnant	25	75	4-May	MD	M	7.41	2.5	45.1	21.6	-
Lodge rock wall	25	75	21-Apr	LM	M	7.83	3.5	46.6	20.6	-
Lodge rock wall	25	75	22-Apr	M	MP	7.52	3	45.6	20.9	-
Lodge rock wall	25	75	22-Apr	L	P	9.7	5.5	47.1	20.8	-
Lodge rock wall	25	75	24-Apr	M	MP	8.48	3.5	46.6	22.2	Injured toe right forelimb 2nd outer (3-5mm from top appears red, swollen & bleeding slightly)
Lodge rock wall	25	75	29-Apr	L	P	8.89	4.5	46.4	21.8	Recapture: injured toe
Lodge rock wall	25	75	6-May	L	P	9.34	5	46.9	20.8	-
Lodge rock wall	25	75	7-Jun	LM	P	10.3	5	48.1	21.5	-
Lodge rock wall	25	75	15-Jun	L	P	9.03	4	46.9	20.5	-
Lodge rock wall	25	75	20-Jun	LM	P	10.4	5	48.2	21.8	Recapture: injured toe
Fort Road	350	25	28-Apr	M	P	6.95	4	41.2	19.5	-
Fort Road	350	25	1-May	L	P	9.73	5.5	46.3	20.7	-
Fort Road	350	25	4-May	L	P	6.97	3.5	45.2	21.3	-
Fort Road	350	25	8-Jun	L	P	9.21	4	47.5	21.6	-
Fort Road	350	25	15-Jun	L	P	5.61	3	40.2	17.8	-

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Date (2006)	Colour	Pattern	Weight (g)	Girth	SVL (mm)	TFL (mm)	Comments
Fort Road	350	25	15-Jun	LM	P	7.27	3.5	45.2	21	-
Fort Road	350	25	15-Jun	L	P	9.48	4.5	48.7	20.5	-
Fort Road	350	25	16-Jun	LM	P	9.03	4	46.2	20.9	-
Fort Road	350	25	16-Jun	LM	P	9.95	4.5	48.1	22	-
Fort Road	350	25	21-Jun	MD	P	5.21	3	38.9	17	-
Fort Road	350	25	21-Jun	LM	P	4.73	2.5	37.4	17.4	-
Fort Road	350	25	21-Jun	LM	MP	5.2	3	39.5	18	-
Fort Road	350	25	21-Jun	LM	P	6.12	3	39.5	17.9	-
Fort Road	350	25	21-Jun	LM	P	6.75	1.5	45.9	20.4	Toe loss: right hind limb inner
Fort Road	350	25	21-Jun	L	P	7.98	3.5	45.5	20.1	
Fort Road	350	25	21-Jun	LM	P	6.65	2.5	43	20.4	
Fort Road	350	25	21-Jun	LM	P	6.95	3	41.8	19.5	
Fort Road	350	25	21-Jun	LM	P	7.09	2	46.1	21.5	-

7.3.6. Habitat mapping data

Table 7.1: Habitat ranking table. Each habitat feature was ranked out of five, and the description of these is outlined below. A ranking of 1 for vegetation type refers to remnant forest, for example, and a ranking of 3 for aspect indicates a steep slope.

Habitat feature	Rank out of five for each feature					
	0	1	2	3	4	5
Aspect	flat	gentle	medium	steep	very steep	vertical
Rock cover	0	<20%	<40%	<60%	<80%	<100%
Rock size	-	<5cm	<10cm	<20cm	<30cm	>30cm
Habitat type	-	remnant forest	regenerating forest	pine forest	shrubs	pasture
Canopy cover	0	<20%	<40%	<60%	<80%	<100%
Canopy height (m)	0	<2m	2-4m	4-6m	6-8m	>8m
Sub-canopy cover	0	<20%	<40%	<60%	<80%	<100%
Ground vegetation cover	0	<20%	<40%	<60%	<80%	<100%
Leaf litter cover	0	<20%	<40%	<60%	<80%	<100%

NE = north-east and SW = south-west

Location	**Distance from remnant edge (m)**	**Elevation (m a.s.l.)**	**Frogs found**	**Rock cover**	**Rock size**	**Aspect**	**Leaf litter cover**	**Habitat type**	**Canopy cover**	**Canopy height**	**Subcanopy cover**	**Ground vegetation cover**
NE regenerating forest	25	75	41	2	5	1	5	5	5	3	1	1
NE regenerating forest	25	100	7	3	5	4	1	2	4	4	1	1
NE regenerating forest	25	125	8	2	5	2	3	2	2	1	1	2
NE regenerating forest	25	150	31	1	3	3	1	2	3	1	0	3
NE regenerating forest	50	100	2	5	5	3	4	2	2	3	4	3
NE regenerating forest	50	150	9	2	4	3	4	2	2	2	4	3

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Frogs found	Rock cover	Rock size	Aspect	Leaf litter cover	Habitat type	Canopy cover	Canopy height	Subcanopy cover	Ground vegetation cover
NE regenerating forest	100	125	0	2	3	3	4	2	4	3	2	2
NE regenerating forest	100	150	7	0	0	2	0	2	1	1	0	5
NE regenerating forest	150	125	0	2	3	2	4	2	4	2	1	2
NE regenerating forest	150	150	0	1	1	3	4	2	4	2	1	2
NE regenerating forest	200	125	0	1	1	3	4	2	4	2	1	1
NE regenerating forest	200	150	0	1	3	3	5	2	4	1	1	0
NE regenerating forest	250	150	0	2	4	3	5	2	4	1	1	0
NE regenerating forest	300	150	0	1	3	3	5	2	3	1	0	0
SW regenerating forest	25	50	4	2	4	5	0	2	5	1	0	1
SW regenerating forest	25	75	3	1	2	4	0	2	1	3	0	5
SW regenerating forest	25	100	1	0	0	4	4	2	3	1	2	4
SW regenerating forest	25	125	12	0	0	4	0	2	2	3	0	5
SW regenerating forest	25	150	3	0	0	4	0	2	2	3	0	5
SW regenerating forest	50	25	1	3	3	2	1	2	5	2	3	1
SW regenerating forest	50	75	0	4	5	3	5	2	4	1	1	1
SW regenerating forest	75	125	9	4	5	3	5	2	3	1	0	2
SW regenerating forest	75	150	0	3	4	2	5	2	3	1	0	1
SW regenerating forest	100	25	0	1	2	2	3	2	5	1	0	0
SW regenerating forest	150	25	0	1	3	3	3	2	5	1	0	0
SW regenerating forest	150	100	0	0	0	3	2	2	4	1	0	0

Location	Distance from remnant edge (m)	Elevation (m a.s.l.)	Frogs found	Rock cover	Rock size	Aspect	Leaf litter cover	Habitat type	Canopy cover	Canopy height	Subcanopy cover	Ground vegetation cover
SW regenerating forest	150	150	0	1	2	3	4	2	2	2	1	5
Lower Regen	25	50	19	2	3	2	1	2	2	1	0	1
Field below NE remnant edge	25	50	2	3	4	3	0	5	0	0	0	5
Field below remnant centre	25	50	12	3	5	2	1	5	0	0	0	5
Field next to lodge	25	50	6	1	2	1	1	5	0	0	0	5
Field below lower regenerating forest	25	50	0	3	5	2	0	5	0	0	0	4
Field next to Richard Henry Creek	50	25	0	0	0	2	0	5	0	0	0	5
Spring above Rifleman Creek	250	50	0	2	2	1	4	2	5	2	0	0
Rifleman Creek	250	25	0	3	3	2	2	2	4	1	2	2
Fort Road	300	25	0	3	3	2	1	2	3	1	1	1
Fort Road	350	25	15	3	2	2	2	2	4	1	0	0
Regenerating forest along shoreline	250	0	0	3	2	5	2	2	4	1	0	0

7.3.7. Weather variables

Taken from Maud Island metstation (at 9am).

Dates	Rainfall (mm)	Relative Humidity	Minimum Temperature (°C)
23/11/05	0.2	64	10.3
24/11/05	0.1	53	10.3
25/11/05	0	64	9.3
27/11/05	1	73	9.4
28/11/05	0	79	10.7
29/11/05	0	76	10.5
3/12/05	13.3	79	11.8
5/12/05	0.1	94	14.4
6/12/05	0	78	14.3
7/12/05	0.6	83	13.7
8/12/05	4.4	90	16.4
9/12/05	0.1	91	16.7
14/03/06	0	82	12.1
16/03/06	0	69	12.5
17/03/06	0	78	12.4
18/03/06	0	73	15.2
19/03/06	28.1	72	14.5
20/03/06	2.4	84	15.2
21/03/06	2.9	83	12.6
22/03/06	1.7	78	13.2
23/03/06	0.5	76	14.4
24/03/06	0	58	11.9
14/04/06	0	81	9.8
15/04/06	0.9	85	12.7
16/04/06	15.2	78	15.4
17/04/06	4.4	84	13.4
18/04/06	0	64	11.5
19/04/06	0	92	10.5
21/04/06	0.9	73	15.4
22/04/06	6	75	16.4
24/04/06	23.6	98	14.5
25/04/06	2.4	78	13.5
28/04/06	0.3	78	13.2
29/04/06	0	71	13.2
30/04/06	0.5	85	10.5

Dates	Rainfall (mm)	Relative Humidity	Minimum Temperature (°C)
1/05/06	0	81	11.2
2/05/06	0	70	13.1
4/05/06	0	71	11.1
5/05/06	0	78	10.8
6/05/06	0	69	11.1
7/06/06	0.1	93	6.7
8/06/06	0	57	8.7
9/06/06	0	59	9.6
10/06/06	39.7	71	9.9
11/06/06	11.2	97	12.2
12/06/06	0.2	66	5.2
13/06/06	0	79	8.4
14/06/06	3.3	62	7.5
15/06/06	10.9	77	9
16/06/06	0	61	5.8
17/06/06	9.1	71	4
17/06/06	9.1	71	4
18/06/06	0	55	5.7
20/06/06	17.5	69	5.1
21/06/06	3.3	74	8.7
25/06/06	0	71	6.3
26/06/06	0	78	7.7
29/06/06	0	78	6.2
30/06/06	0.1	88	6.2
1/07/06	0	91	5.7
2/07/06	8.9	79	6.7
3/07/06	1.2	86	9.5
4/07/06	2.3	56	7.1

7.4. Publications: Abstracts of papers presented at the 12th Biennial Conference of the Society for Research on Amphibians and Reptiles in New Zealand, University of Otago, Dunedin, New Zealand, 9-11 February 2007. SRARNZ abstracts

7.4.1. Le Roux, J., and B. D. Bell. 2007a. A re-estimation of the population size of *Leiopelma pakeka* (Anura: Leiopelmatidae) in its remnant forest habitat on Maud Island. *New Zealand Journal of Zoology* **34:** 265-266.

The Maud Island frog *Leiopelma pakeka* is native to New Zealand, and occurs only on Maud Island in the Marlborough Sounds. In 1994 the population size of *Leiopelma pakeka* in its 16 ha remnant forest habitat on Maud Island was conservatively estimated to be 19 000 frogs. The present study reassesses this estimate of population size following night searches for this nocturnal species in 100, 5 × 5 m plots across the forest. Our estimate was derived using Bootstrap population estimation, corrected for likelihood of emergence and for likely maximum population size on plots. This gave an estimated population size of 34 449 frogs. This new estimate is much closer to another recent population size estimate of 39 563, based on an update of the original 1994 figure. Assumptions made in determining these population size estimates are critically reviewed.

7.4.2. Le Roux, J., and B. D. Bell. 2007b. Temporal changes in the distributional range of the Maud Island frog (*Leiopelma pakeka*), with expansion from its remnant forest habitat on Maud Island. *New Zealand Journal of Zoology* **34:** 266.

New Zealand is home to four native frog species. This study focuses on the Maud Island frog, *Leiopelma pakeka*, until recently confined to one island in the Marlborough Sounds. This island was previously farmed, and this terrestrial frog survived in a 16 ha remnant of native forest. The island is now a scientific reserve, with much forest regenerating. There is limited evidence that the frog has been spreading into both regenerating forest and adjacent pastoral areas. This study investigates the current distribution of *L. pakeka* on Maud Island, specifically the extent to which frogs have dispersed from the main forest remnant into nearby remnant forest and non-forest areas (e.g. pasture). Distribution was determined by searches at night in adjacent regenerating forest and paddocks. Other areas of suitable habitat further afield were also searched. As these nocturnal frogs do not all emerge on a given night, nor at the same time, all areas were searched at least three times. Frogs were found to have generally dispersed up to 50 m from the forest remnant edges, dispersing even further (up to 125 m) into older regenerating forest on the north-east edge. A further population of frogs was found about 300 m from the remnant edge, with no frogs found between the two populations. This distant population has reportedly existed in the area for at least 12 years. Overall, the frog population on Maud Island appears to be expanding in range and therefore numbers, as regenerating habitats slowly become available again, under current restoration management policies.