Conservation issues for Hochstetter's frog (*Leiopelma hochstetteri*): Monitoring techniques and chytridiomycosis prevalence in the Auckland Region, New Zealand.

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Abstract

Amphibians are suffering extinctions and range contractions globally. This is caused by numerous factors and most of them are related to human activities. The overall aim of this thesis was to make a significant contribution to the conservation of the endemic amphibian *Leiopelma hochstetteri* through research. This was achieved by focusing in two of the main conservation issues for this species, the need for standardised and robust monitoring techniques to detect trends and changes in populations, and the determination of the prevalence of chytridiomycosis, caused by the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*). Two populations of the Auckland Region were selected for this study, one on the mainland (Waitakere Ranges) and the only known offshore island population of this species (Great Barrier Island). For both study sites different monitoring methods were used to obtain some population parameters. Site occupancy models of MacKenzie et al. (2002) gave reliable site-specific estimations of *occupancy* and *detection probability* using covariate information and presence-absence data collected from 50 sites in the Waitakere Ranges and four repeated visits during 2008. Elevation and distance searched were found to have an important effect on occupancy levels, while time taken to search the site was important variable determining detection probabilities. Also, parameters were estimated for three age classes separately. Statistical models were used to infer abundance from occupancy analysis, and results were compared with the distribution of relative abundances obtained from repeated transect counts and an established sight/re-sight criterion. In addition, the use of surrogate measures for relative abundance was explored. Detection probability and the distance to first frog found were found to have a significant correlation with relative abundance. These measures can be used to infer relative abundance in future site occupancy surveys. Two surveys and a pilot site occupancy survey were conducted on Great Barrier Island, and presence of frogs was confirmed at the northern block, and in a small seepage in the central block. No new locations were found. Waitakere Ranges and Great Barrier Is. populations were tested for the presence of chytridiomycosis, and all frogs sampled tested negative (n = 124) which means that if present chytridiomycosis prevalence is lower than 5% with a 95% confidence interval. This and previous evidence suggests that *L. hochstetteri* may be resistant or immune to the disease. However, to confirm this additional studies are needed.

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CHAPTER 1

General Introduction

Plate 1. Hochstetter's frog (*Leiopelma hochstetteri*)

1.1 Background

1.1.1 Amphibians

General characteristics

The class Amphibia is a diverse group of vertebrates with more than 6,300 known species (Frost, 2009) in three extant orders: Anura (frogs and toads), Caudata (salamanders and newts), and Gymnophiona (caecilians). These three groups differ morphologically from each other, however all amphibians share certain physiological characteristics that distinguish them from other terrestrial vertebrates. They have scale-less and highly permeable skin, which allows the rapid passage of both water and respiratory gases. They are dependant on aquatic or moist habitats, as their eggs lack a protective shell and most species develop aquatic larvae in the early stages of their life cycle. They also are incapable of generating their own heat (ectothermics) and consequently have much lower metabolic rates than endothermic birds and mammals of comparable mass (Wells, 2007).

Evolution

All living groups of amphibians are descended from a diverse group of tetrapods that first appeared in the Devonian Period, about 400 million years ago (Carroll, 2001). Among anurans, Ascaphidae from North America and New Zealand's endemic Leiopelmatidae are considered the most basal (primitive) families, and both are members of the paraphyletic group archaebatrachia (Hay et al., 1995, Roelants et al., 2007). Genetic analysis has revealed several episodes of accelerated amphibian diversification, which occurred after the end of the Permian mass extinction and in the late Cretaceous, and which are correlated with amniote turnover rates and the rise of angiosperm-dominated forests (Roelants et al., 2007).

1.1.2 Declining Amphibian Populations

Amphibian extinction crisis

At the current time the Amphibian group is suffering from extinctions, range contractions, and population declines on a global scale (Wake and Vredenburg, 2008, Gardner, 2001, Blaustein et al., 1994). Nearly one-third (32%) of the world's amphibian species are threatened, while in the last two decades 168 species are believed to have gone extinct and 2,469 (43%) more have populations that are declining (AmphibiaWeb, 2009). This suggests that the number of extinct and threatened species will probably continue to rise (Stuart et al., 2004). Undoubtedly, species extinctions have always occurred throughout the history of life on earth. However, in the last few decades of the 20th century the amphibian extinction rate exceeded the mean extinction rate of the last 350 million years by 200-2,700 times (Roelants et al., 2007). This massive extinction crisis is believed to be the greatest extinction event in the history of amphibians and its been regarded as the greatest taxon-specific conservation challenge in the history. Figure 1.1 shows the dramatic increase in the number of threatened amphibian species during the past few years, along with a comparison with other vertebrate groups.

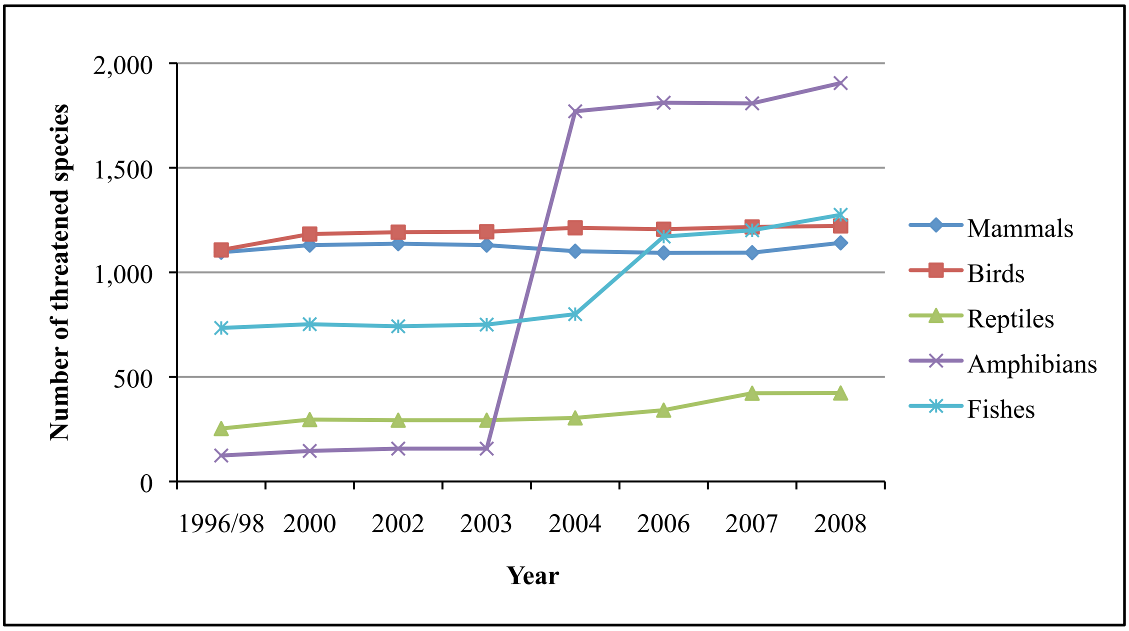

Figure 1.1. Number of threatened species in different groups of vertebrates (Data source: The IUCN Red List of Threatened Species™ (IUCN, 2009)).

Causes

There are several hypothesised causes for recent amphibian declines, and most of them are linked to anthropogenic disturbances, they include: habitat destruction, alteration and fragmentation; infectious disease and pathogens; global climate change; increased UVB radiation; toxic chemicals; invasive species; and commercial trade (Daszak et al., 2003, Blaustein et al., 2003, Collins and Storfer, 2003, Pounds and Crump, 1994). Among these, habitat destruction has been regarded as the greatest ongoing and irreversible threat to amphibians, however more recently chytridiomycosis, an amphibian emerging infectious disease has played a major role in amphibian declines, and is a constant threat to wild populations (see Chapter 4). Accordingly, there is increasing concern about conservation of amphibian species worldwide.

1.1.3 Amphibian Conservation

History

When herpetologists during the 1980s started noticing that amphibian declines were becoming more frequent and severe, conservationists looking at the problem were particularly alarmed by the fact that the phenomenon was occurring at a Class level, potentially threatening thousands of species worldwide (Stuart et al., 2004). The problem of amphibian declines gained priority in the international conservation agenda, and in 1990 the IUCN created the Declining Amphibian Populations Task Force [DAPTF] within the Species Survival Commission [SSC] "to determine the nature, extent and causes of declines of amphibians throughout the world, and to promote means by which declines can be halted or reversed" (IUCN/SSC, 2007a). This lead to the first comprehensive assessment of the conservation status of all amphibians: the Global Amphibian Assessment [GAA] in 2004 (Stuart et al., 2004).

The GAA findings were alarming and caused further concern. These findings lead to the assembly of the Amphibian Conservation Summit [ACS] in 2005. As an outcome from this meeting the first Amphibian Conservation Action Plan [ACAP] was written, which is a "multidisciplinary approach that provides a way forward in addressing the causes of declines and slowing or reversing the losses" (IUCN/SSC, 2007a). In 2006 the DAPTF merged into the new IUCN/SSC Amphibian Specialist Group [ASG] to "form a body that could harness the intellectual and institutional capacity of a conservation and research network at country, regional and global levels" (IUCN/SSC, 2007b).

Action

Among many conservation efforts and management actions created to aid amphibians are habitat protection, the implementation of long-term monitoring programmes of wild populations, captive breeding programmes, reintroductions and translocations. In recent years, there have been some successful captive breeding and reintroduction programmes (Griffiths and Pavajeau, 2008), as well as successful amphibian translocations (Germano and Bishop, 2009), thus, further encouraging applied amphibian conservation projects. Some *ex-situ* conservation actions involve the creation and maintenance of online amphibian databases and online information resources (AmphibiaWeb, 2009), as well as educational campaigns (e.g., "Year of the Frog") aiming to raise awareness on the amphibian extinction crisis .

Issues

One of the main issues for amphibian conservation is that little is known about the distribution and abundance of many species (Duellman, 1999). Because most amphibians live in hard to reach habitats such as dense forests or swamps, they are difficult organisms to study, and the costs of fieldwork are often very high. For many species (25%), present data are not enough for a comprehensive classification into any threat category and remain categorised as DD (Data Deficient, IUCN (2009)). For those species that we know are declining, the causes remain sometimes speculative, and even though there is increasing evidence of disease and global change as a driving mechanism (Bosch et al., 2007), this is still controversial and we still don't always know with certainty what is causing amphibian declines (Collins and Storfer, 2003, Alford et al., 2007, Di Rosa et al., 2007). The fact that habitat preservation alone is not enough to protect amphibian populations (Pounds and Crump, 1994) represents a major conservation challenge, and highlights the need for more diverse strategies. How to deal with the recent and rapid amphibian declines remains a global conservation issue.

1.1.4 New Zealand amphibians

There is only one group of native amphibians in New Zealand, the anuran family Leiopelmatidae. This family contains a single genus *Leiopelma*, with four extant species: Hochstetter's frog (*L. hochstetteri*), Archey's frog (*L. archeyi*), Hamilton's frog (*L. hamiltoni*), Maud Island frog (*L. pakeka*), and three described extinct species: *L. waitomoensis*, *L. markhami*, and *L. auroraensis* (Worthy, 1987). Maud Island frog and Hamilton's frog were once regarded as the same species, but they are now considered separate species because of genetic differences, although more recent genetic studies show very little variation between them (Bell et al., 1998, Holyoake et al., 2001). In addition to the native frogs, three Australian species of the genus *Litoria* are present in New Zealand; *L. aurea*, *L. raniformis* and *L. ewingii* (Gill and Whitaker, 1996).

Molecular analysis show that Leiopelmatidae separated from the ancestor of all other frogs as long as 263 million years ago, during the Triassic Period (San Mauro et al., 2005). They have retained primitive features such as the presence of nine presacral vertebrae, amphicoelous vertebrae, inscriptional ribs, and tail-wagging muscles, which are typical of Jurassic age fossils, which suggests they have changed very little in the past 200 my (Cannatella, 2008). Along with their primitive characteristics, native *Leiopelma* species are characterised for being small (snout to vent length [SVL] <51mm), cryptic, and silent, in contrast to most other frogs, they do not have any breeding call (Gill and Whitaker, 1996).

Distribution

Sub-fossil evidence shows Leiopelmatids were once widespread throughout New Zealand, however since human settlement they have suffered major declines and significant range contractions (Towns and Daugherty, 1994, Worthy, 1987). They are now distributed only in the northern half of the North Island, and in a couple of small predator-free islands at the Marlborough Sounds and Cook Strait. Most populations of native frogs are small and isolated, due to habitat fragmentation (see Figure 1.2).

Threats

Among common amphibian threats, habitat destruction and the impact of introduced fauna in particular have had the greatest impact on native amphibians, and are regarded as principal continuing common threats (Newman, 1996, Thurley and Bell, 1994). More recently, chytridiomycosis (a fungal disease) has also been identified as a major threat, as the fungus was identified in both introduced *Litoria* and the native *L. archeyi* (see Chapter 4). Also, stochastic events represent an important threat for small and isolated populations such as *L. hamiltoni* on Stephens Island or *L. pakeka* on Maud Island.

All *Leiopelma* species are categorised as Threatened by the IUCN Red List and by the New Zealand Threat Classification System (Hitchmough et al., 2007, IUCN, 2009), Table 1.1 summarises the classifications for each frog species. All of them are also ranked in the 60 most Evolutionarily Distinct and Globally Endangered (EDGE) amphibians in the world, with *L. archeyi* currently the no. 1 EDGE species, *L. hamiltoni* no. 17, *L. hochstetteri* no. 38, and *L. pakeka* no. 58 (The Zoological Society of London, 2008).

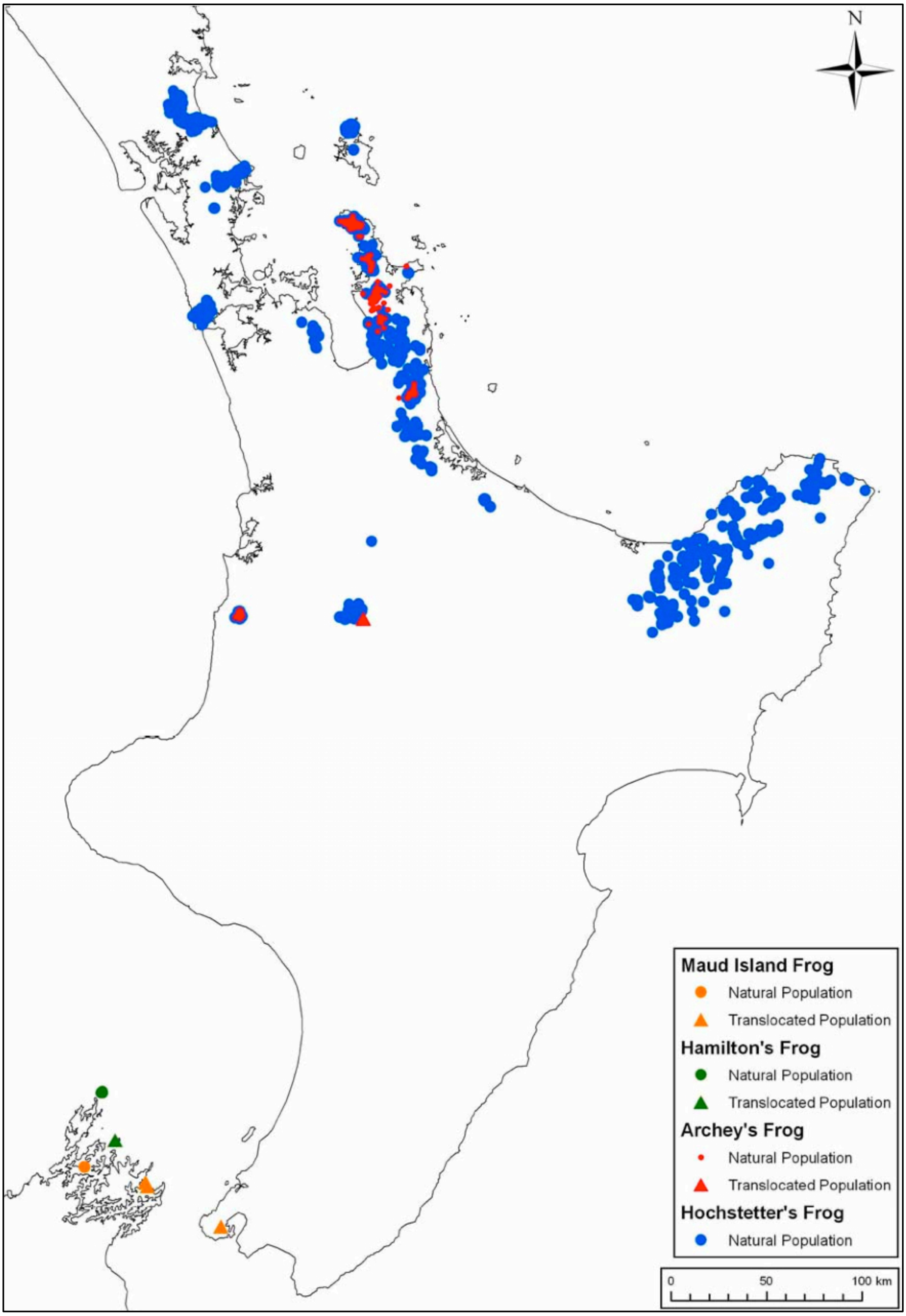

Figure 1.2. Map of the North Island of New Zealand and Cook Strait showing the distribution of all extant *Leiopelma* species (*Source*: Bishop, Haigh, Marshall, & Tocher (2009), Department of Conservation, New Zealand)

Table 1.1. Threat classification of New Zealand endemic frogs by The New Zealand Threat Classification System (Hitchmough et al., 2007) and The IUCN Red List of Threatened Species™ (IUCN, 2009).

Species	New Zealand Threat Classification System	IUCN Red List
L. archeyi	Nationally Critical	Critically Endangered
L. hochstetteri	Sparse (Qualifiers: Human Induced)	Vulnerable
L. hamiltoni	Nationally Critical (Qualifiers: Conservation Dependent, Stable, Human Induced, One Location)	Endangered
L. pakeka	Nationally Endangered (Qualifiers: Conservation Dependent, Human Induced, One Location, Recovering)	Vulnerable

Conservation

Native frogs have been legally protected for decades under the Wildlife Act. However since the mid '90s, the Native Frog Recovery Group within the Department of Conservation has coordinated the research, conservation, and management for these species. Part of their work involved creating the first Native Frog Recovery Plan, which recently finished its first term (1996-2006) and yielded positive results. This will shortly be replaced by a second version for the 2009-2019 term. Some major efforts were undertaken during the first term of the Native Frog Recovery Plan to protect habitat, eradicate pests and restore frog ecosystems, involving intensive pest management, captive breeding, translocations and reintroductions among others (BishopHaigh et al., 2009).

1.1.5 Hochstetter's frog

Distribution

Leiopelma hochstetteri (Plate 1) is the most widespread among New Zealand native frogs, however its populations are mostly small and fragmented (Green and Tessier, 1990). They are known to occur disjunctly in at least ten forested areas throughout the northern half of the North Island and on Great Barrier Island (see Figure 1.2). Individuals have been reported at all altitudes from near sea level to more than 800m above sea level, though they are known to be more abundant at higher elevations (Stephenson and Stephenson, 1957).

Species identity

A clear separation exists between *L. hochstetteri* and the other living native frogs both at a genetic level as well as in their biology, ecology and behaviour (Green et al., 1989, Bell, 1985, Bell, 1978). Evidence shows there is also elevated cytogenetic variation within and between Hochstetter's frog populations (Green, 1988) suggesting each of them should be treated as separate Conservation Management Units (CMUs) (Green, Zeyl et al. 1993; Green 1994; Gemmell, Bowsher et al. 2003).

Ecology

Hochstetter's frog are the most aquatic of native frogs, and prefer shaded streambeds or seepages under mature native forest canopy, but they tolerate to some extent modified habitats such as farmland and exotic forest (BellTocher et al., 2004, Stephenson and Stephenson, 1957). They hunt and eat invertebrates during the night, and shelter in wet cavities and crevices beneath rocks, logs, or leaf packs during the day (Bell, 1978). They appear to be more abundant in high gradient, minor, first order tributaries (Newman and Towns, 1985), where water flows slowly, and erosion and the risk of flooding is lower. Hochstetter's frog are absent from heavily silted streams, or streams without cover (Green and Tessier, 1990). Some evidence suggests Hochstetter's frog have sedentary habits and usually don't move great distances, at least not on a daily basis (Green and Tessier 1990; Tessier, Slaven et al. 1991). Nonetheless, other studies suggest they are able to move widely within and between streams, particularly under wet conditions (Slaven, 1992, Whitaker and Alspach, 1999). Further studies on movement and dispersal are pending while new methods for individual marking are developed.

Reproduction

Hochstetter's frog is the only native species in New Zealand to exhibit some sexual dimorphism. Males usually have more muscular, robust forelimbs than females, which facilitate amplexus in wet conditions (Bell, 1978). The female lays a small clutch of large, yolky, and unpigmented eggs under stones, logs, or vegetation alongside creeks (Turbott, 1949). Eggs hatch after approximately six weeks, and the larvae completes development as a 9-10 mm froglet (see Figure 1.3) at least one month after hatching (Bell, 1978). The larvae are mobile and can swim, but do not feed (Bell, 1985). The growth of the juvenile frog is relatively slow as it takes about 3-4 years to reach maturity. They are considered to have an extended breeding season, from at least August to February (Bell, 1978). It is unknown how frequently they reproduce.

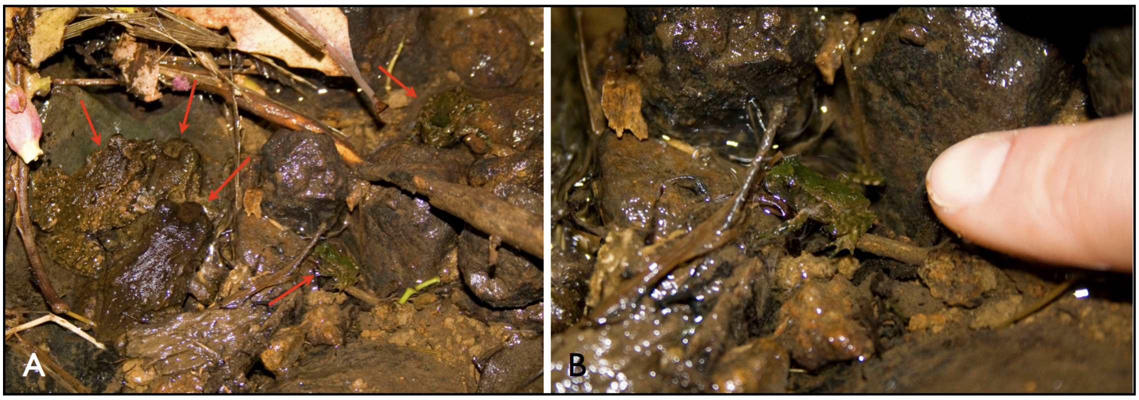

Figure 1.3. Hochstetter's frogs in different life stages. (A) Five frogs hiding together; three adults overlapping (left), one subadult (top right) and a juvenile (middle). (B) Detail of the juvenile on (A). Note the green colouration of the younger frogs (*Photos*: Claudio Aguayo).

1.1.6 Conservation of Hochstetter's frog

Threats

L. hochstetteri is a threatened species. It is categorised as Sparse (Human Induced) by the New Zealand Threat Classification systems list (2005) (Hitchmough et al., 2007), and as Vulnerable by the IUCN Red List 2008 (BellTocher et al., 2004). As with other amphibians worldwide, the main threats faced by *L. hochstetteri* are human induced. Habitat loss and degradation has had a major impact on this species in the past, and it remains an ongoing threat occurring either *directly* through human activities such as the conversion of native habitat to pine plantations, quarrying, road works, and mining, or *indirectly* through the damage caused by exotic animals such as feral goats and pigs, which cause accelerated erosion leading to the silting up of streams (Newman, 1996, Newman and Towns, 1985). The long-term impact of introduced predators on *L. hochstetteri* is uncertain, however this species co-exists with rats (*Rattus rattus*) and stoats (*Mustela erminea*) throughout its range (Newman, 1996). Introduced amphibians (*Litoria sp*) may also be a threat as they are known to prey on *Leiopelma* frogs (Thurley and Bell, 1994). More recently, chytridiomycosis has been identified as a major threat as it has been introduced to New Zealand and identified in the related and sympatrically-occurring *L. archeyi* (Shaw et al., 2009), for details see Chapter 4. To date, the chytrid fungus hasn't been detected on Hochstetter's frog however not all populations have been comprehensively tested (Shaw et al., 2009).

Past and Current Management

The New Zealand Department of Conservation (DOC), through its Native Frog Recovery Group and Native Frog Recovery Plan (NFRP) administers conservation management of Hochstetter's frog. Conservation of this species has occurred mostly through habitat protection, restoration, scientific research, and statutory advocacy (BishopHaigh et al., 2009). Although the impact of introduced predators is unknown, some studies have found positive effects of pest control (targeting other species) on *L. hochstetteri* populations (Baber et al., 2007, Crossland et al. unpublished). The NFRP (Newman, 1996) recognised the need for at least one long-term, self-sustained captive population of the species. For this purpose, a captive population was established at Hamilton Zoo, which is considered secure from chytrid fungus threat, though they are yet to bred successfully there (Goddard, 2008).

Conservation of this species is moving from a stage of *securing* to a stage of *recovering*, although much information and thus research is needed to completely move from one to another (BishopHaigh et al., 2009). For example, one of the basic pieces of knowledge managers must have to make good decisions is an accurate estimation of abundance and trends of a population, as well as the factors that affects these populations through time (e.g., agents of decline) (Yoccoz et al., 2001). Unfortunately, and for diverse reasons, population trends and abundance are often unknown.

One of the research priorities identified in the NFRP (Newman, 1996) was the need for robust, un-invasive, monitoring techniques to be able to assess populations, and detect any trends in frog numbers through time. Because Hochstetter's frogs are small, cryptic and silent, they are relatively hard to find. Imperfect detection makes the commonly used count indices (e.g., frogs/100m) poor estimates of abundance thus the measure is regarded as not suitable for monitoring changes in time (Crossland et al., 2005). More recently, site occupancy models of MacKenzie et al. (2002) have been recommended by DOC for monitoring this species, but very few long term occupancy studies have been established to date. The factors that influence occupancy and detection probabilities, and the relationships between these factors and abundance are still unknown.

1.2 Thesis Aims and structure

The overall aim of this thesis was to make a significant contribution to the conservation of the threatened endemic amphibian *L. hochstetteri* through research. To achieve this, two important conservation issues were investigated: the need for robust monitoring techniques, and the prevalence of chytridiomycosis on this species. Two Hochstetter's frog populations from the Auckland Region were studied, one on the mainland (Waitakere Ranges) and the only offshore island population on Great Barrier Island (see Figure 1.4). The Great Barrier Island population is cytogenetically distinct from all other *L. hochstetteri* populations suggesting it should be treated as an evolutionarily distinct unit (Green, 1994), in addition, little is known about it. In contrast, the Waitakere Ranges population has been studied before (Bradfield, 2005, Ziegler, 1999), which allows for some comparison of the results obtained in this study with previous data. Each of the following chapters of this thesis is written in a stand-alone format, each one having its own objectives.

Chapter 2: *Occupancy and relative abundance of <u>Leiopelma hochstetteri</u> in the Waitakere Ranges, Auckland Region, New Zealand* focuses on the problem of obtaining robust estimations of occupancy and abundance by comparing the outcomes from different monitoring techniques, and its based on the Waitakere Ranges population.

Chapter 3: *A survey for Hochstetter's frog on Great Barrier Island* focuses on the results of two population surveys conducted on Great Barrier Island with the objectives of finding new locations as well as updating distribution and relative abundance information. A pilot occupancy study was also done to be able to make recommendations on the future establishment of long term monitoring programmes at this location. Chapter 4: *Chytridiomycosis prevalence in the Waitakere Ranges and on Great Barrier Island* contains the results obtained from chytridiomycosis surveys on both populations. Finally, in Chapter 5: *General Conclusion* the thesis is discussed as a whole, while relevant conclusions are reviewed in a wider context.

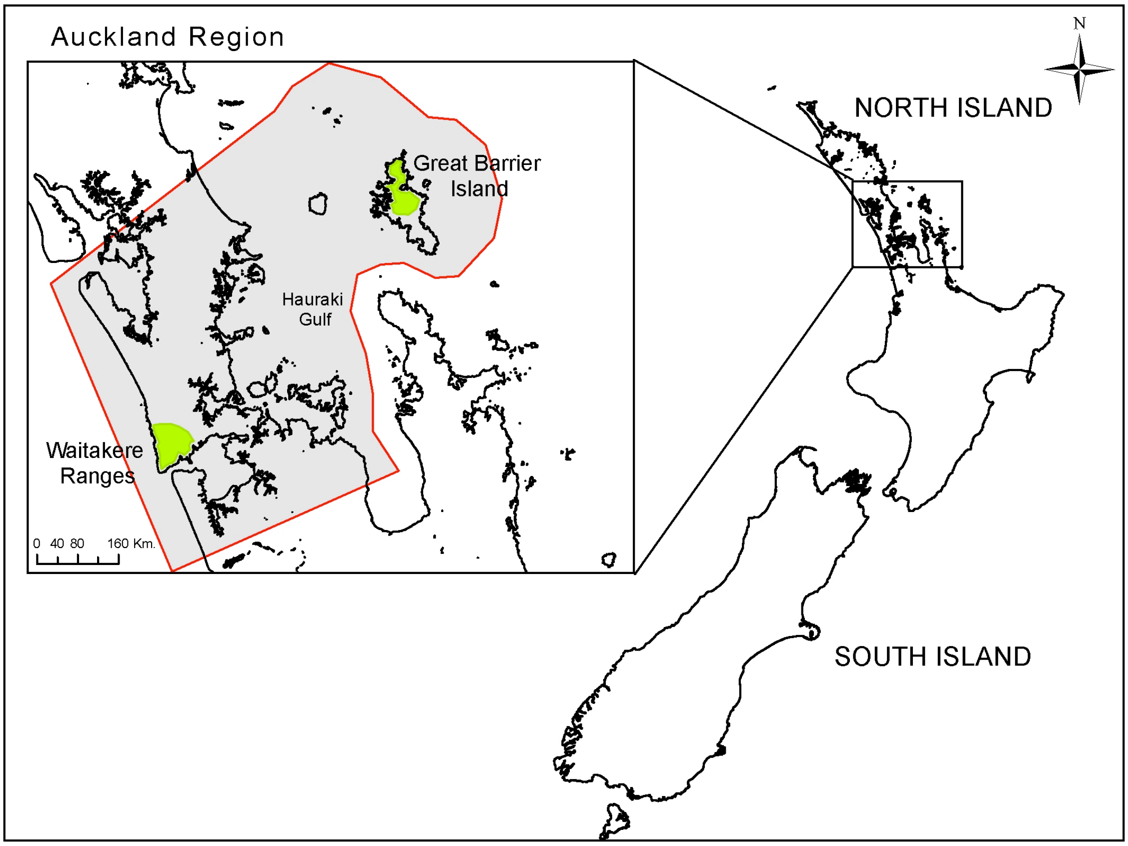

Figure 1.4. Map of New Zealand showing the Auckland Region in detail (left), and the locations of the two Hochstetter's frog populations studied (in green).

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CHAPTER 2

Occupancy and relative abundance of *Leiopelma hochstetteri* in the Waitakere Ranges, Auckland Region, New Zealand

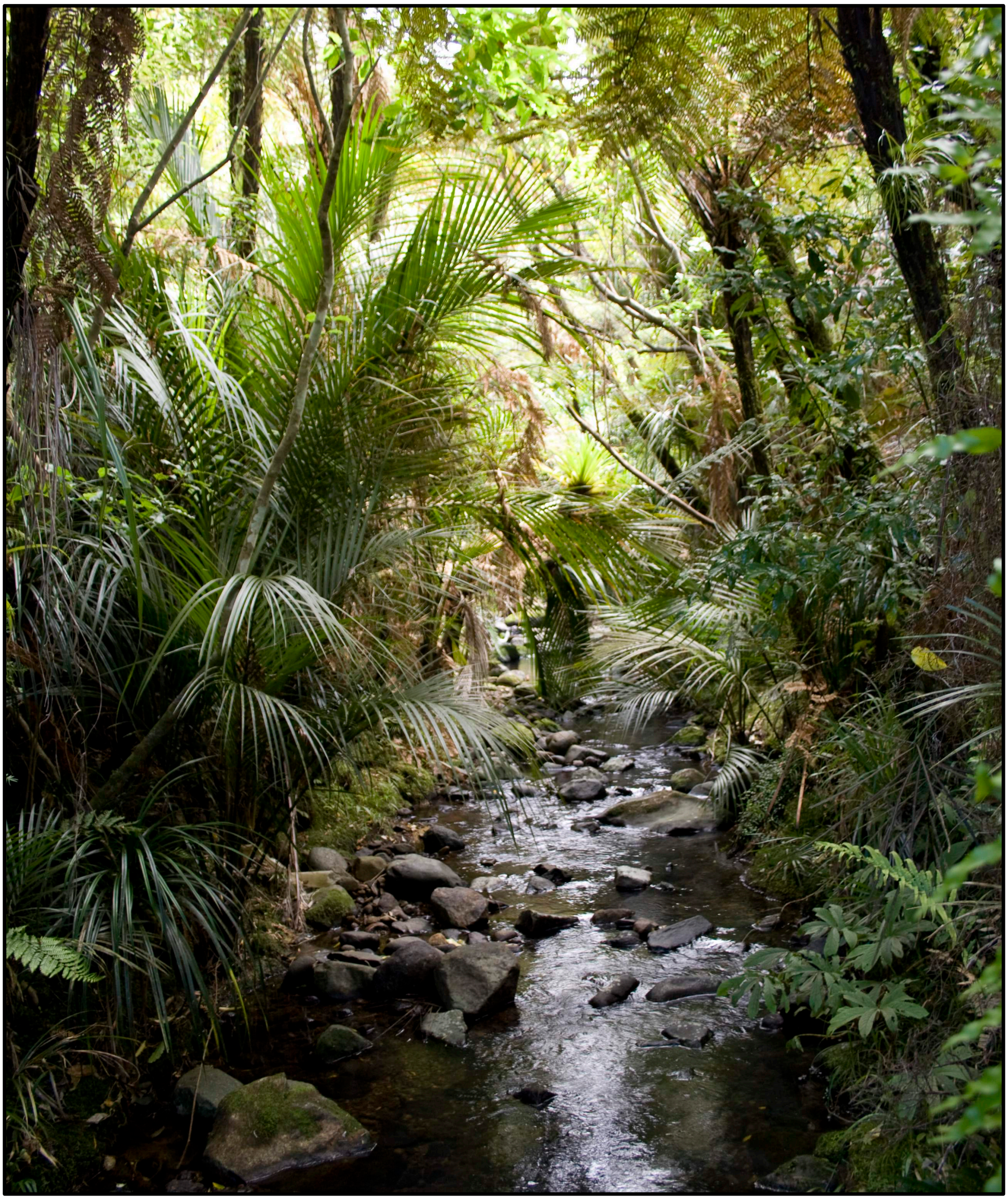

Plate 2. Typical Hochstetter's frog habitat (*Photo*: Claudio Aguayo)

2.1 Abstract

Given the worldwide declines in amphibian populations, it is of fundamental importance to monitor population trends, and factors influencing population trends, including key threats and initiatives aimed at population recovery. Unfortunately, reliable estimations of amphibian population abundances and trends have proven difficult to obtain. Recently, the use of site occupancy modelling (MacKenzie et al. 2002) has shown promise as a method for monitoring Hochstetter's frog (*Leiopelma hochstetteri*) populations (Crossland et al., 2005). In this study I apply site occupancy models to obtain reliable site-specific estimations of *occupancy* and *detection probability* using covariate information and presence absence data collected from 50 sites in the Waitakere Ranges on four repeated visits during 2008. Elevation and distance searched were found to have an important effect on occupancy levels, while search time was important in determining detection probabilities. Parameters were estimated for each age class separately and juveniles were found to have the lowest detection probabilities and occupancy, followed by sub-adults and finally adults. Based on the fundamental relationship that exists between occupancy and abundance, statistical models were used to infer abundance from occupancy and repeated transect counts data. Royle & Nichols' (2003) and Royle's (2004) abundance models were applied to these data and these results were compared with the distribution of relative abundances obtained from repeated transect counts and an established sight/re-sight criterion. The use of surrogate measures for relative abundance was explored, and distance to first frog found and detection probabilities were correlated significantly with relative abundance. In conclusion, these surrogate measures can be used to infer relative abundance during future site occupancy surveys in the Waitakere Ranges.

2.2 Introduction

One of the fundamental roles of Conservation Biology is to protect and preserve biodiversity (Groom et al., 2006). To meet this aim, it is necessary to have (1) a basic knowledge (*baseline*), of the species, habitat and/or ecosystem of concern and (2) to understand the *changes* or *trends* to these conservation units over time (Pullin, 2002, Yoccoz et al., 2001). Monitoring abundance and distribution of species has a long history in ecology, and many techniques have been developed for specific purposes (Hill et al., 2005). In particular, a diversity of methods exists to survey and monitor amphibian distribution and abundance. Among the most commonly used are Visual Encounter Surveys (VES), Audio Strip Transects, quadrant, and transect sampling (Heyer et al., 1994). In general, the appropriate technique to use will depend largely on the objectives of the study, aspects of the ecology of the target species such as life history and habitat, and the resources available.

2.2.1 Monitoring native frogs

The cryptic and silent nature of the *Leiopelma* species, as well as the rugged nature of their habitat, have constrained and delimited the kind of techniques suitable for surveying and monitoring New Zealand native frog species. “Some studies have used predefined transects or grids for intensive search and long term population studies, while other more casual surveys involved simple local area searches” (Bell, 1996). Only limited mark-recapture population studies (which requires individual ID) have been done (Tessier et al., 1991), due to the lack of a suitable marking method. The previously common toe-clipping method was stopped as it was considered potentially harmful and non productive due to very low recapture rates (Whitaker and Alspach, 1999). Natural markings are currently being investigated as a potential individual ID technique for *Leiopelma* species, and has proven useful for some cases (*L. archeyi*), but its suitability for monitoring Hochstetter’s frog populations is yet unknown (Bradfield, 2004).

The relatively linear distribution of *L. hochstetteri* along streams has meant that the most suitable and commonly used methods for assessing their abundance are the standard-length transect counts (Bell, 1996). Hochstetter’s frog abundances have been expressed as indices such as number of frogs per area and/or number of frogs per hour of search, which are often referred as *relative abundance* and *encounter rate* respectively. Among these, the most robust measure of frog density is the number of frogs per distance (frogs/100m), as encounter rates (frogs/hour) can vary greatly due to observer and/or type of habitat (Green and Tessier, 1990).

Indices

It is widely recognised that Hochstetter's frog index counts are influenced by many factors (McLennan 1985; Whitaker and Alspach 1999; Baber, Babbit et al. 2007). The absolute abundance will probably be reflected in the survey counts to some degree, however environmental variables (e.g.: habitat type, weather conditions), observer variables (e.g., experience), and the species characteristics and habits (e.g., cryptic species, nocturnal) might also affect the probability of detecting the species, and therefore the number of individuals found at any given survey (Anderson, 2001). Relative abundance therefore becomes a "product of the actual numbers of individuals present in the study area and the likelihood of detecting those individuals (i.e., detection probability)" (Crossland et al., 2005, Yoccoz et al., 2001). Index counts assume detection probability to be constant through space, time, observer and other factors, which is a difficult assumption to meet. Therefore, any inference based on index values cannot be expected to yield reliable information *sensu* Romesburg (1981) (Anderson, 2001, Anderson, 2003).

Due to the issues described above in monitoring Hochstetter's and other native frogs, the Native Frog Recovery Group recognised the need for establishing statistically robust methods as one of the Native Frog Recovery Plan priorities (Newman, 1996). In 2005, the Department of Conservation (Crossland et al., 2005) recommended that *L. hochstetteri* populations be monitored using the site occupancy models of MacKenzie et al. (2002), which explicitly accounts for variability in detection.

2.2.2 Site occupancy modelling

Site occupancy models developed by MacKenzie et al. (2002) were designed to estimate *occupancy* (ψ) rates and *detection probability* (p) of a species based on repeated presence-absence data using multinomial maximum likelihood procedures. Occupancy is the proportion of area occupied by a species, which gives an estimation of range and distribution. However, there is a strong relationship between occupancy and abundance, thus occupancy is often viewed as a surrogate measure of abundance (Gaston et al., 2000, MacKenzie et al., 2006, MacKenzie et al., 2005). Site occupancy models have been used in monitoring a wide range of animal species including birds, mammals and amphibians, and can be particularly useful for long-term, large-scale monitoring programs and investigations of meta-population dynamics (MacKenzie et al., 2006, Olson et al., 2005, Bailey et al., 2004, O'Connell Jr. et al., 2006). Occupancy is regarded as an important state variable that provides useful conservation and theoretical insights about ecosystem processes (MacKenzie et al., 2005).

One of the concerns with presence-absence (occupancy) surveys is that when a species is detected imperfectly it is unknown if an *absent* site is in fact *unoccupied* by the species, or if the species was just not detected. Thus, occupancy estimation can be biased and prone to underestimation (Gu and Swihart, 2004). Hence, if reliable inferences are to be made using these models, then detection probability must be incorporated into the occupancy estimation. Thus, estimation of detection probability is a necessary component for making accurate inferences about species occurrence (MacKenzie et al., 2006, MacKenzie et al., 2002).

Site occupancy models provide a flexible framework by enabling the inclusion of site-specific and survey-specific covariates. Site-specific covariates are parameters that remain constant in time but can vary among sites, and these can be incorporated in modelling ψ and p. Survey-specific covariates are parameters that can vary between surveys and are incorporated when modelling survey-specific detection probabilities. Covariate data collected in the field (e.g.: environmental conditions, site characteristics) can be modelled, and the relative importance of different factors on the occupancy rates and detection probabilities can be assessed. These models assume there is no un-modelled heterogeneity among sites, therefore it is important to consider the ecology of the focal species and include as covariates those ecological and behavioural factors that are likely to affect occupancy and detection probability.

2.2.3 Abundance models

One limitation of occupancy models is that they cannot estimate absolute abundance (Royle and Nichols, 2003). Abundance of a species in an area is of central importance in wildlife management and conservation (Hill et al., 2005, He and Gaston, 2003). The uncertainties related to relative abundance estimation using raw counts have lead to the development of many statistically robust methods such as mark-recapture population studies, and the use of alternative parameters (e.g., occupancy) as surrogate measures. Indeed, based on the fundamental relationship between occupancy and abundance it is possible to infer abundance using occupancy data (He and Gaston, 2000, Gaston et al., 2000). Moreover, it is recognised that the probability of finding an animal depends on how many animals are available for detection (local abundance: N_i) (Royle and Nichols, 2003, Royle, 2004). Based on this, Royle & Nichols (2003) used abundance-induced heterogeneity in detection probabilities to infer distribution of abundances across sites. They developed models that are extensions of the site occupancy models of MacKenzie et al. (2002) (which assumes that the species abundance is constant across sites), which can be used to infer local and overall abundance from repeated presence-absence data. In addition, Royle (2004) describes an alternative approach, *N*-mixture models, that might be used to infer abundance when repeated counts are available. *N*-mixture models can estimate population size from spatially replicated counts. Both models (Royle & Nichols (2003) and Royle (2004)) explicitly account for imperfect detection, and they also allow for the incorporation of covariate data and therefore represent good candidates for inferring abundance distribution and population size based on statistically robust methods.

2.3 Objectives

The general aim of this chapter is to assess different monitoring techniques and make recommendations on how to obtain reliable estimations of population parameters for *L. hochstetteri*. These estimates can then be used as baseline estimations to detect changes in the population through time or in response to ongoing and future management actions. To achieve this aim, the following specific objectives were established;

1) Estimate **occupancy** and **detection probability** of Hochstetter's frog in the Waitakere Ranges, and compare these parameters for different age classes (juveniles, subadult, adult).

2) Examine the relative influence of site and survey specific **covariates** on the distribution of occupancy rates and detection probabilities.

3) Assess three different methods for estimating **abundance** patterns; transect counts, surrogate measures, abundance models.

4) **Compare** previously used techniques (index counts) with site occupancy modelling in terms of cost, results, and reliability.

5) Compare the current results with previous data collected from the Waitakere Ranges Hochstetter's frog population.

2.4 Methods

To be able to achieve the objectives of this study, transect counts and site occupancy surveys were conducted simultaneously. The general design of the study included the establishment of 50 randomly chosen *sites* (defined transects along streams). Each site was surveyed using a VES technique, counting all frogs within the site to get relative abundance estimates. This was repeated four times to account for imperfect detection and to get robust estimations of the proportion of sites occupied and site specific occupancy rates.

2.4.1 Study Area: The Waitakere Ranges

The Waitakere Ranges are located West of Auckland, between Muriwai Beach in the North and the Manukau Harbour entrance in the South, in the Auckland Region of New Zealand. This rugged and steep area is relatively low in altitude, with most peaks reaching 300-400m (McLure, 2008). This region was entirely covered by forest when Maori people initially inhabited it 700-800 years ago (Harvey and Harvey, 2006). It remained almost unchanged until the arrival of Europeans in the 1830s, when extensive milling of Kauri (*Agathis australis*), Kahikatea (*Dacrycarpus dacrydioides*), and Rimu (*Dacrydium cupressinum*), among other native species, led to the most visible changes in the area (ARC, 2009). Since 1900, the Auckland City Council began purchasing much of this land as a water supply catchment and because of its scenic qualities. In 1940, the 6,400 hectares Auckland Centennial Memorial Park was established to mark 100 years since the city's founding. This park was later enlarged through the gifts of land by donors to become the Waitakere Ranges Regional Park (1966).

The Waitakere Ranges Regional Park is now administered by Auckland Regional Council [ARC] and includes nearly 17,000ha of native rainforest (ARC, 2009). This land is now fully protected and contains several native species of animals and plants, including the native frog *L. hochstetteri*, as well as introduced pests such as possums, stoats and rats (Harvey and Harvey, 2006). Its vegetation includes some remnants of un-milled forests, but it mostly consists of secondary forest at varying stages of regeneration (Esler, 2006). Restoration projects such as Ark in the Park endeavour to recover the Waitakere Ranges biodiversity; efforts included are intensive pest control management and reintroduction of threatened species (Bellingham et al., 2008). In 2008, the Waitakere Ranges Heritage Area Act was passed, which purposes are to "recognise the national, regional, and local significance of the Waitakere Ranges heritage area and promote the protection and enhancement of its heritage features for present and future generations" (New Zealand Government, 2008).

2.4.2 Site selection

A total of 50 sites were included in this study. A site was defined as a 40m long transect, based on Crossland et al. (2005) and Bradfield's (2005) research. The site area extended 1m each side of the stream edge, and up to 60cm above the water level. The locations and individual ID numbers of the sites are shown in Figure 2.1 and Appendix II, while the descriptions of the sites are available in Appendix III. To use available data on past distribution and relative abundance of *L. hochstetteri* in the Waitakere Ranges, 36 sites surveyed previously by Bradfield (2005) for the ARC were included in the present study. Two previously established sites were visited, but not included; "Opanuku 2" was not surveyed because of difficult access and flooding upon visit, and was replaced by a section of stream in the same catchment about 100m away; "Piha 4" was dry due to a landslide that caused subterranean water flow and was replaced by an adjacent section of stream. These sites retained the original name given by Bradfield (2005), but were considered as new sites as no previous data were available. One site ("Anawhata 4") was not included as it had been recently and frequently surveyed by Peter King (La Trobe Mainland Island restoration project) as part of research on the effects of predator control on *L. hochstetteri* populations.

New sites were selected using a random stratified procedure. Each quadrant of the topographic map (i.e., $1km^2$) within the Waitakere Ranges Regional Park was given a number (from 1 to 173). Quadrants that already contained a site were excluded. A random number was generated within the available quadrants. A site was only selected if the randomly selected quadrant contained an order 1 to 3 stream, and if these streams were accessible through an existing track. To insure a wide distribution of the sites, the study area was divided into 5 sub-areas of similar size, and no more than 10 sites could be randomly selected from any one sub-area. The process continued until 15 potential sites were selected each of which were visited to check that they had the minimum requirements for frogs (shaded, not heavily silted, moist (Green and Tessier, 1990)). A total of 12 new sites were surveyed and included in this study, with no prior knowledge of the presence or absence of frogs at each.

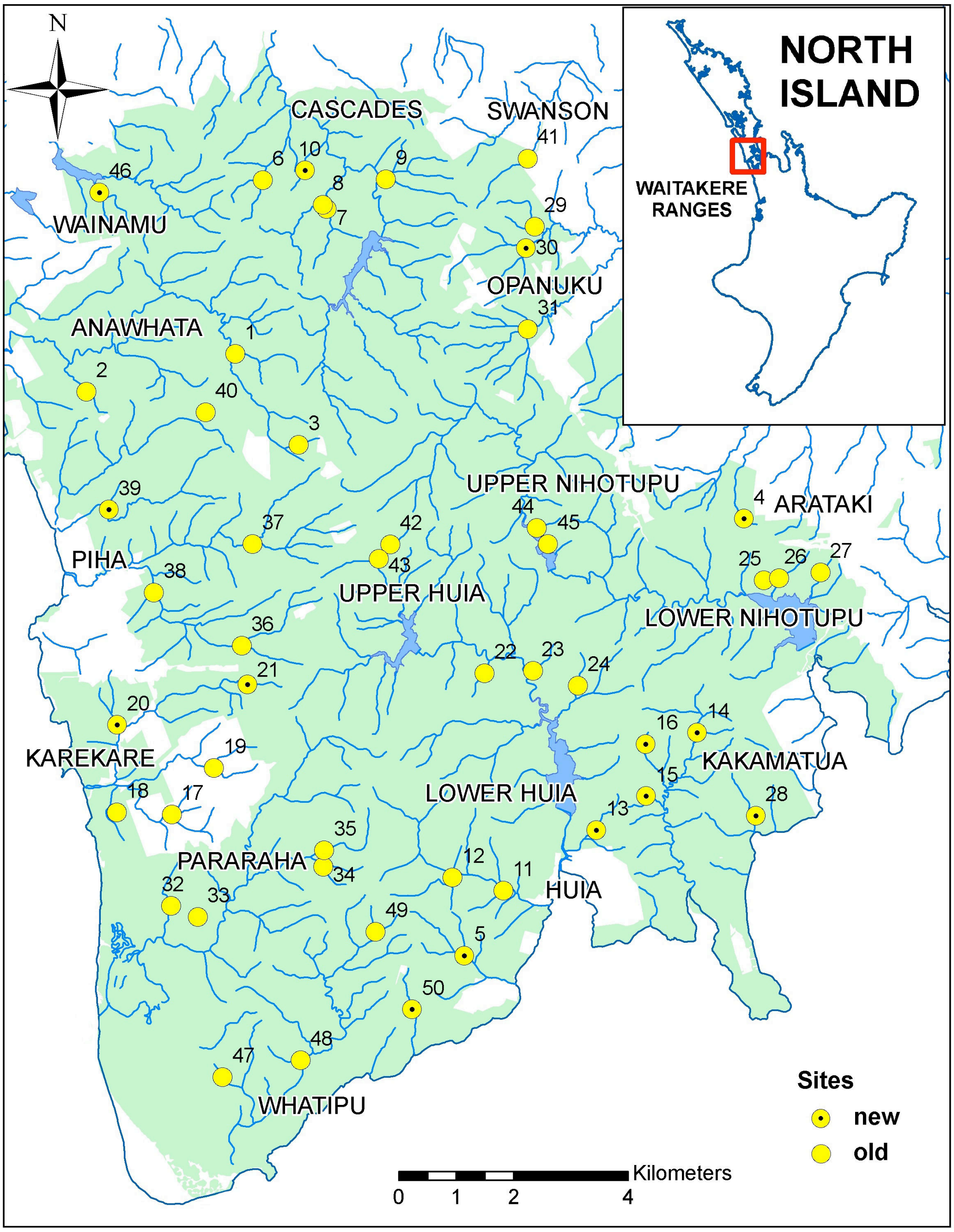

Figure 2.1. Map of the Waitakere Ranges area showing the locations of all study sites (numbered from 1 to 50). The green shaded area represents regional parkland administered by Auckland Regional Council.

2.4.3 Field methods

Surveys

All sites were surveyed between May and December 2008. All surveys were conducted during daytime, either in the morning or afternoon. A 40m measuring tape was laid on the streambed, and temporary markers (flagging tape) were used at 10m intervals. These marks were removed at the last visit. The location (New Zealand Map Grid, NZMG) of the 0m mark was measured using a GPS receiver (Garmin™ etrex Vista HCx). Each site was surveyed by slowly moving upstream from the start point (0m mark), carefully examining all suitable frog refugia (rocks, logs and leaves, inside crevices and tunnels). In some cases the sites included sections of unsuitable or impossible to search habitat (e.g., fallen trees across stream, track crossing). In such cases, the length of the un-searched section of the site, and the reasons why it was not searched were noted. The total distance searched was calculated by subtracting the unsearched length from 40m.

Following Bell's (1996) recommendations, while searching any objects removed were carefully replaced in their original position to minimise habitat disturbance, but if replacing an object posed a risk to the frog, the frog was nudged aside using a blunt object, and after replacement of the rock it was nudged back to the shelter. The number of refugia searched was counted using a hand counter. Head-lamps (white LED light, Petzl™ MYO XP) were used to maximise the chance of spotting the frogs, as most refugia are dark and difficult to search. Both sides of the stream were searched, and the searching pattern was from the water's edge to up to 1 m from the stream bank but no further than 60cm above the water level.

Frog measurements

The snout-vent length (SVL) of every frog found was measured using a plastic ruler (without handling) to the nearest mm. In cases where the frog was in a difficult position to be measured, or if the frog jumped away, only age-class classification was possible. There are at least three different classifications into age-classes used previously in the literature. Here, in order to make the results comparable, the three of them were used (see Table 2.1 below). The location (distance from the start of the transect to the nearest 10 cm, the side of the stream and the refugia type), and time of day were recorded for each frog found. In addition, other observations (e.g. distinctive colour, distance from water, if frog jumped) were made (see data sheet, Appendix I).

Table 2.1. Three different age-class classifications used for Hochstetter's frog based on snout-vent measurements (SVL) in mm.

	Juvenile	Sub-adult	Adult	Adult female
Whitaker & Alspach (1999)	<18	18-24	25-39	>39
Bell (1978)	<18	18-29	30-39	>39
Slaven (1992)	<20	20-35	36-38	>38

Repeated surveys

Each site was surveyed four times (Crossland et al., 2005). When severe weather conditions such as heavy rain in the previous 24h impeded the completion of all four visits, the remaining surveys were considered missing observations. In one case, the habitat at the site was considered too fragile and easily disturbed (e.g., loose rocks), and only one survey was conducted to avoid further damage. Each site was visited on two separate occasions within the course of a week; typically 3-4 days apart. This timeframe allowed the site to be considered a closed population (no immigration/emigration) as *L. hochstetteri* are known to have very low daily movements (Green and Tessier 1990; Tessier, Slaven et al. 1991). During each visit, two surveys were made, each by a different observer. To make surveys independent, the second observer did not observe the searching by the first observer. The second searcher began searching once the first searcher was past the 20m mark, and at least 20min later, to allow for disturbed frogs to return to their shelters (Green and Tessier 1990; Tessier, Slaven et al. 1991). The same two observers carried out all surveys and both had the same levels of experience.

For each survey, a data sheet (Appendix I) was completed which contained a description of the site, date of survey, and environmental conditions. The air temperature and relative humidity were measured at the beginning and end of each survey and the average from these two observations was used in the analysis. The stream width was measured at 0m, 20m, and 40m and the average was used in analysis. Canopy cover was estimated and expressed as percentage of sky covered by vegetation (scale used: 0-24, 25-49, 50-74, 75-100). The total number of refugia searched was noted as well as the start and finish time.

To avoid the potential risk of introducing or spreading diseases between study sites (e.g., amphibian chytrid fungus, *Phytophthora* taxon Agathis or PTA, associated with Kauri dieback), all footwear and field equipment was cleared of mud and disinfected with Tri-gene™ at the beginning of each field day and when moving between catchments.

2.4.4 Data Analysis

Re-sighting criteria

Frogs were considered re-sighted if their size (SVL) and position matched an earlier sighting. In some cases, where observations of distinctive colouration, particular shelter, or distance from water were available, these were used too. To account for variability in measurements, SVL values within ± 5mm were considered potential re-sightings. *L. hochstetteri* is known to be sedentary over short periods of time and when climatic conditions are relatively constant (Tessier et al., 1991). However, they are known to move away from streams during flooding periods and heavy rain, and usually gather along streams in dry periods (McLennan, 1985). Hence, position along transect alone was not considered a distinctive enough criteria for determining re-sighting. As there was typically a delay of only 30 minutes between first/second and third/fourth surveys, and three to four days between visits, it was unlikely that frogs travelled a long distance during this period, except in the cases where frogs jumped when found. In cases where it was not clear if a frog was re-sighted, a conservative approach was used, and such cases were classified as possible re-sights (i.e., abundance was more likely to be underestimated).

Relative abundance

The relative abundance for each site was calculated using the estimated (sight/re-sight) number of frogs at a site and the total distance searched (usually 40m), and then transformed to frogs/100m. Relative abundance was also expressed as the minimum number alive [MNA]; the highest frogs count during the sampling period at each site.

2.4.5 Statistical methods

The data collected were analysed using the software PRESENCE 2.3 (Hines, 2006) http://www.mbr-pwrc.usgs.gov/software/presence.html). For site occupancy analysis the sampling period (May-December, 2008) was considered a single season. Mean abundances are reported with standard errors (±SE) unless otherwise stated.

Estimation of occupancy and detection probability parameters

The observations were transformed into presence = 1 and absence = 0 data. Occupancy probability (ψ: probability that a species is present at a randomly selected site) and detection probability (p: probability that a species will be detected at site, given it is present) were estimated using MacKenzie et al. (2002) models based on presence-absence. In the case where ψ and p were assumed constant across sites (i.e., constant model, denoted $\psi(.)p(.)$), the combined model likelihood is described by Equation 1 where T is the total number of sampling occasions, t is the sampling occasion or time, n_t is the number of sites where the species was detected at time t, and $n.$ is the number of sites where the species was detected at least once.

Equation 1

$$L(\Psi,p) = \left[\Psi^{n.}\prod_{t=1}^{T} p_t^{n_t}\left(1-p_t\right)^{n.-n_t}\right] \times \left[\Psi\prod_{t=1}^{T}\left(1-p_t\right)+\left(1-\Psi\right)\right]^{N-n}$$

The assumptions of this model are: (1) the system is demographically closed to changes in the occupancy status of site during the sampling period (at the species level, this means that a species cannot colonise/immigrate to a site, or go locally extinct/emigrate from that site during the course of the study); (2) species are not falsely detected; (3) detection at a site is independent of detection at other sites; (4) there is no un-modelled heterogeneity (MacKenzie et al., 2002).

Covariates

Covariate data (X) were incorporated into the parameter of interest θ (ψ and/or *p*) using a logistic model as shown in Equation 2, where B is the vector of model parameters (i.e., containing the beta's). The beta that maximised the likelihood function were found using (Equation 1), and then transformed into derived parameters (ψ, *p*) using the logit link function. The effect of covariates was modelled as a logit function of *site-specific* and/or *survey-specific* covariates.

The potential effect of three measured site-specific covariates (elevation, *E*; distance searched, *DS*; stream width, *SW*) on occupancy rates was assessed. The potential effect of nine survey-specific covariates on detection probabilities was also assessed. These included four environmental variables (temperature, *T*; relative humidity, *H*; rain in the previous 24 hours, *Rp*; rain during survey, *Rd*), the effect of the observer (*O*), time of the day (*t*), day of the year (*D*), and two parameters for search effort (search time, *St*; and number of refugia searched, *R*). All covariates (except the effect of the observer and rain) were normalised and treated as continuous variables, while the effects of the observer and rain were treated as categorical variables. The code used to incorporate observer data defined Observer 1 = 0 and Observer 2 = 1. The rain was categorised as; none = 0, showers =1, continuous rain (light) = 2, continuous rain (moderate) = 3, continuous rain (heavy) = 4. The constant model "ψ(.)*p*(.)" was also added for comparison.

Equation 2

$$\theta = \frac{\exp(XB)}{1 + \exp(XB)}$$

Models

Only linear and additive models were considered in the analysis. First, occupancy was held constant "ψ(.)" and the detection probabilities were allowed to vary with sampling occasion "p(time)" and the nine survey-specific covariates. Because the number of survey-specific covariates is relatively high, there are a large number ($>2^{10}= 1024$) of possible models. To simplify the analysis only single covariate effects were assessed: first p(Cov) as denoted by the equation: $\text{logit}(p) = \beta_0 + \beta_n(\text{Covariate}_n)$. After the most important covariate/s for p were detected, occupancy was added to the best model for p and was allowed to vary with each combination of the three site-specific covariates (eight models) described by the equation: $\text{logit}(\psi) = \alpha_0 + \alpha_1 (\text{elevation}) + \alpha_2 (\text{distance searched}) + \alpha_3 (\text{stream width})$. The constant model "$\psi(.)p(.)$" was also added for comparison.

Model selection

Models were ranked using Akaike's Information Criterion (AIC), which is based on parsimony: models that capture the main aspects of the data with a minimal number of parameters have lower AIC (are considered more parsimonious) and are ranked higher (Akaike, 1974). The difference between a model's AIC and the top ranked model's AIC was denoted as ΔAIC. Models with ΔAIC < 2 were considered to have substantial support, while models with ΔAIC 4-7 were considered to have considerably less, and models with ΔAIC >10 had essentially no support (Burnham and Anderson, 2002). Model weights (w_i) were also obtained, and these were summed for all models with a particular variable to get an indication of the relative importance of each variable to the parameter estimation. Correction for low effective sample size was done by using second-order criterion AIC_c instead of AIC (Burnham and Anderson, 2002). In cases where more than one model had substantial support, model averaging was used to estimate variables using Akaike's weight w_i as shown in Equation 3 where $\bar{\hat{\theta}}$ denotes a model averaged estimate of parameter θ, w_i is the Akaike's weight of model i, and R the total number of models (Burnham and Anderson, 2002). Standard errors for the averaged model estimates were calculated using Equation 4.

Equation 3

$$\bar{\hat{\theta}} = \sum_{i=1}^{R} w_i \hat{\theta}_i$$

Equation 4

$$SE(\hat{\theta}_A) = \sum_{l=1}^{m} w_l \sqrt{Var(\hat{\theta}_l | M_l) + (\hat{\theta}_l - \hat{\theta}_A)^2}$$

Goodness of fit

The best model selected using AIC values may not necessarily be a good fit model. The goodness-of-fit (GOF) of the models needed to be assessed to make accurate inferences. The method used for GOF testing follows MacKenzie & Bailey (2004) methods, where Pearson chi-square statistics are calculated and a parametric bootstrap procedure is used to determine if there is any evidence of lack of fit (MacKenzie and Bailey, 2004). The GOF test was performed using the most general model.

Abundance models

1) Royle & Nichols (2003): Estimating abundance from repeated presence-absence data or point counts

Royle & Nichols (2003) noted that the probability of detecting at least one individual of a target species at any site (p_i: site detection probability) is a function of the abundance of animals there (N_i), and the inherent detection probability of the species (r: binomial sampling probability that a particular individual is detected), as described by Eq. 5.

Equation 5

$$p_i(N_i, r_i) = 1 - (1 - r)^{N_i}$$

The key assumptions of the Royle-Nichols model are: (1) the number of animals at a particular site follows a Poisson probability distribution for which lambda (λ) indicates the mean abundance across all sites ($N_i \sim$ Poisson (λ)); (2) the probability of detecting animals at each site is related to the species' r and the site abundance, N_i. The two key parameters in the Royle-Nichols model are λ and r, which are obtained using maximum likelihood procedures (Eq. 6).

Equation 6

$$L(w) = \prod_{i=1}^{R}\left\{\sum_{k=0}^{K}\binom{T}{w_i} p_k^{\,wi}(1-p_k)^{T-w_i} f_k\right\}$$

where

$$p_k = 1-(1-r)^k$$

and

$$f_k = \frac{e^{-\lambda}\lambda^k}{k!}$$

This model computes the likelihood of w detections across the R sites, given T surveys. The formula works on separate sites, and computes the probability of observing w_i detections at the site given p_k, the probability of detection at that site. The potential site abundance, k, is then used to calculate p_k. Each level of k is included and the resulting probabilities are then combined according to f_k, the probability that a given $N_i = k$. In this model the estimated probability of occupancy is derived from λ (Royle and Nichols, 2003, Donovan and Alldredge, 2007).

2) Royle (2004): *N*-Mixture Models for Estimating Population Size from Spatially Replicated Counts

The Royle (2004) model is an extension of the Royle & Nichols (2003) model, and estimates abundance (λ) and detection probabilities (p) using spatially replicated counts (instead of repeated presence-absence data) and maximum likelihood procedures. Parameters were estimated using Equation 7. The assumptions of this models are: (1) the population is assumed to be demographically closed over the course of the T surveys; (2) the spatial distribution of the animals across the R survey sites follows the Poisson distribution; (3) the probability of detecting n animals at a site represents a binomial trial (Bernoulli trial) of how many animals are actually at that site.

Equation 7

$$L(p,\lambda \,|\, \{n_{it}\}) = \prod_{i=1}^{R} \left\{ \sum_{N_i = \max_t n_{it}}^{\infty} \left(\prod_{t=1}^{T} Bin(n_{it}; N_i, p) \right) f(N_i; \lambda) \right\}$$

Surrogate measures for relative abundance

To identify potential surrogate measures for relative abundance, the correlation between detection probability, time and distance to first frog found, and relative abundance at a site was measured using a Spearman's Rank Correlation test. Detection probability was obtained using MacKenzie et al. (2002) models with covariates. The data were pooled so the *first frog* considered for the analysis is the one that was closest to the 0m mark over the four visits. Consequently, the relative abundance considered was obtained from repeated visits, using the sight/re-sight criteria. A non-linear regression was done to fit a curve to the data.

Comparison of techniques

Simple transect counts were obtained using only data from the first visit to each site, which is analogous to Bradfield's (2005) survey. Repeated presence-absence results included only presence-absence data (from all visits), and corresponded to the results obtained using MacKenzie et al. (2002), and Royle & Nichols (2003) models.

2.5 Results

2.5.1 Site occupancy modelling, MacKenzie et al. (2002)

Constant model

When both occupancy and species detection probability were assumed to be constant across all sites and visits (i.e., model "$\psi(.)p(.)$"), the overall estimation of occupancy was $\hat{\psi}$ = 0.68 ± 0.07 and the estimated value of detection probability was $\hat{p}$ = 0.83 ± 0.03. Overall detection probabilities and occupancy for each age class using Whitaker & Alspach (1999) classification are shown in Table 2.2.

Table 2.2. Estimates with standard errors for separate age classes, using the constant model.

AGE CLASS	$\hat{p}$	$\hat{\psi}$
Juvenile	0.37 ± 0.08	0.35 ± 0.09
Subadult	0.47 ± 0.07	0.38 ± 0.08
Adult	0.77 + 0.04	0.67 ± 0.07

2.5.2 Covariates

Survey-specific covariates

The single most important variable influencing detection probabilities was search time, with 100% of the summed models weights (Table 2.3). The effect of site-specific covariates was also explored as factors that affect ψ can also affect p, though none were identified as important factors (analysis not shown). The combined effect of the last ranked variables with the top ranked one was explored, to see if the combined effect could improve the model performance, but none of them resulted in high ranked models (not shown).

Table 2.3. Summary of model selection procedure examining factors potentially affecting detection probabilities (temperature (*T*); relative humidity (*H*); rain in the previous 24 hours (*Rp*); rain during survey (*Rd*); observer (*O*); time of the day (*t*); day of the year (*D*); search time (*St*); number of refugia searched (*R*); survey occasion (*time*)) with a constant model for occupancy (i.e., ψ(.)); w_i: model weight; *k*: number of parameters.

Model	AIC_c	ΔAIC_c	w_i	Model Likelihood	*k*
p(*St*)	143.97	0	1	1	3
p(*R*)	168.54	24.57	0	0	3
p(.)	180.58	36.61	0	0	2
p(*H*)	181.27	37.30	0	0	3
p(*O*)	181.32	37.35	0	0	3
p(*D*)	181.75	37.78	0	0	3
p(*Rp*)	181.81	37.84	0	0	3
p(*t*)	181.82	37.85	0	0	3
p(*T*)	181.93	37.96	0	0	3
p(*Rd*)	182.26	38.29	0	0	3
p(*time*)	183.42	39.97	0	0	5

Site-specific covariates

Site-specific covariates were modelled using the best model for detection probabilities (i.e., search time as covariate). The eight competing models are shown and ranked according to their AIC_c's values in Table 2.4. Using the summed model weights from Table 2.4, elevation (*E*) and the distance searched (*DS*) were identified as the most important variables determining occupancy rates with 58% and 59% of the model weights, respectively. Stream width was the least influential factor with only 33% of the model weights. When a GOF test was performed (MacKenzie and Bailey, 2004) on the most general model considered ψ(*E*+*DS*+*SW*)*p*(*St*), there is no evidence of lack of fit (X^2= 1.29, p value = 0.27, $\hat{c}$ = 1.18). The top three models all have considerable support (w_i >0.9); hence it is not possible to select a single 'best' model. Therefore, model averaging was used to estimate parameters, using the three top-ranked models (Table 2.5). The averaged estimation of overall occupancy was $\bar{\hat{\psi}}$ = 0.78 ± 0.11 and the averaged estimation of overall detection probability was $\bar{\hat{p}}$ = 0.68 ± 0.04. Site-specific estimates are shown in Table 2.6.

Table 2.4. Summary of model selection procedure examining the effects of covariates on occupancy (elevation, (*E*); distance searched, (*DS*); stream width, (*SW*) with a search time dependant detection probability (i.e., *p*(St))

Model	AIC_c	ΔAIC_c	w_i	Model Likelihood	*k*
ψ(*E*+*DS*), *p*(*St*)	142.61	0.00	0.199	1.000	5
ψ(*DS*), *p*(*St*)	142.76	0.15	0.185	0.928	4
ψ(*E*), *p*(*St*)	142.80	0.19	0.181	0.909	4
ψ(*E*+*DS*+*SW*), *p*(*St*)	143.87	1.26	0.106	0.533	6
ψ(.),*p*(*St*)	143.97	1.36	0.101	0.507	3
ψ(*DS*+*SW*), *p*(*St*)	144.00	1.39	0.100	0.499	5
ψ(*E*+*SW*), *p*(*St*)	144.24	1.63	0.088	0.443	5
ψ(*SW*), *p*(*St*)	145.85	3.24	0.040	0.198	4
ψ(.), *p*(.)	180.58	37.97	0.000	0.000	2

Table 2.5. Parameter (beta's and derived) estimates from the three best models. Occupancy parameters include covariates Elevation (*E*) and distance searched (*DS*). Detection parameters include search time as covariate (St), α_0 and β_0 are the intercept parameters.

MODEL		Occupancy parameters				Detection parameters		
	w_i	α_0	$\alpha_1(E)$	$\alpha_2(DS)$	$\bar{\hat{\psi}}$	β_0	$\beta_1(St)$	$\bar{\hat{p}}$
ψ(*E*+*DS*), *p*(*St*)	0.35	19.11 ± 5.23	0.76 ± 0.51	-36.72 ± 10.68	0.78 ± 0.08	1.82 ± 0.38	3.04 ± 0.57	0.68 ± 0.04
ψ(*DS*), *p*(*St*)	0.33	20.35 ± 5.96	-	-39.50 ± 12.17	0.80 ± 0.06	1.81 ± 0.38	3.08 ± 0.58	0.67 ± 0.04
ψ(*E*), *p*(*St*)	0.32	1.34 ± 0.46	0.80 ± 0.46	-	0.76 ± 0.09	1.81 ± 0.37	2.93 ± 0.60	0.68 ± 0.05
Averaged					**0.78 ± 0.11**			**0.68 ± 0.04**

Table 2.6. Site-specific averaged model estimates for detection probability $(\bar{\hat{p}})$, occupancy $(\bar{\hat{\psi}})$ and occupancy conditional on detection history $(\bar{\hat{\psi}}_c)$.

SITE ID	$\bar{\hat{p}}$	±SE	$\bar{\hat{\psi}}$	±SE	$\bar{\hat{\psi}}_c$	±SE
1	0.74	0.06	0.79	0.09	1	0
2	0.61	0.07	0.80	0.10	0.06	0.05
3	0.83	0.03	0.86	0.12	1	0
4	0.75	0.05	0.76	0.09	1	0
5	0.97	0.01	0.65	0.13	1	0
6	0.49	0.05	0.80	0.10	0.11	0.09
7	0.08	0.05	0.93	0.10	0.90	0.14
8	0.57	0.06	0.74	0.09	0.04	0.03
9	0.29	0.08	0.65	0.13	0.48	0.16
10	0.11	0.05	0.95	0.08	0.92	0.12
11	0.88	0.04	0.87	0.18	1	0
12	0.92	0.03	0.75	0.09	1	0
13	0.66	0.06	0.62	0.16	1	0
14	0.96	0.02	0.70	0.09	1	0
15	0.51	0.07	0.91	0.14	1	0
16	0.86	0.04	0.95	0.08	1	0
17	0.32	0.08	0.76	0.09	0.38	0.17
18	0.54	0.07	0.68	0.11	0.04	0.03
19	0.57	0.07	0.81	0.10	1	0
20	0.66	0.05	0.60	0.17	1	0
21	0.96	0.01	0.97	0.05	1	0
22	0.73	0.06	0.71	0.09	1	0
23	0.97	0.01	0.67	0.11	1	0
24	0.98	0.01	0.72	0.09	1	0
25	0.24	0.07	0.89	0.16	0.78	0.30
26	0.52	0.07	0.63	0.14	1	0
27	0.69	0.06	0.71	0.09	1	0
28	0.23	0.06	0.58	0.18	0.31	0.18
29	0.57	0.06	0.69	0.10	0.01	0.01
30	0.84	0.04	0.69	0.10	0.00	0.00
31	0.98	0.01	0.77	0.09	1	0
32	0.83	0.04	0.76	0.09	1	0
33	0.87	0.04	0.97	0.05	1	0
34	0.54	0.06	0.86	0.12	1	0
35	0.68	0.06	0.85	0.12	1	0
36	0.90	0.02	0.80	0.10	1	0
37	0.98	0.01	0.74	0.09	1	0
38	0.34	0.06	0.63	0.15	0.23	0.15

39	0.47	0.04	0.60	0.17	1	0
40	0.45	0.08	0.97	0.05	1	0
41	0.39	0.08	0.66	0.12	0.21	0.14
42	0.76	0.06	0.99	0.03	1	0
43	1.00	0.00	0.86	0.12	1	0
44	1.00	0.00	0.84	0.11	1	0
45	0.90	0.03	0.97	0.05	1	0
46	0.68	0.05	0.64	0.14	0.05	0.04
47	0.20	0.06	0.81	0.10	0.55	0.20
48	0.89	0.03	0.86	0.20	1	0
49	1.00	0.00	0.88	0.12	1	0
50	0.99	0.01	0.82	0.11	1	0
Average	**0.68**	**0.04**	**0.78**	**0.11**	**0.78**	**0.04**

2.5.3 Relative abundance

Relative abundance

During the study 414 frogs were sighted, from which 142 records were identified as possible re-sights using the established criteria (for a detailed list of frogs found see Appendix IV). The final count of individual frogs was estimated as $\boldsymbol{n}_{(\mathbf{s-r})}$ = nº sightings – nº re-sightings = 272. The relative abundance of frogs at each site ($\boldsymbol{n}_{(\mathbf{s-r})\mathbf{i}}$) ranged from 1 to 29 frogs. The mean number of frogs per site was 5.4 ± 0.9 (SE). Estimated relative abundance of frogs ranged between 2.5 to 72.5 frogs/100m, which represents one of the highest recorded for this species (for site-specific relative abundance see Appendix V). The total distance searched across all sites and visits was 1,904 metres, and the mean relative abundance of frogs per 100m of searched habitat (n=50) was 14.2 ± 2.4 (SE) frogs/100m.

Relative abundance distribution

Frogs were detected at 34 of the 50 sites included in this study. Abundance was not homogenous; some sites had very low relative abundance, while others supported high densities of frogs (Figs. 2.2 and 2.3). To compare relative abundance across all sites a ranking of low (< 10 frogs/100m), medium (10-25 frogs/100m), and high (>25 frogs/100m) was used and is indicated on Figure 2.2.

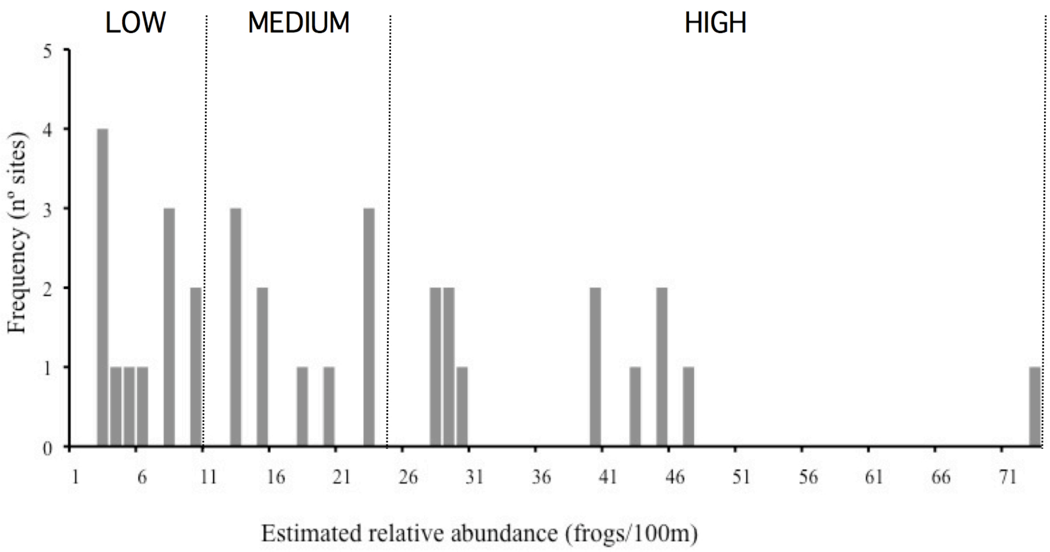

Figure 2.2 Frequency distribution of relative abundance of *L. hochstetteri* in occupied sites in the Waitakere Ranges.

Encounter rate

The total time spent searching for frogs was 177.1 person hours. The mean encounter rate was 1.78 ± 0.26 frogs/person-hour and ranged from 0.33 to 10.59 frogs/person-hour.

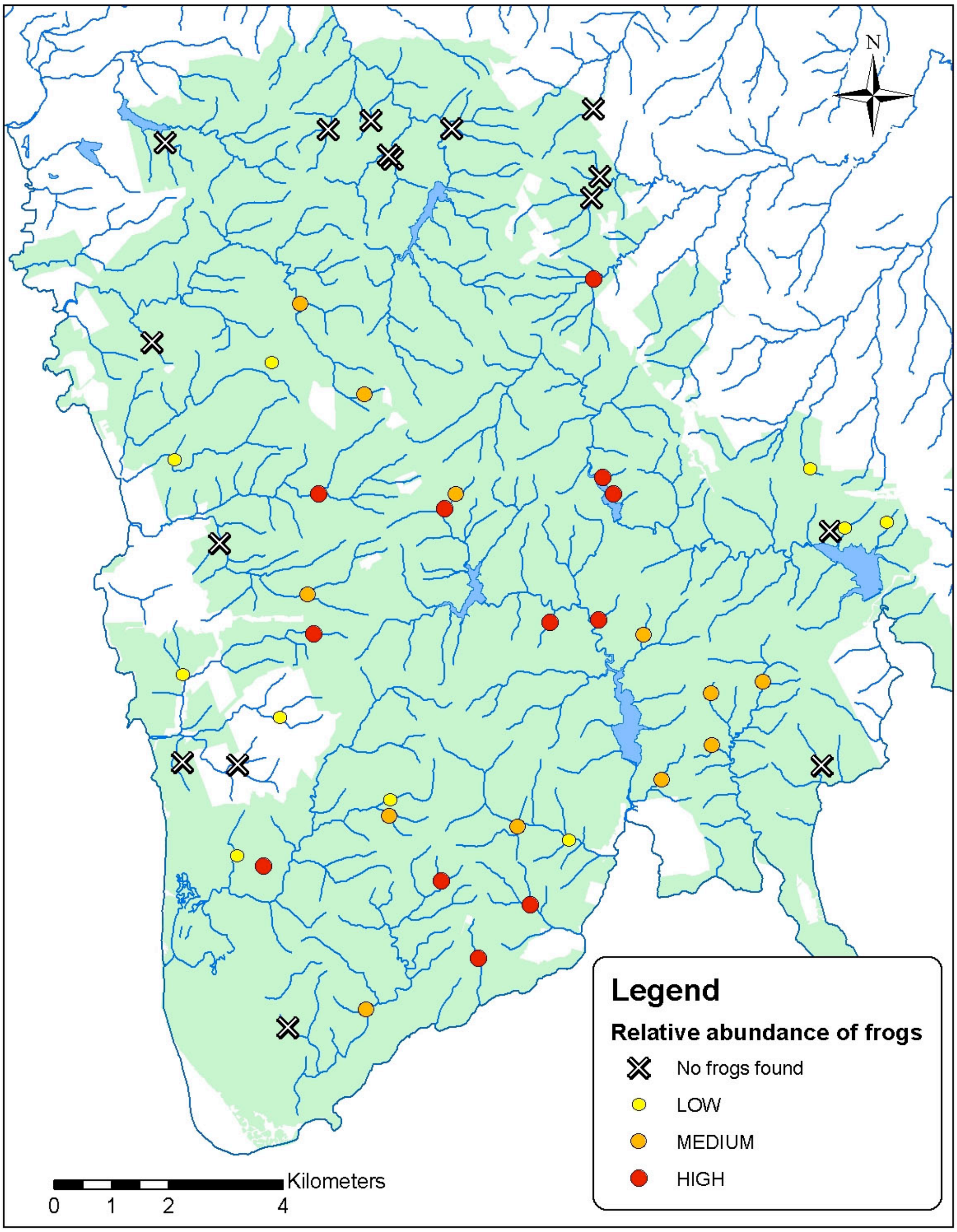

Figure 2.3. Map of relative abundance distribution of Hochstetter's frogs in the Waitakere Ranges. Abundance categories are; LOW < 10 frogs/100m; MEDIUM = 10-25 frogs/100m; HIGH >25 frogs/100m.

Population structure

The mean SVL of all measured frogs (*n*=272) was 29.13 ± 0.58mm and ranged from 6 to 45mm. Figure 2.4 shows the frequency distribution of body sizes, while Table 2.7 shows the percentage of frogs on each age-class using three different size classifications. The majority of frogs found were adults except when using Slaven (1992) classification where most frogs are considered sub-adults. The number of juveniles and adult females is similar among the three classifications. Using only Whitaker & Alspach (1999) size classes, fourteen (28%) sites had juveniles present, 17 (34%) sites had sub-adults present, and 33 sites (66%) had adults (including large females).

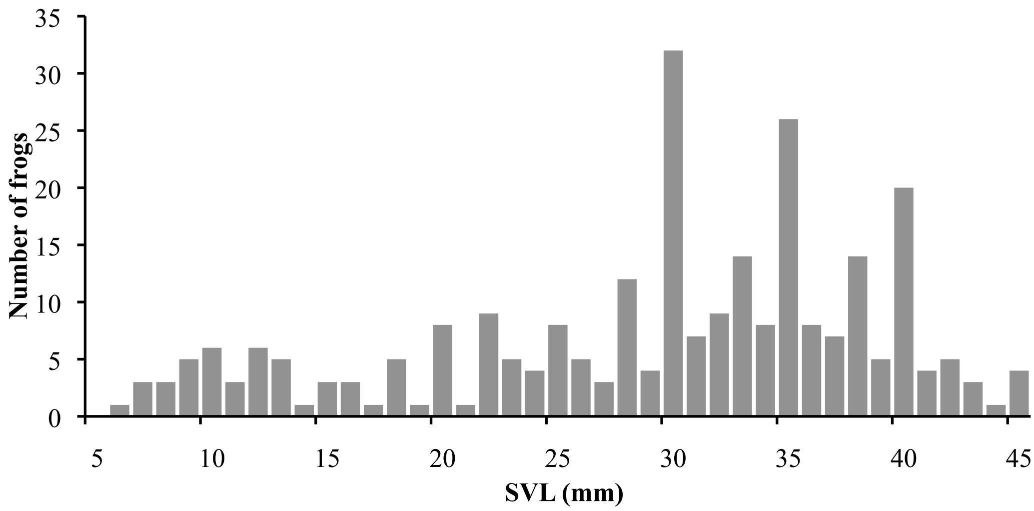

Figure 2.4. Frequency distribution of body sizes (SVL, snout-vent length) of *Leiopelma hochstetteri* found in the Waitakere Ranges from May to December 2008 (*n* =272).

Table 2.7. Percentage of the measured population on each age-class according to three different classifications.

Age-class	Whittaker & Alspach (1999)	Bell (1978)	Slaven (1992)
Juvenile	14.7	14.7	16.9
Sub-adult	12.1	23.9	57.0
Adult	59.6	47.8	10.7
Adult Females	13.6	13.6	15.4

2.5.4 Abundance models

1) Royle & Nichols (2003): Estimating abundance from repeated presence-absence data or point counts

The covariates incorporated in the analysis are the ones identified in 2.5.2 as having important influence on modelling occupancy and detection probabilities. Elevation and distance searched were added as covariates affecting mean abundance (λ), and search time was added as a covariate affecting the species detection probability (*r*) (models parameters and ranking are shown in Table 2.8). There was considerable support for the top ranked model $\lambda(E)r(St)$ ($w_i = 0.65$), and considerably less support for the remaining models, where $\Delta AIC_c > 2$. Evidence supports elevation as the main factor affecting mean abundance with 85% of the model weights. Overall there is very strong evidence that search time is an important covariate for detection probabilities as all models involving this term have substantially smaller AIC_c values than those without. The best model $\lambda(E)r(St)$ estimated a mean abundance of 1.78 ± 0.59 frogs per site, and a total number of 89 ± 29.5 frogs across all sites.

2) Royle (2004): N-Mixture Models for Estimating Population Size from Spatially Replicated Counts

Elevation and distance searched were added as covariates affecting abundance, λ, and search time was added as a covariate affecting the species detection probability *p* (models parameters and ranking are shown in Table 2.9). There was considerable support for the top ranked model $\lambda(E)p(St)$ ($w_i = 0.62$), and considerably less support for the remaining models, where $\Delta AIC_c > 2$. Elevation was the main factor affecting mean abundance with 81% of model weights. The best model $\lambda(E)p(St)$ estimated mean abundance $\bar{\hat{\lambda}} = 10.37 \pm 1.45$ and $\bar{\hat{p}} = 0.161 \pm 0.02$. The total abundance of frogs across all sites estimated by this model was $N_t = 518 \pm 72.5$.

Table 2.8. Royle & Nichols (2003) models with covariates (*E*: elevation; *DS*: distance searched; *St*: search time) and parameter estimates ($\bar{\hat{r}}$: averaged species detection probability; $\bar{\hat{\lambda}}$: averaged number of individuals per site, $\bar{\hat{\psi}}$: averaged occupancy, N_t : estimated total number of frogs across 50 sites).

Model	AIC_c	ΔAIC_c	w_i	Model Likelihood	*k*	Abundance parameters			Detection parameters		Derived parameters			
						β_0	$\beta_{1(E)}$	$\beta_{3(DS)}$	β_4	$\beta_{5(St)}$	$\bar{\hat{r}}$	$\bar{\hat{\lambda}}$	$\bar{\hat{\psi}}$	N_t
λ(*E*)*r*(*St*)	142.11	0.00	0.65	1.00	4	0.47 ± 0.27	0.45 ± 0.19	-	0.75 ± 0.54	2.62 ± 0.56	0.57	1.78	0.78	89
λ(*E*+*DS*)*r*(*St*)	144.46	2.35	0.20	0.31	5	0.49 ± 0.28	0.44 ± 0.19	-0.07 ± 0.20	0.74 ± 0.55	2.67 ± 0.57	0.57	1.82	0.78	91
λ(.)*r*(*St*)	145.69	3.58	0.11	0.17	3	0.44 ± 0.26	-	-	0.80 ± 0.53	2.64 ± 0.55	0.58	1.55	0.79	78
λ(*DS*)*r*(*St*)	147.57	5.46	0.05	0.07	4	0.48 ± 0.27	-	-0.14 ± 0.19	0.76 ± 0.55	2.73 ± 0.57	0.57	1.64	0.80	82
λ(.)*r*(.)	179.37	37.26	0.00	0.00	2	0.15 ± 0.18	-	-	0.98 ± 0.30	-	0.73	1.16	0.69	58

Table 2.9. Royle (2004) models and parameter estimates ($\bar{\hat{p}}$: averaged site detection probability (unconditional), $\bar{\hat{\lambda}}$: averaged number of individuals per site, $\bar{\hat{\psi}}$: averaged occupancy, N_t : estimated total number of frogs across 50 sites).

Model	**AIC_c**	**ΔAIC_c**	**w_i**	**Model Likelihood**	***k***	**Abundance parameters**			**Detection parameters**		**Derived parameters**			
						β_0	$\beta_{1(E)}$	$\beta_{3(DS)}$	β_4	$\beta_{5(St)}$	$\bar{\hat{p}}$	$\bar{\hat{\lambda}}$	$\bar{\hat{\psi}}$	N_t
λ(*E*)*p*(*St*)	578.59	0.00	0.62	1.00	4	2.33 ± 0.13	0.16 ± 0.07	-	-1.85 ± 0.16	1.32 ± 0.10	0.16	10.37	1	518
λ(*E+DS*)*p*(*St*)	580.98	2.39	0.19	0.30	5	2.33 ± 0.13	0.16 ± 0.07	-0.02 ± 0.08	-1.85 ± 0.16	1.32 ± 0.10	0.16	10.42	1	521
λ(.)*p*(*St*)	581.58	2.99	0.14	0.22	3	2.43 ± 0.12	-	-	-1.96 ± 0.16	1.36 ± 0.10	0.15	11.31	1	566
λ(*DS*)*p*(*St*)	583.71	5.12	0.05	0.08	4	2.43 ± 0.12	-	-0.04 ± 0.08	-1.96 ± 0.16	1.36 ± 0.10	0.15	11.38	1	569
λ(.)*p*(.)	840.68	262.09	0.00	0.00	2	1.63 ± 0.09	-	-	-0.25 ± 0.13	-	0.44	5.10	1	255

2.5.5 Surrogate measures for relative abundance

Correlation between detection probability and relative abundance

A statistically significant correlation between site-specific *detection probabilities* (Table 2.6) and relative abundance was found (Spearman r = 0.84, P < 0.01, Figure 2.5).

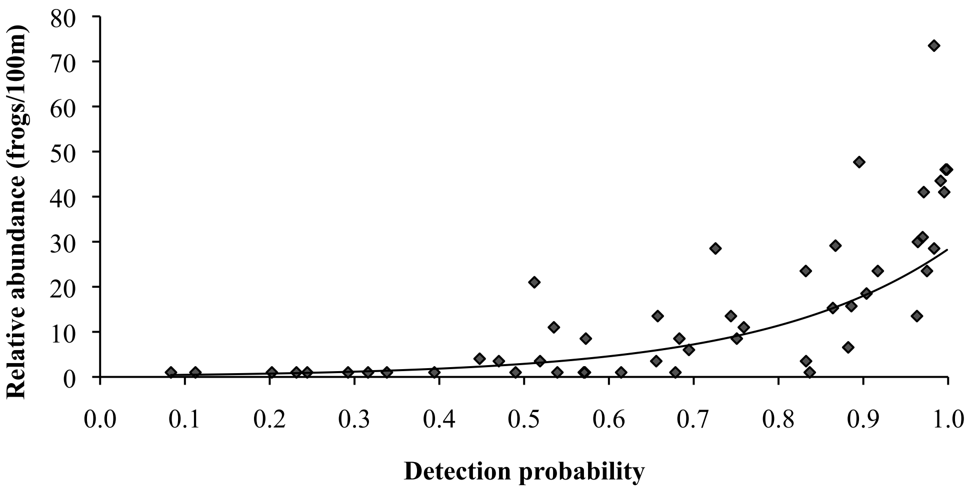

Figure 2.5 Relationship between detection probability and relative abundance (*n* = 50). Dots represent observations and the line represents the fitted exponential curve ($y = 0.30e^{4.56x}$, R^2=0.66).

Correlation between first frog found and relative abundance at a site

A statistically significant negative correlation between *distance to first frog* and site-specific relative abundance was found (Spearman r = -0.79, P < 0.01, Figure 2.6), while a relatively weaker but still significant correlation was found for *time to first frog* (Spearman r = -0.55, P < 0.01, Figure 2.7).

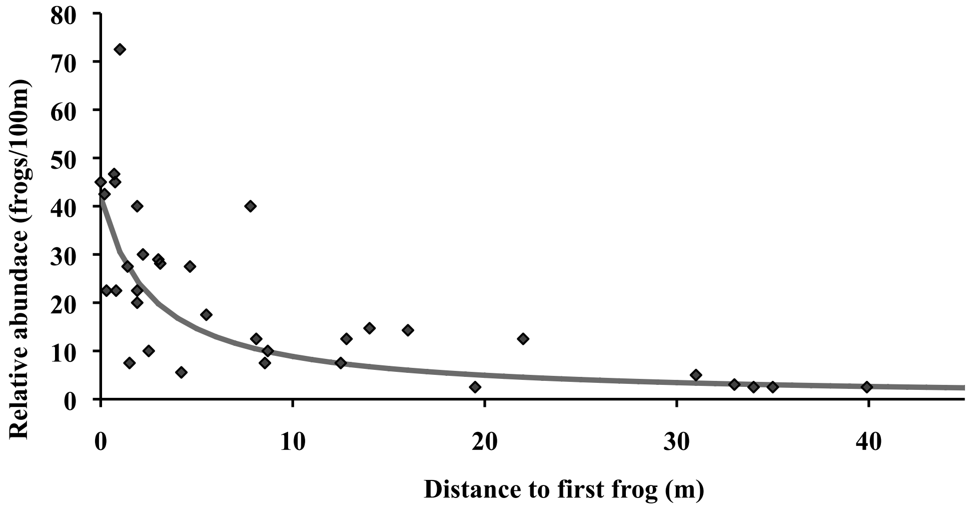

Figure 2.6. Relationship between distance to first frog found and relative abundance (*n*=34). Dots represent observations and the line represents the fitted curve (y = 1/(0.0089x + 0.0239), R^2= 0.73).

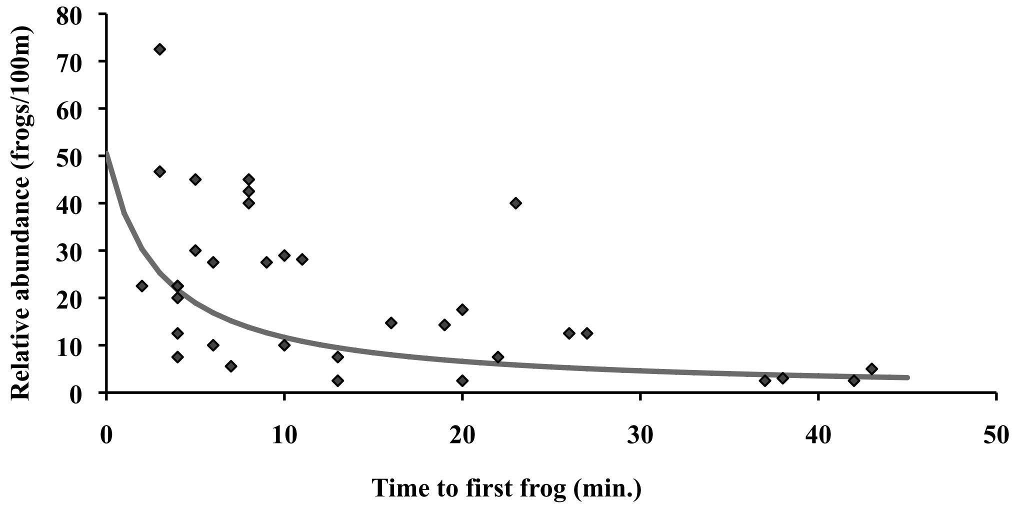

Figure 2.7. Relationship between time to first frog found and relative abundance (*n*=34). Dots represent observations and the line represents the fitted curve (y = 1/(0.0066x + 0.0198), R^2=0.41).

2.5.6 Comparison of techniques

The cost (time) and outcomes associated with the different sampling schemes (transect counts, repeated presence-absence surveys for site-occupancy modelling, and repeated counts) are shown in Table 2.10. In terms of cost, the cheapest and fastest method was the single transect count, however this was the least reliable method as no inference can be made from results obtained this way. The most costly methods were those that involved repeated transect counts. In terms of disturbance, repeated transect counts had considerably higher impact on the habitat, while this was minimised for repeated presence-absence surveys. The results from the different methods differ considerably. Occupancy (or proportion of sites occupied) was underestimated when not accounting for detection probability, while this was overestimated by Royle (2004) models.

Table 2.10. Comparison between different sampling methods. Measures used are: (t) = time taken for a person to *access* one site; (d) = disturbance produced in one visit; ($) = costs (including transport to site) of doing one survey. (*): derived from species detection probability, not directly estimated.

METHOD	COST				RESULTS			
	Search effort (person hours)	Access to sites (person hours)	Disturbance	Money	Occupancy	Detection probability	Mean abundance (frogs/site)	Total abundance across 50 sites
Single Transect Count	45.7	t	d	$	0.52	-	1.86 ± 0.41	93
Repeated Transect Counts, (sight/resight)	177.1	4t	4d	4$	0.68	-	5.44 ± 0.93	272
Repeated presence-absence, MacKenzie et al (2002)	88.1	4t	2d	4$	0.78 ± 0.11	0.68 ± 0.04	-	-
Repeated presence-absence, Royle & Nichols (2003)	88.1	4t	2d	4$	0.78	0.85(*)	1.78 ± 0.59	89 ± 29.5
Repeated counts Royle (2004)	177.1	4t	4d	4$	1	0.16 ± 0.02	10.37 ± 1.45	518 ± 72.5

2.6 Discussion

2.6.1 Site occupancy modelling

The site occupancy models of MacKenzie et al. (2002) gave robust estimations of occupancy levels and detection probabilities. Models including covariates performed better than those that did not include them. This demonstrates that occupancy and detection probabilities are not constant across sites, but are spatially and temporally heterogeneous. This heterogeneity could be accounted for using variables measured in the field. Very few occupancy studies exist to date for this species, and all have used slightly different designs (e.g., different number of visits or sites, different definition of site). The overall occupancy (0.78) and detection probability (0.68) of Hochstetter's frog found here are comparable to estimates found elsewhere. Crossland et al. (2005) reported overall detection probabilities of 0.61 to 0.94 in the Hunua Ranges, 0.75 to 0.77 in the Brynderwyn Hills, and 0.57 to 0.97 in Mahurangi Forest depending on different types of habitat or season. M. Crossland (unpublished data) found higher overall occupancies of frogs (0.87 to 0.96) inside the pest-controlled area of the Kokako Management Area (KMA) in the Hunua Ranges. Nonetheless, to validate comparisons between study sites (geographically distinct populations) the same variables (covariates) should be included in the model from which parameters are estimated. The identification of important covariates is also of particular importance for long-term monitoring programmes as by including them results become comparable. It is hoped that the results and recommendations from this study will help elucidate this issue.

The most important covariates for occupancy estimation were elevation and transect length (i.e., distance searched). It is probably not elevation *per se* that influences frog occupancy but the patterns that arise from variations in altitude, hydrology and forest cover. This supports previous observations from D. G. Newman & Towns (1985) that Hochstetter's frog are more likely to be found in high gradient first order tributaries. The fact that elevation is *known* across the Waitakere Ranges, allows for the inference of occupancy probability by constructing a predictive model, which can be mapped using GIS tools. These types of predictive models may be used to identify target areas where conservation measures (e.g., pest control) may yield optimum results. The effect of distance searched needs careful interpretation as it was negatively related to occupancy (the opposite relation was expected). This means that under models with distance searched as covariates, occupancy was lower as the distance searched increased, which has no biological interpretation. This could be because the effect of distance searched may not be a reflection of occupancy but rather some other factors such as difficulty of terrain, which can be negatively related to occupancy (e.g., more available refugia for the frogs).

The marked effect of *search time* on detection probabilities found in the present study also requires careful interpretation. It is important to note that *search time* in this study comes from searching the whole length of the transect (usually 40m), which is not the case in common site occupancy surveys, where searching halts when presence of the target species is found, and thus unlike here, *search time* is negatively related to detection probability. The time taken to search a site (the whole transect) comes from a combination of factors. First, it will be directly related to the transect length (i.e., distance searched). Those transects that had unsearchable sections took less time than those that were searched completely. Also, *search time* reflects an aspect of the habitat, as sites with more available refugia (representing a better quality habitat) took longer to search than those with few refugia (which are likely to represent poor habitat). Also it is important to note that there is a positive relationship between the abundance of frogs and *search time* as the time taken to measure the frog and take notes was included in this. Finally it may also represent some observer bias, as different observer may have differing searching speeds.

Previous studies found that abundance of frogs, although confounded with detection probability, was significantly different after periods of rain (Whitaker and Alspach, 1999). In contrast, the current study didn't find rain as having an important effect in detection probabilities. This factor, however, was partly controlled in this study as no surveys were conducted after periods of heavy rain, when effects would likely to be more evident. Observer differences in detection probability were expected, but this effect was not identified as important covariate, presumably due to both observers having the same level of experience in finding frogs. Nevertheless, comparing the total frogs found by Observer 1 (n=172) and Observer 2 (n=242) it is clear that observers differ to some degree in their ability to find frogs.

Monitoring age classes separately

Crossland et al. (2005) discussed the monitoring of age classes separately using MacKenzie et al. (2002) site occupancy models, in relation to sampling effort. They conclude that separating age classes could be achievable in most instances with small sampling effort (two to five repeat surveys per site). In this study, where four repeat surveys were done per site, it was possible to get an overall estimation for three separate age classes (using the constant model), however results were not as precise as when data from all age classes were pooled. In addition, no covariate data were added as including this information resulted in a poor fit (i.e., increased variability) meaning that site-level occupancy couldn't be obtained with precision for each separate age class (results not shown). Juvenile detection probability (0.37) was lower than those found in the Hunua Ranges (0.50-0.90) and Mahurangi Forest sites under native forest (0.79), and relatively high compared to one found in the Brynderwyn Hills (0.28) (Crossland et al. (2005). Juvenile occupancy was also relatively low compared to values found by M. Crossland (unpublished data) inside the Kokako Management Area (0.65-0.78) in the Hunua Ranges. The relatively low occupancy and detection probability found for juveniles means that to monitor this age class more precisely, more than four repeated visits may be needed (MacKenzie and Royle, 2005). With the present sampling design, precision for each age class was such that all standard errors were < 0.1. In addition to the above, and considering the heterogeneous distribution of juveniles discussed earlier, monitoring the three age classes separately will result in the majority of sites being searched along their entire length, increasing habitat disturbance and the time taken to complete the surveys.

One possible approach to monitor separate age classes without increasing effort and minimising habitat disturbance would be to use just two age classes. This can be done in two ways; grouping adults and subadults together as in Crossland et al. (2005), or grouping juveniles and subadults together. According to the data obtained by the present study, the best approach in relation to accuracy of results, disturbance and search effort would be the second option. When considering subadults and juveniles in the same age class (namely "young"), the detection probability of the "young" class increases (0.60 ± 0.06) allowing for a more precise estimation of occupancy (0.42 ± 0.07), while it reduces search effort and habitat destruction. This separation is still meaningful at an ecological level as presence of either juveniles or subadults is evidence of recent breeding and/or recruiting. Another possible approach could be to identify possible "breeding sites" (where juveniles and sub-adults are known to occur) and only at those sites monitor separate age classes (i.e., double sampling design) (MacKenzie and Royle, 2005). To further avoid disturbance of the habitat, especially at the breeding sites, a *removal* sampling design may be used (see (MacKenzie et al., 2006), where no further visits are made if presence of the species (age class) is confirmed.

Violation of model assumptions

The models of MacKenzie et al. (2002) have several assumptions (see methods), and some of these may have been violated to some degree. Independence of surveys for instance is one of them, as each observer searched a site twice, and the observer already knew their own result from the first survey. Hence the observer had *a priori* knowledge of the presence or absence of frogs on sequential surveys. Also the observer might remember the particular refugia where frogs were found in the first visit, and this may also influence the independence of results from the second visit (the magnitude of this effect although might be insignificant). The *closed site* assumption was possibly violated in cases where frogs jumped into the stream, and were carried downstream with the flow. On these occasions, and if the frog was close to the beginning of the site (0m mark), the frog could have left the site area (i.e., emigrating). Nonetheless, the site is assumed closed in terms of *occupancy* state, so the assumption is violated only when the *only* individual from a site emigrates, which seems unlikely. Another assumption was that there was no un-modelled heterogeneity, and this is likely to be violated. An effort was made to include all potential sources of variation, but ecosystems are complex and occupancy and detection probabilities are likely to be affected by numerous and subtle factors.

Habitat and forest type

Hochstetter's frog habitat can vary throughout the range of this species. They normally live in wet conditions along streams, but they have also been found in drier places with no surface water (but still humid), and even in ridges far from streams. They can tolerate different riparian forest compositions and levels of stream coverage, in different regenerating states (Stephenson and Stephenson, 1957). In the Waitakere Ranges, different areas have been historically under varying pressures from milling and farming, which has resulted in a mosaic distribution of forests types (for a detailed map see Esler (2006)). These characteristics are likely to have an influence in occupancy levels and may account for the heterogeneous distribution of these frogs.

Seasonal effect

It is possible that population parameters such as occupancy and detection probability vary with the time of year. The breeding ecology of *Leiopelma* species is not fully understood, though it is believed that *L. hochstetteri* has an extended breeding season from at least August to February (Bell, 1985). Eggs hatch after approximately six weeks, and the larvae completes development at least one month after hatching (Bell, 1978). This means that froglets are predicted to be present in the population from at least October to April. Any seasonal effect would be greatest for estimates of juvenile parameters, as their numbers would vary the most. Nevertheless, growth of *Leiopelma* is relatively slow, and juveniles remain small for several months (Bell, 1978). This means that regardless of the present breeding activity of the population, juveniles may be present throughout the year (if breeding occurs each year at least during the past year). This was true for this study where juveniles where detected in cold months (May-July) and warmer months (December). Juveniles were not detected, or very little detection occurred, during September-November.

Human-induced disturbance

The different sites studied had different levels of human related disturbance. Even though the Waitakere Ranges is mostly parkland, there is considerable sub-urban development within its boundaries. Proximity to human structures or activities (e.g., roads, towns, tracks, farmland) may influence occupancy levels. Unfortunately, there are several issues that make adding *human disturbance* as a covariate difficult. First, the concept is very broad, and may include very different and complex processes. Also, the precise impacts of human activity on Hochstetter’s frog populations are unknown.

Finally, it would be difficult to classify and quantify human disturbance in the field, and a qualitative approach may further introduce subjectivity into the analysis. The time and resources needed to assess human disturbance at a site level were beyond the scope of the current study.

Impact of introduced pests and pest control management

The effect of pest control couldn't be assessed with statistical inference in this study as few of the sites included here had pest management (only 7 out of 50 sites). Also, different pest management projects in the area differ in intensity, length of time established, and the diversity of pest control strategies used, thus making it difficult to assess effectiveness across different projects. The total area under intensive ecological restoration (including pest control) in the Waitakere Ranges is 1,650ha, which represents nearly 10% of the total area. In the present study, frogs were detected in only 1 of the 7 sites that are currently under pest control. The most extensive pest control area in the Waitakere Ranges is the Ark in the Park restoration project, which involves 1,100ha of intensive mammalian pest control (Bellingham et al., 2008). Since the implementation of this project in 2003, there has been no detectable increase in frog numbers (Bradfield 2005; Bellingham, Jack et al. 2008; Brejaart 2008). Furthermore, abundance of frogs inside the Ark in the Park are significantly lower than other areas in the park (Brejaart, 2008). Two other restoration projects that undertake pest control in the Waitakere Ranges are located in Karekare catchment. The first one, La Trobe mainland island restoration project covers 200ha, and the effects of pest control in this area on Hochstetter's frog is currently being investigated. The second, Lone Kauri Forest Restoration project covers 350ha, and no frogs have been found in this area either by Bradfield (2005) or this study (however only one site within the area was searched).

The results obtained by Brejaart (2008) in the Waitakere Ranges regarding the effects of pest control contrasts with the results obtained from the Hunua Ranges population by Baber et al., (2007), where a significant difference was found in the relative abundance of frogs inside and outside the Kokako Management Area (KMA, 850ha of pest control). They suggest that Hochstetter's frog may benefit from pest control, although they acknowledge the difference may be due to other factors such as elevation at the

KMA sites. Furthermore, Crossland (unpublished data) found occupancy to be higher inside the KMA. The differing results from Waitakere and Hunua Ranges might be attributable to the fact that KMA has been under pest control since 1994 while projects in the Waitakere Ranges are more recent. This is an encouraging interpretation as it means that sustained efforts are likely to have positive results, but it may take up to a decade for the changes to be detected. Nevertheless, results from the Hunua Ranges might be biased as elevation is higher inside the KMA, and as this study demonstrates, elevation is an important covariate for occupancy and abundance estimation. In this case, the effect of elevation is confounded with the effect of pest control, and results become inconclusive.

It is yet unclear what impact introduced pests have on Hochstetter's frog, however in this study frogs were present at sites where signs of predators were found (e.g., possum excrement, pig uprooting in the surroundings). In addition, the rear legs of a frog were found clearly showing signs of predation in an area where frogs were found to be relatively abundant. The damage of pig uprooting was also evident at some sites where frogs were present. This and previous evidence (Thurley and Bell, 1994, Bell, 1978) suggests that introduced predators and frogs coexist to some extent, however the impact of introduced pests (including introduced frogs) should be further investigated.

2.6.2 Relative abundance estimation by repeated transect counts and sight-re-sight criteria

By doing repeated surveys at each site, and using the established sight/re-sight criteria it was possible to obtain an estimation of frog abundance more accurately than from surveys that are done using a single visit. For example, sites 1, 11, 15, 20, 22, 27, 39, 40 had no detections in their first survey, but frogs were detected in subsequent visits. If only one visit was done, estimation of abundance and occupancy of these sites would have been greatly underestimated. In other cases, very different counts were obtained at each visit. For example, site 37 and 45 had detection histories of (4,15,15,18) and (1,2,3,10) respectively. In these cases, if only one visit was done, abundance of frogs would have been classified as relatively low at these sites as only 4 and 1 frogs, respectively, were detected in survey 1, however in survey 4, 18 and 10 frogs were detected for sites 37 and 45 respectively, revealing that these sites had higher actual densities of frogs. These results show how variable estimation of relative abundance can be in this species, as surveys conducted just a few minutes apart yielded remarkably different results. This further emphasises the need to quantitatively include the probability of detecting the species when estimating abundance.

Even though the sight/re-sight method used here to estimate relative abundance from repeated transect counts has its limitations (e.g., it can be subjective in some situations due to the lack of individual marking of frogs), it was considered a valid approach and a better estimator than the minimum number alive. The conservative approach taken here means that estimation of relative abundance is still more likely to be underestimated, than overestimated.

2.6.3 Abundance models

One of the objectives of this study was to assess applicability of abundance models (of Royle & Nichols (2003) and Royle (2004)) for estimating abundance distribution of frogs in the Waitakere Ranges. By comparing the results obtained for relative abundance from repeated transect counts, site occupancy modelling, and the abundance models it is clear that these are dissimilar. Royle & Nichols' (2003) model estimates of abundance had relatively high standard errors and large confidence intervals, meaning that they were not precise (at a site level), while Royle's (2004) model predicts high abundances in all sites (even in sites where no frogs were found) as it computes that on each survey, only 16% of the frogs are actually found. These models appear not to fit the data; unfortunately this couldn't be assessed, as no goodness of fit test has been developed to date for these models. This apparent poor fit may be due to the relatively high heterogeneity on abundance levels found throughout the study area.

The different results obtained from the abundance models used may be attributable to one or more of the assumptions of the models being violated. For abundance models in particular, the assumption of a previous abundance distribution (e.g., Poisson, negative binomial) in occupancy estimation may be critical (Royle et al., 2005). Previous studies have demonstrated that the negative binomial distribution gives better estimates (Royle et al., 2005) while others support Poisson distribution assumption (Royle and Nichols, 2003). Here, only the Poisson distribution was used, although it is acknowledged that negative binomial model could allow for more variation in abundance (Royle and Nichols, 2003). Also, the use of alternative mixing distributions on abundance should be further considered (e.g., nonparametric finite mixtures).

The use of abundance models shouldn't be discarded. The value of these models may reside in their ability to assess the different importance of factors over abundance, or to assess distribution of abundances through the study area. Nevertheless, the relationship between occurrence and abundance is an area of current research interest (MacKenzie et al., 2006) and it is possible that new models will be developed that can be applicable to the data obtained here.

2.6.4 Surrogate measures

The significant correlations found between detection probability and the distance to the first frog found, and estimated relative abundance at a site may be used to infer abundance in future site occupancy surveys in the Waitakere Ranges. It is important to note that this method should not be used to infer *absolute* abundance at a site. However they can be used together with occupancy results to compare differences in abundances between sites. Mapping detection probabilities may represent a good insight in estimating distribution of abundances. This result is supported by previous observations in the Waitakere Ranges made by S. Ziegler (1999), who found a similar correlation between first frog data and relative abundance, and might be a cost-effective way for estimating abundance at this population.

2.6.5 Overall comparison of monitoring techniques

As expected, there was considerable difference between data obtained from one visit only (index counts) with data obtained from repeated surveys. Indices obtained using single visits underestimate abundance and occupancy, because Hochstetter's frogs are detected imperfectly. Indices obtained lack statistical inference and do not represent an accurate estimation of the population. Because of the uncertainties related to these sorts of surveys, they are not regarded as good candidates for long term monitoring of this species. The more accurate and reliable estimates were obtained from occupancy models of MacKenzie et al. (2002) using covariate data. The sampling methods involved required more search effort (in relation to single visits index counts) but are likely to have less impact on the habitat. Different sample schemes can be accommodated, so it offers the most flexible approach. Among abundance models used, Royle & Nichols (2003) gave the most reliable and conservative results. As there is no additional effort involved in using this model it is recommended that it be applied in future monitoring to estimate distributions of abundance.

2.6.6 Comparison with previous studies

Relative Abundance

Most of the previous Hochstetter's frog population studies used a VES technique to search along transects and often reported abundance as an index (i.e., frogs/100m). This index is often regarded as a comparable measure between studies (Green and Tessier 1990; Whitaker and Alspach 1999). The mean relative abundance of *L. hochstetteri* obtained here (14.2 frogs/100m) is similar to values obtained from other populations. Whitaker & Alspach (1999) reported a mean relative abundance of 17.7 frogs/100m in the Coromandel, and similar abundances were reported from the Hunua Ranges (12 frogs/100m), East Cape (12 frogs/100m), and Brynderwyn (12 frogs/100) by Green & Tessier (1990) (but these are from single streams, and do not represent the whole population).

Previous population studies in the Waitakere Ranges have reported mean abundances of 7.5 frogs/100m across 39 sites (Bradfield, 2005) and 33.8 frogs/100m across 23 sites (Ziegler, 1999) (for site-specific comparison of relative abundances see Appendix VI). While it is recognised that these studies applied different methodologies, their results should not be discarded or ignored as they can be qualitatively compared to the results obtained here. Bradfield's (2005) estimation of mean abundance was half that found in this study. This, rather than representing an increase (doubling) of the population size in the last three years, is more likely to be due to the present study using repeated surveys at each site, consequently increasing the probability of encountering frogs. When comparing only the results obtained in the first visit of this study (to equate search effort) the estimated mean abundance is lower (4.77 frogs/100m) but similar to Bradfield's estimation. When considering data obtained from the first visit only and from the same sites as Bradfield (n=36), the mean abundance is closer (5.3 frogs/100m) but still lower than the one found by Bradfield. This small difference may be due to the different methodologies used. Ziegler (1999) estimated relative abundance from some very short transects (one or two metres where frogs were abundant), thus it is likely that she overestimated abundance by assuming high abundances were constant through 100m.

Distribution

There is considerable variation in the distribution of abundance across sites; indeed, the spatial distribution of frogs was not homogeneous throughout the study area. This contrasts with the previous observations made by Green & Tessier (1990) that *L. hochstetteri* was either absent or present in high abundances in the streams. In fact, the current study found that lower abundances were more frequent than higher abundances. In general, Hochstetter's frogs appear to be more abundant in the southern and central areas of the Waitakere Ranges, as previously found by Bradfield (2005) and Ziegler (1999). However, in the northern areas of the ranges including the Cascades, Wainamu, Swanson catchments, and in other peripheral sites, frogs were not detected. Bradfield (2005) found only two adult frogs in the Cascades catchment ("Cascades 3") in 126m of searched stream. It is likely that frogs are still present there, and that they were not detected in the present study because of their very low density.

The low densities of frogs reported in the Cascades catchment represents a challenge for management, as this area is under intensive pest control as part of the Ark in the Park restoration project. Moreover, in an additional visit to "Opanuku 1", (which was not included in the study because of flooding), only one adult frog was found. Also, frogs were detected near "Opanuku 2" site during informal surveys, though no frogs were found at either site during the formal surveys. Again, frogs might not have been detected in the formal surveys because of very low abundance rather than being completely absent from the sites.

Population structure

As in previous studies, the majority of frogs found were classified as adults. A relatively high proportion of frogs were juveniles (14.7-16.9%), which contrasts sharply with the

1.4% found previously by Bradfield (2005), but is similar to the proportion found by Ziegler (1999) (13%) in the Waitakere Ranges (Bradfield used Whitaker & Alspach (1999) classification while Ziegler used Slaven (1992)). The proportion of streams where juveniles were present was also greater in this study (28%) compared to both Ziegler (13%) and Bradfield (5%). This variability may be due to the difficulty of finding juveniles, which might in turn increase observer bias. Also, juvenile populations may change with the season. The proportion of juveniles found in this study shows that the Waitakere Ranges population is breeding, while the proportion of sub-adults shows that recruitment is also occurring. However, juveniles were not detected in every site where frogs were found. Some sites were occupied entirely by adults, while others had high proportions of juveniles. This supports previous observations that frogs have special “breeding sites”, often first order tributaries or headwater seepages (Turbott, 1949).

Even though it appears that there is no evidence of Hochstetter’s frogs declining in the Waitakere Ranges, the limitations of using count indices as a measure of abundance must be acknowledged (Anderson, 2001), meaning that no reliable conclusions regarding population trends can yet be drawn.

It is expected that monitoring of Hochstetter’s frog in the Waitakere Ranges will occur every three years on a long-term basis. This way, the results obtained in this study form a baseline on which future changes such as management actions can be compared. The results presented here are not treated as the last word in frog monitoring, but more like a step toward a better understanding of the methods that could best aid the management and conservation of native frog species, particularly *L. hochstetteri* in the Waitakere Ranges.

2.7 Recommendations

1) Keep monitoring all sites using site occupancy models of MacKenzie et al. (2002) and include at least elevation as covariate for occupancy.

2) Test the importance of other factors not included here on occupancy and detection probabilities (e.g., habitat type).

3) Monitor at least two separate age classes (i.e., young and adults).

4) Avoid disturbance of breeding sites using alternative sampling schemes (e.g., removal sampling).

5) Use multiple-season analysis approach in future sampling occasions (included in PRESENCE 2.3).

6) Use an adaptive management approach (MacKenzie et al. 2006, p.16).

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CHAPTER 3

A survey for Hochstetter's frog (*Leiopelma hochstetteri*) on Great Barrier Island

Plate 3. Hochstetter's frog from Miners Cove at the northern block of Great Barrier Island

3.1 Abstract

This chapter contains results obtained from two separate survey occasions. The first survey (January 2008) was exploratory and aimed to search for frogs in areas with no previous sightings. No new locations were found in the three catchments surveyed in the central block. The second objective of this first survey was to do a pilot site occupancy monitoring at Miners Cove Stream in the northern block; only twelve frogs were found in four days of survey. The absence of frogs in the central block and the low frog encounter rate at Miners Cove may be due to many reasons, but it is likely that sections of stream surveyed were not optimal (low altitude, wide streams), and that the lack of experience of the observers affected the results obtained. The second survey (March 2009) aimed at confirming the presence of frogs where they are known to occur (northern block and Kaiaraara Stream in central block). All streams surveyed in the northern block had frogs present, and some streams supported high densities of frogs. Frogs were confirmed as present at the single location with previous sightings in the central block and this may represent a subpopulation isolated from all other known localities. Overall there is no evidence for immediate concern regarding the Great Barrier Island population of Hochstetter's frog, however the almost complete absence of frogs outside the northern block is enigmatic and should be studied further. The main issues concerning surveying and monitoring frogs on Great Barrier Island are the amount of effort and costs involved in getting to the remote tributaries where frogs are found, and this should be kept in mind if future long term site occupancy monitoring is to be established there.

3.2 Introduction

This chapter contains the results obtained from two separate survey occasions. The first visit to Great Barrier Island (January 2008) aimed at finding new locations for Hochstetter's frog within suitable habitat (protected area) and assessed the use of site occupancy monitoring at a site that is known to contain frogs (Miners Cove Stream). The second visit (March 2009) aimed to confirm the presence of frogs in catchments in the northern block and at the only known locality within the central block of the island. The general aim of studying frogs on Great Barrier Island was to update their distribution and to examine the current state of the population, while being able to make recommendations on how to monitor this population in the future.

3.2.1 Great Barrier Island

Location and land-form

Great Barrier Island [GBI] is the largest island off the coast of the North Island in the Hauraki Gulf of New Zealand (see Figure 1.4). It is approximately 40km long and 20km wide, and measures about 274km^2. The island's landscape is rugged with mountain peaks reaching up to 627m (Mt. Hirakimata). Geologically, GBI consists of sedimentary rocks overlain by a variety of rhyolitic and andesitic materials, except in the north of the island, where it is mainly greywacke (Ogle, 1981, Moore, 2004). It is believed that GBI was connected to the mainland for most of its geological history. The Colville Channel, which now separates the island from the Coromandel peninsula, is only 50m deep, therefore it is believed that at least until the peak of the last Ice Age (18,000 years ago) when sea level was 120m lower, GBI was still connected to the mainland (Coromandel Peninsula). Separation may have been as recent as 10,000 years ago (Moore, 2004).

Recent history

First human settlements were by Maori people who were attracted by the island's mild climate and food resources. The first European visitors arrived at the island during the eighteenth century mainly in whaling ships. The island was covered by dense forest, and soon after European arrival was exploited for mining and timber industry. Kauri

(*Agathis australis*) was logged with increasing intensity from the mid 19th to the mid 20th century. Some areas of original Kauri forest survived, and much of the remainder has since regenerated (Department of Conservation, 2006). The island is now mostly covered by a mosaic of forest remnants, regenerating shrublands, and secondary forest (Ogle, 1981).

Vegetation

The island can be divided into three mountain blocks, which differ in geology, climate and past land use, and also show differences in vegetation. The northern block [NB], which was privately owned until 1984 is dominated by Tataweka peak (526m), it is mostly covered by native forest including Kauri patches, however some land has been cleared for pasture. The central block [CB] is the most diverse forest on the island, with the most ancient Kauri forests, however it was also the most disturbed by timber and logging activities. It is a regenerating forest, with patches of manuka and kanuka (*Leptospermum sp*) scrub. The southern block [SB] is much lower in altitude reaching only 402m and is mostly covered by manuka and kanuka scrub, notably Kauris are almost absent from here. Forest composition also changes with elevation, at lower altitudes (up to 250 metres a.s.l.) it is mainly covered by mixed broadleaf forest, while from 200 to 340 metres a.s.l. is a kauri-rimu-towai forest, and at higher altitudes (Mt. Hirakimata) yellow-silver pine forest dominates (Ogden, 2004).

Biodiversity and conservation value

Great Barrier Island is considered a wilderness and it is of great conservation value. The island is home to many native threatened species of birds including the black petrel, brown teal, and Kaka. Also, its is a refuge for eight species of native skinks (including the critically endangered chevron skink), five native gecko species, and the ancient frog *Leiopelma hochstetteri* (Department of Conservation, 2006). It is free of possums, stoats, weasels, ferrets, deer, feral goats, wallabies, hedgehogs and Norway rats, which makes it very different from current mainland ecosystems. However, some introduced pests exist on the island such as feral cats, pigs, ship rats, kiore (Pacific rat), mice and rabbits. Sixty percent of the island is administered by the Department of Conservation who actively protect the island's biodiversity. In addition, private landowners and volunteers also work to restore the island's ecosystems. The Glenfern Sanctuary (Port Fitzroy) with its recently completed pest excluder fence, and the Little Windy Hill projects, represent a major step towards the restoration of the island's biodiversity as well as an example of community effort towards conservation.

3.2.2 Hochstetter's frog on Great Barrier Island

Distribution and abundance

GBI holds the only known island population of Hochstetter's frog (*Leiopelma hochstetteri*). They are known to occur particularly in the NB, but very little is known about this population in comparison to its mainland counterparts. The first records of Hochstetter's frog are from a wildlife survey done in 1980, when twenty specimens were found in five catchments of the NB. Also, the introduced frog *Litoria raniformis* was found in sand dunes and swamp environments (Ogle, 1981). Nevertheless, Newman and Towns did the first comprehensive survey of GBI Hochstetter's frog population in 1983, and looked for frogs and lizards in the northern and southern blocks. They found relatively high abundances and presence of frogs in eleven streams in the northern block (total n = 234), however they found none in the south (Newman and Towns, 1985). In 1985, a single frog sighting was reported from a small tributary (seepage) in Kaiaraara Stream near lower Kauri dam in the CB, and a second sighting at this location was reported in 2005 (Department of Conservation, 2009a). This represents the only locality where frogs have been found outside the NB.

Conservation issues

GBI Hochstetter's frog population is known to be cytogenetically distinct from mainland populations and it is considered an independent evolutionary unit (Green, 1994). This evidence suggests that this population should be treated as a separate Conservation Management Unit [CMU] (Green, 1994). Main threats to native frogs on GBI are introduced animals. Feral goats used to be abundant in the NB and caused deterioration of forest habitat by inducing erosion through removal of ground cover and shrubs. They have been eradicated, however some wandering stock remains (cows).

Wild pigs are abundant at some places of the island (e.g., NB) and they can also cause important damage by eroding catchments through uprooting, and it is believed they also prey on native frogs. Rodents (Ship rats, kiore, and mice) are also considered threats as they are known to prey on native herpetofauna (Hoare et al., 2007).

3.3 Objectives

The general aim of this chapter was to update the known distribution and look at the current state of the Hochstetter's frog population on Great Barrier Island, and to make recommendations on how to monitor this population in the future. This chapter includes results from two surveys, and each of them with different objectives.

3.3.1 First survey (January 2008)

- Search for new locations of frogs in the central block of Great Barrier Island
- Do pilot site occupancy monitoring at Miners Cove Stream catchment in the northern block of Great Barrier Island

3.3.2 Second survey (March 2009)

- Confirm presence of frogs in different catchments of the northern block
- Confirm presence of frogs in the single locality in the central block where they have previously been found

3.4 Methods

3.4.1 First survey (January 2008)

Central Block

Three catchments (Kaiaraara Stream, Coffins Creek, and an unnamed stream) in the CB were searched for frogs during January 2008. Streams were selected based on habitat attributes (forest type) known to be associated with the presence of frogs, and by accessibility through established track networks. Only stream sections that were under mature native forest, and with relatively close access points were considered. All surveys were conducted during daytime, and streams were searched using a mixed sampling method. Nine *sites* were surveyed and additional *informal* searches were done while accessing and moving between sites. *Sites* were defined as 20m transects along streams. They were selected randomly while walking upstream. The sites were searched thoroughly looking under every potential refugia throughout the entire length (following the methods described in Chapter 2 of this thesis). Site characteristics and descriptions were noted as well as search effort (search time, number of refugia), and weather conditions. Any sign of disturbance was also recorded. While moving between sites through a stream, an opportunistic search (i.e., informal survey in which only the best refugia were turned, for example rocks that were flat and large) was done by the two observers.

Miners Cove

Eleven *sites* (as defined above) were selected in the Miners Cove Stream catchment. All sites were within a day-trip distance from basecamp (sea level, near the mouth of Miners Cove Stream). They were selected in different tributaries (see Figure 3.2). All sites were searched twice for frogs (different observers) to increase detection probability and to be able to apply site occupancy models of MacKenzie et al. (2002).

Data analysis

Site occupancy models of MacKenzie et al. (2002) (as described in Chapter 2) were used to obtain overall occupancy and detection probability (assuming occupancy and detection probability constant across sites and survey occasion).

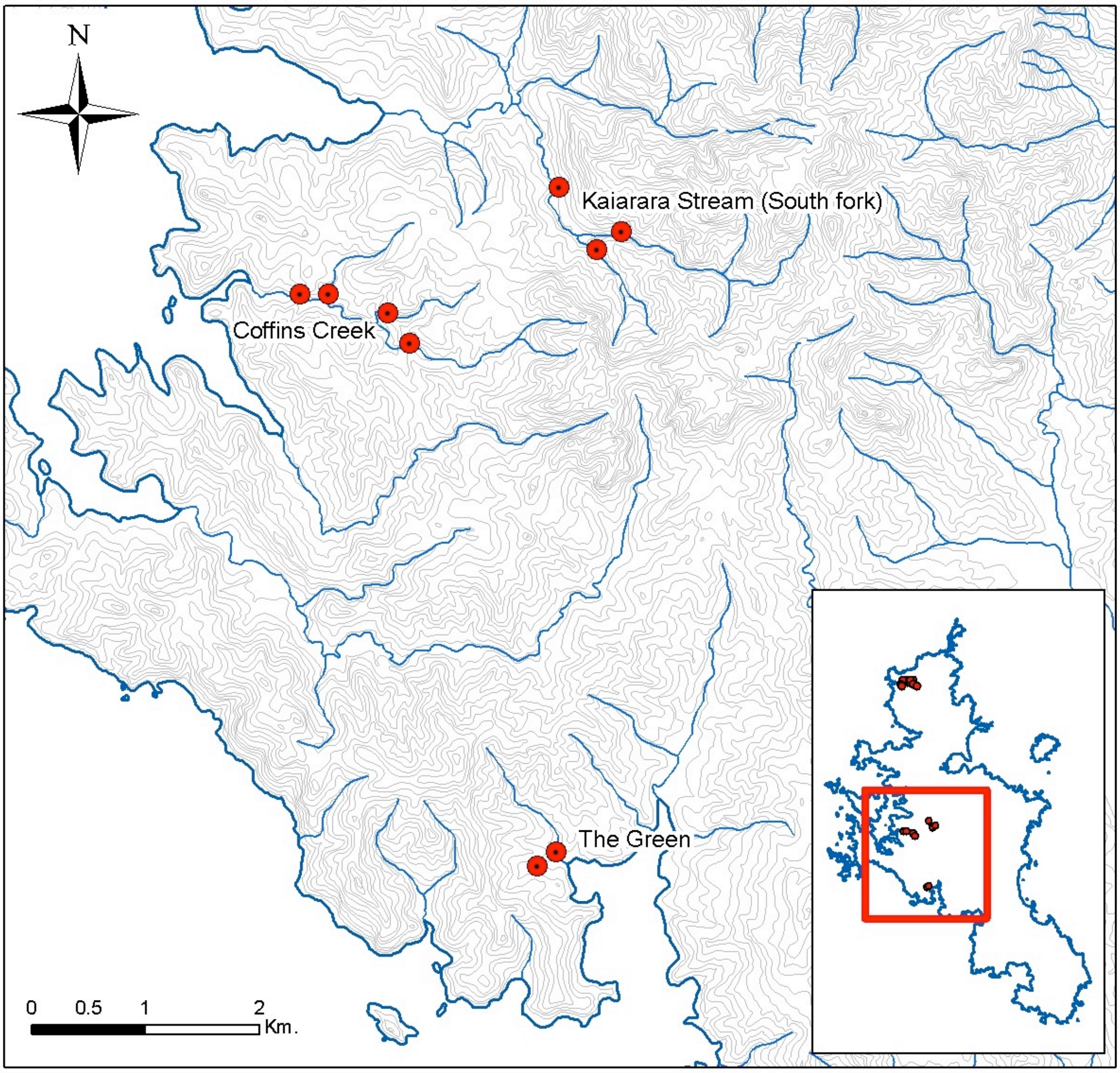

Figure 3.1 Map showing the sites surveyed for Hochstetter's frogs in the central block of GBI during January 2008.

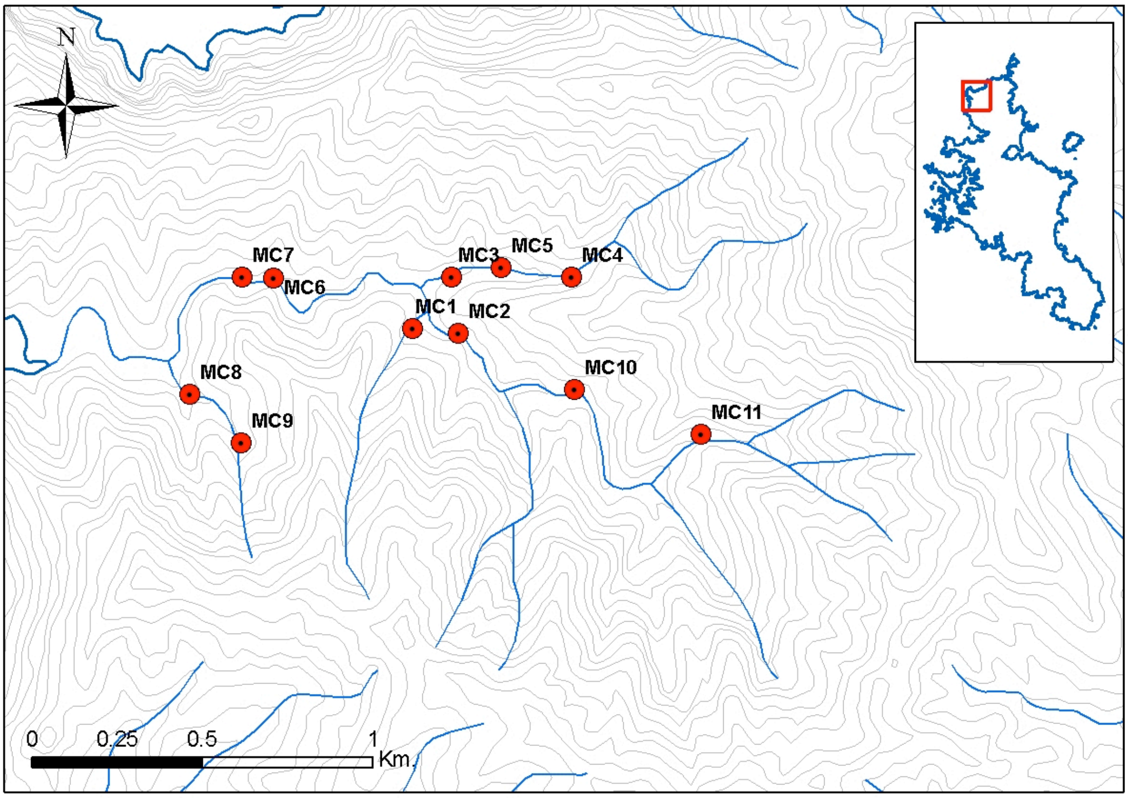

Figure 3.2 Map showing the location of sites surveyed for Hochstetter's frog in Miners Cove catchment in the northern block of Great Barrier Island during January 2008.

3.4.2 Second survey (March 2009)

Three catchments (i.e., Miners Cove Stream, Motairehe Stream, Aloha Stream) in the NB (see Figure 3.3), and two small tributaries of Kaiaraara Stream in the CB (see Figure 3.4) were surveyed for frogs during March 2009. Surveys were *informal* (as described above) and not all sections of streams were searched with same intensity. Searches were conducted during the daytime. Two or three observers searched along the streams in the most favourable refugia available. Frogs found were measured using a plastic ruler and their position was fixed using a GPS receiver.

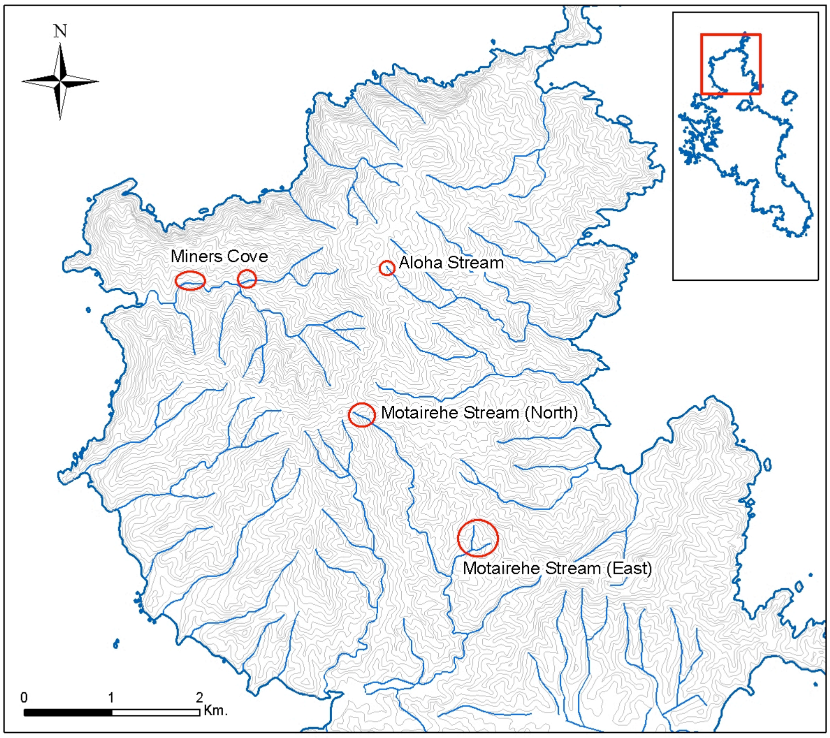

Figure 3.3 Map showing areas in the northern block of Great Barrier Island surveyed for Hochstetter's frog during March 2009.

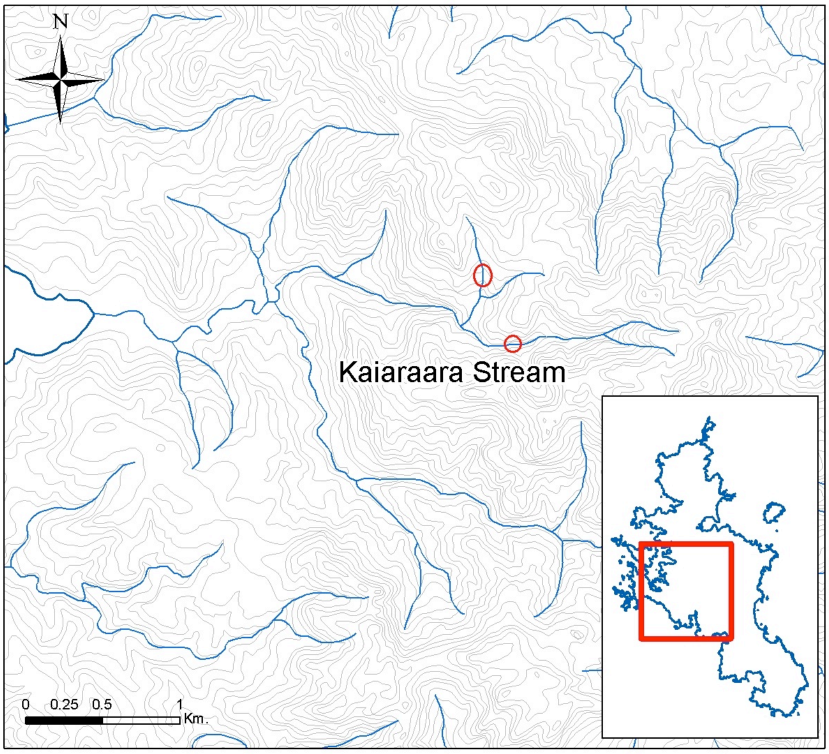

Figure 3.4 Map showing areas surveyed in the central block of Great Barrier Island during March 2009.

3.5 Results

3.5.1 First survey: January 2008

Central block

No frogs were found in any of the streams searched in the CB. All sites surveyed had potential refugia such as rocks and logs. In general, all sites surveyed looked suitable for frogs, with no apparent disturbance, with the exception of one site that had signs of animals (footprints), probably pig. Vegetation was dense at all sites and canopy cover was dense except when the streambed was wide (>5m) allowing for sunny spots in the streams.

Miners Cove Stream

Frogs were detected in 5 of the 11 sites surveyed (see Figure 3.5). Estimated detection probability and occupancy was $\hat{p}$ = 0.75 ± 0.17 (SE) and $\hat{\psi}$ = 0.49 ± 0.17 (SE), respectively. Nine frogs were detected inside the sites and three additional frogs were found outside the sites. Site locations and descriptions are attached in Appendix VII.

3.5.2 Second survey: March 2009

Frogs were found in all areas searched in the NB (see Figure 3.6). The highest abundance observed was in the Aloha Stream headwaters, where 21 frogs were found in a quick search of nearly 30 metres of stream. Presence of frogs was confirmed in a small tributary (seepage) near Kauri Dams in the CB, while a quick search done in a close tributary failed to detect frogs in the surroundings.

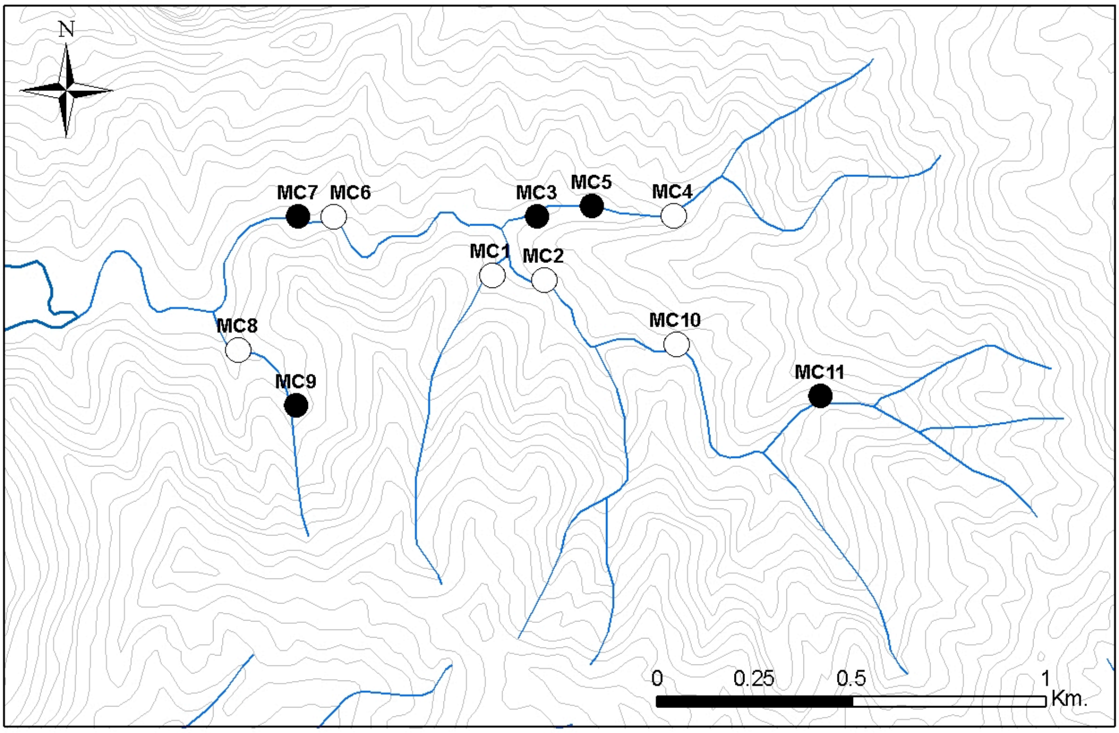

Figure 3.5 Map of Miners Cove Stream catchment showing presence/absence of frogs at surveyed sites, black circles represent occupied sites, while white circles represent sites where no frogs were detected.

Table 3.1 Results obtained from survey conducted during March 2009 in different catchments of Great Barrier Island.

Catchment	Approximate distance searched (metres)	Search time (person hours)	Nº frogs found
Motairehe Stream (North)	250	9	6
Motairehe Stream (East)	460	6.6	13
Aloha Stream	30	3.6	21
Miners Cove Stream	400	13.5	11
Kaiaraara Stream	25	3	5
TOTAL	**1,165**	**35.7**	**56**

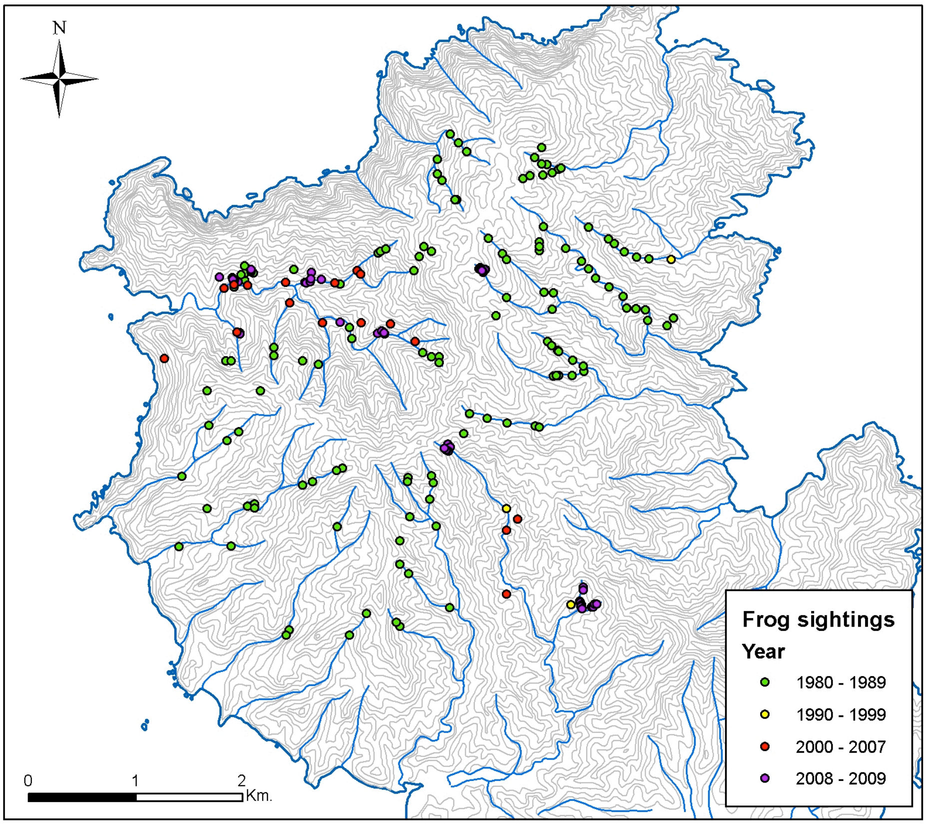

Figure 3.6 Map showing all reported Hochstetter's frog sightings in the northern block since 1980 (*Source*: Department of Conservation, New Zealand, Herpetofauna database).

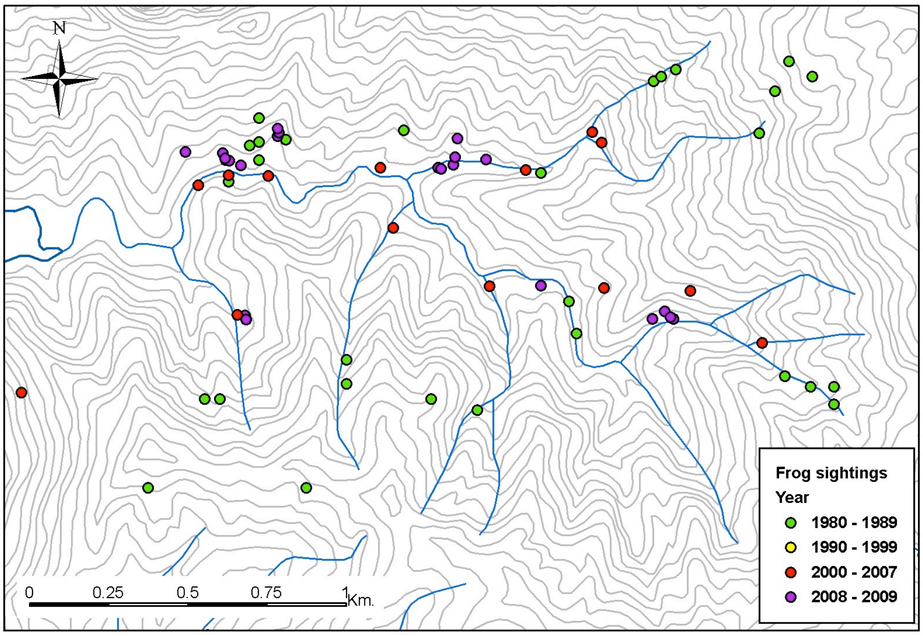

Figure 3.7 Detailed map of Miners Cove Stream catchment showing all reported frog sightings since 1980.

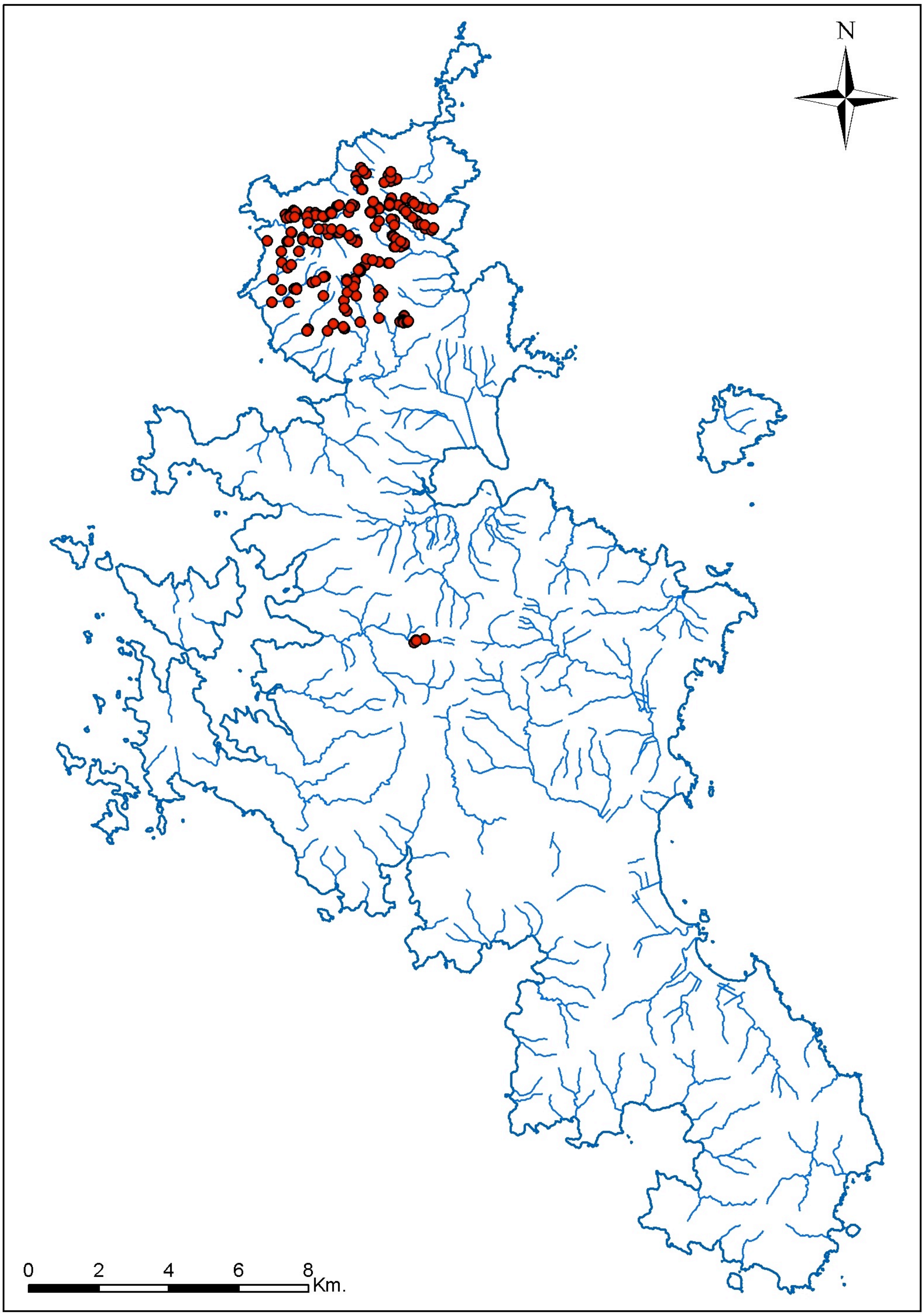

Figure 3.8 Map of Great Barrier Island showing all reported Hochstetter's frog sightings to date.

3.5.3 Population structure

A total of 56 frogs were measured during the second survey. Using Whitaker & Alspach (1999) classification (see Chapter 2), most measured frogs were adults (71%), followed by subadults and juveniles (14% each). Size frequencies are shown in Figure 3.9. The mean snout vent length was 26.8 ± 0.96 mm (SE) and ranged from 10 to 40mm.

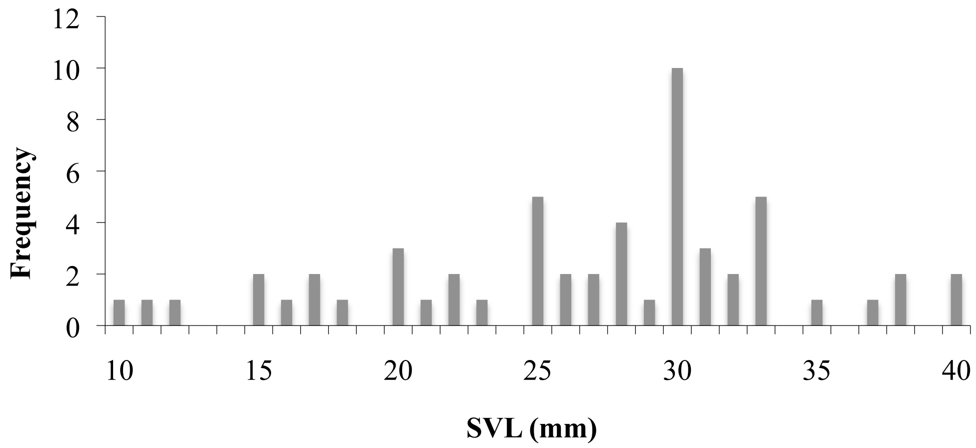

Figure 3.9 Frequency distribution of body sizes (*n*=53)

3.6 Discussion

No new locations were found for Hochstetter's frog in the CB of GBI, however interpretation of this result requires some qualification. The lack of experience of the observers in finding frogs (at the time) may have played an influential role. Although it is *not* likely that frogs were present at sites surveyed (at least not in high abundances), it is possible that sites selected for the survey were not ideal frog sites. Most streams searched were relatively wide, with rather open canopy, and probably prone to flooding during heavy rain periods. It is still likely that frogs are present in the CB at higher altitudes and smaller tributaries, which were not included in this survey due to accessibility problems.

Even though frogs were found at Miners Cove Stream during the first survey, they were present at lower densities than had been previously recorded (Newman & Towns, 1985). This result however, may be due to a number of reasons. First, lower order tributaries were not reached due to difficult access and safety considerations (most of previous sightings occurred in the high altitude first order tributaries). Also, both observers had very little experience looking for frogs prior to this survey, and search effort was allocated in doing repeated surveys rather than covering a larger number of streams. Although it is possible that this population has declined during the past 20 years, the limitations of the current study do not provide conclusive results of a decline.

The pilot site occupancy study at Miners Cove stream yielded statistically poor results, however this was expected due to the low number of sites and visits. Nevertheless, it served to get a better idea of what conditions and constraints are important in establishing a site occupancy monitoring programme at this location. Time taken to survey and difficulties in accessing sites were two of the main constraints. One way of minimising access time is to do all repeated visits on the same survey occasion. Depending on the target number of repeated surveys this may cause considerable disturbance and biased results due to frogs jumping away. An alternative way of doing repeated visits but without searching the same transect (to avoid disturbance) is to survey close transects (close enough to be considered the "same site") and survey each just once (see MacKenzie et al., (2006)). With more than one observer this can be done simultaneously. For example, a site may be considered as a section of stream, and three adjacent 20-30m transects may be surveyed by three observers independently. This way, no additional effort is allocated in a second visit to the same stream section (site), and resources can be used to survey a greater number of sites instead, and cover a greater area. Based on the estimates obtained here and by Crossland et al. (2005) at least three to four repeated surveys should be done at each site. Ultimately, the number of sites will depend on what desired level of precision, the number of repeated surveys and the resources available (total level of survey effort) (MacKenzie and Royle, 2005).

Miners Cove catchment was visited again by the same observers a year after the first survey, to see if more experience could yield more frog findings. More frogs were found in the second visit than the first, however, no high abundances such as those reported by Newman & Towns (1985) were found either. The second survey at Miners Cove included only small tributaries, though all of them were located at relatively low altitudes, and this may be related to the low frog abundances found. The results obtained from the areas surveyed at higher altitudes, particularly at Aloha Stream headwaters supports this. From the results obtained here, it is not possible to make any conclusion as to whether the frog population at the northern block is declining or not, but the confirmation of the presence of frogs in all areas surveyed, including very high abundances suggests that there is no immediate cause for concern. Furthermore, feral goats were abundant two decades ago when frogs were first surveyed, and have since been eradicated (though some cattle are still present). This suggests that disturbance has probably diminished during the past 20 years. Considering that the northern block is recovering from past disturbances, and if no new threats are introduced, it may be expected that this frog population will increase in the future.

The confirmation of the presence of frogs in the central block suggests a sustained population exists there. This finding is encouraging as the seepage where they are found is very small and relatively isolated. It is possible that frogs are present at nearby tributaries (which haven't been surveyed) forming a continuous distribution with the northern block, however habitat is fragmented by roads, farmland, and human settlement and it is unknown if this species is able to disperse under these conditions. It is likely then, that this could be considered a subpopulation, which has been isolated from the northern block for some time.

It is clearly important to confirm the degree of isolation of this subpopulation as conservation issues such as vulnerability to stochastic events or genetic inbreeding may arise. Also, the survival of a small subpopulation in such a small area suggests that other tributaries may have remaining frog subpopulations (which may or may not be isolated from their neighbours), and that the population should best be considered a metapopulation. Either way, frogs at this locality should be included in long term monitoring, and potential threats and disturbances minimised in order to protect them. For example, the area where they live is crossed by the Kaiaraara track and it is close to a popular Great Barrier Island attraction (Kauri Dams) making potential impact of human disturbance a concern.

Despite the limited presence of frogs, and the possibility that other subpopulations may exist in the central block, it is striking that frogs are not more widespread throughout the island. Considering the island is mostly covered by native forest and that fewer introduced predator/pest species exist here in comparison to mainland, the reasons why frogs are not abundant in areas other than the northern block is obscure. In order to elucidate this, further studies are required. For example, pigs and rats may have important impacts on frog abundances, thus measuring rat levels (tracking tunnels) or pig disturbance in the northern block where frogs are abundant and elsewhere (central and southern blocks) may throw some light on this issue.

Overall, one of the major challenges in surveying (and monitoring) frogs on Great Barrier Island was actually getting to the sites where they occur (no tracks, steep slopes). This leads to a logistic problem when designing monitoring programs as often time and monetary resources are limited, which in turn leads to *convenience* sampling (sampling only where access is relatively easy). The problems of convenience sampling are multiple (Anderson, 2001) and it should be avoided whenever possible.

3.7 Recommendations

1) Compare levels of disturbance between the northern block and the rest of the island and relate them to frog abundance.

2) Survey small first order tributaries (high altitude) in the central block.

3) Create management actions likely to increase abundance and distribution in the central block.

4) Establish site occupancy monitoring throughout the entire range on Great Barrier Island.

5) Assess the potential for translocations of frogs inside pest management areas (e.g., Glenfern Sanctuary).

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CHAPTER 4

Chytridiomycosis prevalence in the Waitakere Ranges and Great Barrier Island, Auckland Region, New Zealand

Plate 4. Swabbing the ventral surface of a frog (*Photo*: Claudio Aguayo)

4.1 Abstract

Chytridiomycosis is an amphibian emerging infectious disease caused by the chytrid fungus *Batrachochytrium dendrobatidis*. The fungus parasitizes the amphibian skin causing sickness, and eventually death of the host. It has been linked to many amphibian declines worldwide, and has been recently discovered in New Zealand native frogs (*Leiopelma archeyi*), but it has not yet been detected on any Hochstetter's frog (*Leiopelma hochstetteri*) population. This study aimed to test two populations of Hochstetter's frog (Waitakere Ranges and Great Barrier Island) for the presence of chytrid fungus. Both populations tested negative, and in addition no obviously sick frogs were found. Overall all frogs found looked healthy, however it is not 100% certain that the fungus is absent from these populations, as testing of all individuals would be needed. However, the size of the sample checked indicates that if present the prevalence is extremely low. The apparent absence of chytridiomycosis in Hochstetter's frog populations from Whareorino forest and Coromandel (where the fungus has infected *L. archeyi*), and elsewhere suggests Hochstetter's frog may be resilient or immune to the fungus. Future research on the susceptibility of *L. hochstetteri* to the chytrid fungus, as well as the study of potential defence mechanisms may be of great importance in understanding the disease and aiding in the conservation of amphibians worldwide.

4.2 Introduction

4.2.1 Chytridiomycosis

Chytridiomycosis is a recently discovered amphibian infectious disease caused by the chytrid fungus *Batrachochytrium dendrobatidis* [Bd] (Phylum Chytridiomycota) (Longcore et al., 1999). The fungus parasitizes the keratinised tissue of the amphibian skin causing sickness and eventually death of the host. Sick frogs might show signs of physical and neurological damage such as lethargy, lack of appetite, skin discolouration, presence of excessive sloughed skin, and abnormal sitting posture with hind legs adducted (BergerSpeare and Hyatt, 1999). It is unknown exactly how the fungus kills the individual, but three potential causes have been proposed: (1) epidermal hyperplasia impairs cutaneous respiration and osmoregulation; (2) fungal toxins are absorbed systemically; and (3) a combination of (1) and (2) (BergerSpeare and Kent, 1999, Berger et al., 1998, Daszak et al., 1999).

Chytrids are ubiquitous fungi found in aquatic and moist soil environments (Daszak et al., 1999). Bd like most chytrids (and other fungal pathogens) is capable of developing and reproducing saprophytically at least for short periods, which may enhance its persistence in the environment (Daszak et al., 1999). Furthermore, it has been demonstrated that it can survive without a host and remain infectious for at least three weeks in sterile aquatic environments (Johnson and Speare, 2003). This way, the flagellated zoospore of Bd may travel long distances through water until it eventually associates with a surface, which may be a new host or other organic material such as moist soil or bird feathers (Johnson and Speare, 2005). Also, infected tadpoles can serve as vectors and reservoirs of the disease as the pathogen does not have a lethal effect on them (they only have keratin in their mouthparts) (Daszak et al., 1999). Nonetheless, Bd does not survive prolonged periods of desiccation or sustained high temperatures (i.e., >47ºC for 30 min) (Johnson and Speare, 2003).

4.2.2 Bd impact on amphibian populations

Chytridiomycosis has been linked to the declines of several populations and extinctions of anurans worldwide, including North, Central and South America, Asia, Africa, Europe, and Oceania (Berger et al., 1998, Daszak et al., 1999, Daszak et al., 2003, Waldman et al., 2001, Skerratt et al., 2007, Lips, 1999, Une et al., 2008). Since the first outbreaks of chytridiomycosis were documented in Australia and Central America in the late '90s, the extent of its occurrence has expanded rapidly, producing "waves" of mass deaths and declines (Daszak et al., 1999, Lips et al., 2008). To date, Bd has been detected in over 200 species (Skerratt et al., 2007) from at least 37 countries (Olson and Ronnenberg, 2008). Based on retrospective analysis of museum specimens, it has been hypothesised that Bd originated in Africa, and from there it disseminated through the international trade of *Xenopus laevis* that began in the mid-1930s (Weldon et al., 2004).

The impact of Bd appears to be most severe in montane rain forest areas (Lips et al., 2006), however the effect of the disease can vary with many factors, such as latitude (Kriger et al., 2007), season and temperature (Berger et al., 2004), and strain (Berger et al., 2005). Moreover, each species can be affected to a different degree (Woodhams et al., 2007). Some may be completely immune while others may persist with endemic infections (Retallick et al., 2004, BishopSpeare et al., 2009). The immune mechanisms present in some species are still poorly understood, however it is known that antimicrobial peptides produced in granular glands, and bacteria present in the skin may play a fundamental role in the innate response (Rollins-Smith and Conlon, 2005, Harris et al., 2009). More recently, the role of acquired immune defences has been investigated and supported by preliminary evidence (Richmond et al., 2009). In spite of the above, further studies are needed in order to understand the immunological response to Bd, which makes this an active field of research.

4.2.3 Diagnosis

Chytridiomycosis can be diagnosed by different methods including histology (BergerSpeare and Kent, 1999), histochemistry (Berger et al., 2002, Olsen et al., 2004), electron microscopy and real-time PCR Taqman assay (Boyle et al., 2004, Hyatt et al., 2007). Histological methods have been used in dead and preserved specimens, and for live animals where toe-clipping the individual is needed. Less invasive techniques such as PCR assays have been used for detecting chytridiomycosis in wild populations, to date, the most reliable, rapid, and less invasive technique used for detecting chytridiomycosis in wild amphibians is the swab-PCR assay (Kriger et al., 2006, Hyatt et al., 2007).

4.2.4 Cure

No solutions are known to date for chytridiomycosis in wild populations, however research on captive sick frogs have yield some positive results. Treatment with high temperatures (Woodhams et al., 2003), chloramphenicol (Poulter et al., 2007), itraconazole (Forzán et al., 2008, Garner et al., 2009), and the addition of the antifungal bacterial species *Janthinobacterium lividum* (Harris et al., 2009) had prevented morbidity and mortality of infected captive frogs. These techniques may be of great importance in maintaining chytrid-free captive breeding programs, and in quarantine procedures in translocations and reintroduction of species into unaffected areas.

4.2.5 Bd in New Zealand

In 1999 chytridiomycosis was found in wild exotic frogs (*Litoria raniformis*) in the South Island of New Zealand (Waldman et al., 2001). In 2001, it was found in the Coromandel Peninsula's population of the endemic frog *Leiopelma archeyi*, and it has been suggested that this could be the reason for this species substantial and recent decline (BellCarver et al., 2004). More recently, in 2006 chytridiomycosis was found in the only other population of *L. archeyi* at Whareorino forest, despite no decline being detected in that population in the recent years (2005-2008) (Haigh et al.). The question remains if this population declined prior the start of monitoring in 2005.

To date *L. archeyi* remains the only native species for which the fungus has been discovered, despite *L. hochstetteri* sharing its range distribution with both of the infected populations of *L. archeyi*. These two populations of *L. hochstetteri* have tested negative for the presence of chytridiomycosis, however other populations have not been surveyed or have not had adequate samples tested and results are inconclusive (Shaw et al., 2009). Given that *L. hochstetteri* is the most aquatic of all native frogs, it is believed to be at very high risk of infection with Bd (Waldman et al., 2001).

It is yet unknown if the Waitakere Ranges and Great Barrier Island *L. hochstetteri* populations are infected with Bd as no chytrid fungus survey has ever been done at these sites. The Waitakere Ranges population is one of the biggest, best known, and most protected in the Auckland Region and it appears to be stable (see Chapter 2), however chytridiomycosis, along with introduced mammals, remains one of this population's main threats. The population on Great Barrier Island is presumably smaller, and certainly much less studied. It is genetically distinct from the mainland populations and is the only island population of this species, so it should be treated as a separate conservation unit (Green, 1994). The Coromandel peninsula where the fungus is present is only 20km distant and some birds such as the New Zealand dotterel and presumably the North Island Kaka and New Zealand Harrier commute from the island to the mainland and back (H. Jamieson pers. comm.), which increases the chance of the fungus reaching the island. In addition, in the Waitakere Ranges as well as on Great Barrier Island, the introduced Australian genus *Litoria* is present, however it is unknown if these populations are infected with the chytrid fungus.

4.3 Objective

Determine chytridiomycosis prevalence in the Waitakere Ranges and Great Barrier Island populations of *Leiopelma hochstetteri*.

4.4 Methods

4.4.1 Sample collection

To detect at least one infected individual (with a 95% confidence level) from a population with low disease prevalence (5%), a minimum of 60 samples is required for testing (DiGiacomo and Koepsell, 1986). In the Waitakere Ranges, swab collection was done during survey and monitoring conducted from May-December 2008 (see Chapter 2). Between one and four swabs were taken per study site (including close surroundings), depending on local availability of frogs (site density). On Great Barrier

Island swabs were collected during surveys conducted from January 2008 to March 2009 (see Chapter 3), and swabs were taken from all frogs found (except for those that escaped capture). Samples were collected from different areas (catchments) within a population to cover the maximum area possible. Collection of samples halted when the minimum number of samples needed per population was reached. All samples were taken after all surveys and monitoring at the site had finished to avoid disturbing the frogs, and to minimise sources of variation in survey counts.

4.4.2 Swabbing protocol

The technique used for detecting Bd presence was the swab-PCR assay described in Hyatt et al. (2007). The swabbing protocol followed was the one prepared and recommended by the Department of Conservation (Haigh, 2007). A new dry swab (MWE MW100-100) was used for each frog. Sterile gloves were used for handling each frog. If a frog had soil on the surfaces to be swabbed, the soil was gently removed using stream water. All ventral areas of the frog were swabbed, including the underside of the legs and axilla, with particular emphasis on the feet and the inguinal region. All areas were swabbed at least three times. After swabbing the frog, the swab was placed back into a sterile container and labelled with the frog ID, location (NZMG coordinates from GPS receiver), and size (snout to vent length, SVL) of the frog. In the field, swabs were kept as cool as possible. Upon returning from the field swabs were stored at 4ºC (from 1 to 12 months) to avoid growth of other non-target microorganisms prior to sending the sample to the diagnostic laboratory.

4.4.3 Testing

All swab samples were sent to a qualified laboratory (EcoGene™, Landcare Research) for testing for the presence of Bd. The method used for testing was the real-time PCR with three replicates per sample as described in Hyatt et al. (2007). Samples were either tested separately (single sample/swabs per test) or pooled (two samples per test) as shown in Appendix VIII.

4.5 Results

Sixty-one swab samples were collected from the Waitakere Ranges, and 63 from Great Barrier Island. Locations of the samples taken are shown in Figure 4.1 (detailed locations are available in Appendix VIII). All swabs tested negative for the presence of chytrid fungus. Estimated prevalence of chytridiomycosis was <5% (95% confidence level) for both populations.

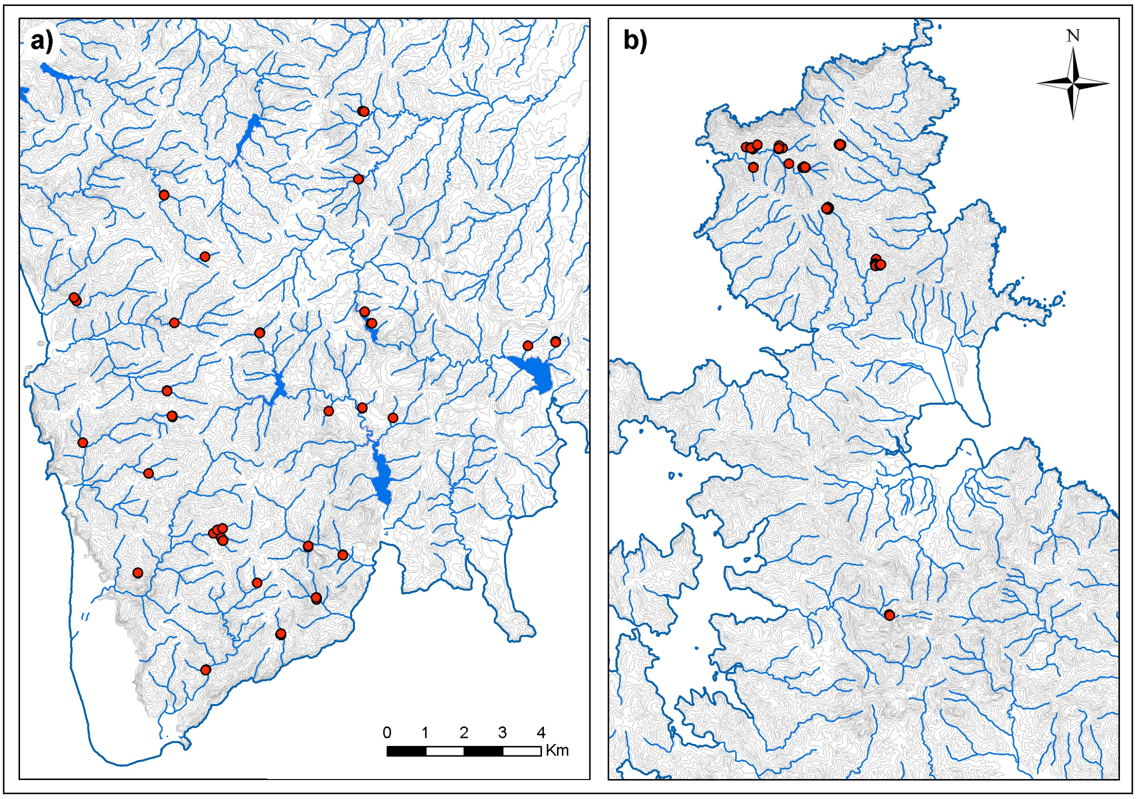

Figure 4.1 Map showing all swab samples taken (dots) in; a) Waitakere Ranges and; b) Great Barrier Island populations of Hochstetter's frog (both maps are at the same scale).

4.6 Discussion

Chytrid fungus was not detected at any location sampled in this study. Based on the number of samples tested, it is 95% certain that chytrid fungus prevalence is lower than 5%, but it is not possible to be 100% certain that the fungus is not present at lower prevalence. However, Bd prevalence, when present, is often higher than 5% (McDonald et al., 2005). Nonetheless, all Hochstetter's frog populations sampled for Bd presence to date, including those from areas where the fungus is known to be present, have tested negative. These results suggest that *L. hochstetteri* is relatively resilient to the disease, or possibly even immune. The recent discovery of the spontaneous elimination of the chytrid fungus by infected captive individuals of *Leiopelma archeyi* (BishopSpeare et al., 2009) raises the question of whether all native frogs might have low levels of susceptibility to the disease.

Immunity to chytridiomycosis has been found previously in some species. In Australia, where Bd is widely present some species such as *Mixophyes* spp. and *Litoria lesueurii* appear not to have had population declines, despite being exposed to the fungus in the environment. Moreover, after an initial decline *Litoria genimaculata* increased to pre-decline numbers, which suggests that Bd may have become endemic after the initial epidemic wave (McDonald et al., 2005).

Further studies on the response of native frogs to Bd infection may help elucidate the level of threat that chytridiomycosis really imposes to wild populations. Knowing this is critical in effectively allocating resources available for conservation of these species. Experimental infections have proven to be useful in identifying species at higher risk of becoming infected with Bd and developing chytridiomycosis (Vazquez et al., 2009). If Hochstetter's frogs are found effectively resistant to Bd they could also serve as a model for studying the immune mechanism, which would lead to a better understanding of the disease.

4.7 Recommendations:

1) Laboratory studies on the vulnerability of Hochstetter's frog to Bd. While this is not clear keep surveying populations.

2) Test for presence of Bd in the introduced *Litoria* species where they share their distribution with native frogs.

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CHAPTER 5

General Conclusion

Plate 5. Two Hochstetter's frogs (*Photo*: Claudio Aguayo)

5.1 Introduction

The general aim of this thesis was to make a significant contribution to the conservation of the threatened endemic amphibian *Leiopelma hochstetteri* through research. This was achieved by focusing on two of the main conservation issues for this species, the need for standardised and robust monitoring techniques to detect trends and changes in populations, and the determination of the prevalence of chytridiomycosis, a recently introduced amphibian disease. Two populations were selected for this study, one on the mainland (Waitakere Ranges) and the other the only known offshore island population of this species (Great Barrier Island). For both study sites different monitoring methods were used to obtain occupancy, detection probability and relative abundance parameters, as well as recommendations on the establishment of long term monitoring programmes. In this chapter I will review the main findings and conclusions of this thesis and put them into a more general context. Some general recommendations are made, and future research directions are suggested.

5.2 General conclusions and future research directions

About the species

Hochstetter's frog and all native frogs of New Zealand are under constant threat. Once widespread, they have now reduced their range to a few isolated populations, and most of them survive only because their habitat has been protected from introduced species and human disturbance. The results obtained here suggest that both studied populations (Waitakere Ranges and Great Barrier Island) appear to be stable (i.e., frogs were relatively widespread, with some sites supporting high densities), and healthy (i.e., no evidently sick frogs were found, all swab samples tested negative for chytrid fungus). However care must be taken in generalising these results, as this may not reflect the state of the species at a national level. Also, the limited comparability of previous data with data obtained here means no firm conclusions can be drawn regarding overall trends in these populations.

The status of many other Hochstetter's frog populations, that haven't been recently studied (e.g., some Northland populations) are still unknown. Even where frog habitat may be protected from threats such as deforestation, the frog populations are still vulnerable to other types of threats such as disease, increased UV radiation, and global warming. Furthermore, based on the results from this study along with previous findings (Baber et al., 2006) it is still possible that there are Hochstetter's frog populations yet to be discovered, which means they may be unprotected and at high risk of habitat modification or removal. As it has been suggested before (Green et al., 1993, Green, 1994), Hochstetter's frog populations should be managed as independent Conservation Management Units, each of which still requires further genetic and distribution studies. It is likely that the identification of CMU's will be one of the research focuses of the next period of the Native Frog Recovery Plan for this species (Bishop et al., 2009).

Monitoring techniques

Robust estimations of occupancy and detection probability in the Waitakere Ranges were obtained using MacKenzie et al. (2002) models with covariate data. Important factors affecting these parameters as well as distribution and abundance patterns were identified. In addition, occupancy was estimated for three separate age classes, which allowed for a better assessment of the populations reproduction and recruitment status. These results contribute to form a baseline for long term monitoring at this location and to the development of this method as monitoring technique for Hochstetter's frog. Some factors affecting occupancy and detection probabilities are still unknown, but ongoing monitoring of this and other populations using this technique will undoubtedly help in identifying them. Future surveys at this location will also enable the analysis of multiple season data, which will be valuable for understanding the population dynamics of this species.

The advantages of using site occupancy modelling of MacKenzie et al. (2002) as a monitoring technique were discussed in detail in this thesis, and these advantages have been increasingly recognised by researchers around the world. These models provide a flexible framework and thus they can be used on a variety of different organisms to answer many ecological questions (for some recent applications of this methods see: (De Wan et al., 2009, O'Connell Jr. et al., 2006, Stanley et al., 2005, Olson et al., 2005). Also, the availability of the analytical software PRESENCE 2.3, which includes several models, makes this method attractive for conservation biologists and wildlife managers as it provides a more friendly and direct way of analysing the field data without creating complicated spreadsheets. As more scientists use these methods, the models and applications will continue to improve and the literature will grow rapidly.

In estimating relative abundance the method most representative in this study was the repeated transect counts and the use of sight re-sight criteria. Although I wouldn't recommend this for long term monitoring because of the elevated cost and low statistical inference. The two abundance models used gave contrasting results. Based on presence/absence data only, the Royle & Nichols (2003) model underestimated abundance, while the repeated counts model of Royle (2004) was likely to have overestimated frog abundance. Therefore, these models (as constructed here, using covariate data) failed at providing reliable abundance estimation. It is possible that with the use of other appropriate covariates the models will perform better. Nevertheless, the results obtained here highlight the importance of statistical inference in estimating abundance when dealing with species with imperfect detection. The development of these and other similar abundance models is a field of current research, which holds promise as a method of inferring abundance (MacKenzie et al., 2006). Therefore, these abundance models shouldn't be discarded as the data obtained here, and in future surveys, may be re-analysed or analysed respectively as new methods appear.

The use of *detection probability* (obtained using occupancy models) and *first frog* data as surrogate measures of relative abundance should be cautious. The significant relationships found may be used for the Waitakere Ranges population as a rough approximation only, and could help identify spatial correlations and patterns, but shouldn't be used to infer absolute abundance, nor should they be used in cases where abundance is the primary parameter of interest. The use of mark recapture (i.e., individual ID) methodologies would enable a better estimation of abundance parameters and would also give information on movement patterns, dispersal, mortality, longevity and other parameters of interest. The use of the photo stage (Bradfield, 2004, Department of Conservation, 2009b) is promising considering it has been used in studies of the related *L. archeyi*, and it may be possible that technology on photographic ID will allow the use of ID software in the near future. Nevertheless, methods for identifying individual Hochstetter's frog should be further investigated.

Because we live in a changing world, we can expect that ecosystem processes, populations, and the threats and variables determining species abundance, distributions and persistence will also change. This means that the issues for biodiversity in conservation are constantly evolving. New threats appear (e.g., emerging infectious diseases) while others may disappear (at least at a local scale e.g., pest eradication, habitat protection). Management of threatened species has to be able to cope with these changing conditions, but perhaps most importantly it has to learn from ecosystem responses to change. As knowledge of ecosystem functioning increases, the key elements may be identified, as well as the outcomes of conservation efforts. This use of management as a tool not only to change a system, but as to learn about the system is fundamental to *adaptive management* (Walters and Holling, 1990), a desirable approach in long-term and large-scale monitoring programmes, such as the one here established in the Waitakere Ranges.

Chytridiomycosis

Both studied populations tested negative for the presence of chytrid fungus, which means that *if* present, the fungus has very low disease prevalence. This result is encouraging considering Hochstetter's frog were previously thought to be at very high risk of infection from the chytrid fungus (BellTocher et al., 2004). It appears that *L. hochstetteri* is relatively resistant to chytridiomycosis, however this must be confirmed with further studies. Not only should all populations be frequently monitored (as chytridiomycosis can spread relatively fast), but also a greater confidence interval is needed, particularly in large areas such as the Waitakere Ranges. The cost involved in collecting and testing more samples is certainly an issue, but pooling them can reduce it significantly. If further immunological studies are done, and *L. hochstetteri* is found resistant to the disease, then surveying populations may not be necessary, so the best way to allocate effort now may be through the study of the vulnerability to the disease, both in captivity and in the wild. Also, the prevalence of chytridiomycosis should be determined in introduced amphibian populations (*Litoria spp*) and the potential risk of these species spreading or acting as a reservoir for the disease should be assessed.

Amphibian conservation

The sudden decline of amphibian populations worldwide has been a great issue for conservation during the past decade, and many scientific studies have been carried out to identify the possible causes of such decline. In New Zealand, the main causes of decline during the past century have been habitat loss through the transformation of native forest to farmland and human development, and the introduction and establishment of exotic predators and pests into native ecosystems. More recently chytridiomycosis has also been identified as a potential cause of decline. Even though these agents of decline are widely accepted, they have not been conclusively demonstrated (BishopHaigh et al., 2009). Other agents of decline and/or potential synergistic effects may still be unknown, and further research in this issue will certainly benefit the conservation of amphibians.

With the increasing effort for restoring natural ecosystems through pest management in New Zealand, it is expected that in the future more pest-proof areas will allow the recovery of existing populations and the establishment of new ones. The advances made in translocations and reintroductions of herpetofauna are encouraging (Germano and Bishop, 2009), and this may allow for a future restoration of much of the original range of New Zealand's native frogs.

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Appendix I. Survey data sheet

SEARCHER: ________________________ DATE: ______________________

LOCATION (catchment/site nº): ____

E: _______________ N:_______________ Elev.:__________ Acc.:+/-__________

ENVIRONMENTAL CONDITIONS

AIR Tº: ___________ HUMIDITY:______________

RAIN (during survey): none showers constant (light/ moderate/ heavy)

RAIN (last 24hr): none showers constant (light/ moderate/ heavy)

CANOPY COVER(%): ___________ STREAM ORDER:________

FLOW:_____________

STREAM width; 0m:_____________ 20m:___________ 40m:_________________

OBSERVATIONS (e.g., vegetation type, disturbance, other species, water clarity):

____
____
____
____

SEARCH EFFORT:

Start Time:_________Finish Time:________ Search Time:__________
Total Distance Searched (m):____________
Total Nº of Refugia Searched:____________

FROG DATA:

Time	Distance (m)	Side of stream	Cover object	S.V.L	Nº Refugia	Notes (distance from water, colour)

Figure I.1: Survey data sheet.

Appendix II. Location of Waitakere Ranges sites

Table II.1 Sites locations (GPS reading, NZMG coordinates), ID numbers, and catchment names. (*): New sites.

SITE ID	Catchment	Nº	Location	GPS Reading (at 0m)			
			Stream name	Easting	Northing	Elevation	Acc. (±)
1	Anawhata	1	Pigwallow Stream	2644127	6474874	169	8
2	Anawhata	2	Gentil Stream	2641525	6474209	179	4
3	Anawhata	3	Stream in Saunders Gully	2645240	6473285	278	17
4	Arataki*	1	Cantys Stream	2653028	6471992	145	19
5	Nutts Stream*	1	Nutts Stream	2648135	6464356	61	5
6	Cascade	1	Maioha Stream	2644614	6477915	180	15
7	Cascade	2	Tributary of Robinson Stream	2645730	6477407	133	11
8	Cascade	3	Cascade Stream	2645662	6477477	125	10
9	Cascade	4	Toetoeroa Stream	2646767	6477929	60	9
10	Cascade*	5	Bacon Stream	2645352	6478082	177	16
11	Huia	1	Stream in Dublin Gully	2648816	6465494	49	5
12	Huia	2	White Stream	2647927	6465723	134	6
13	Huia*	3	Tributary of Dingle Brook	2650446	6466555	41	10
14	Kakamatua*	1	Kakamatua Stream	2652209	6468260	97	8
15	Kakamatua*	2	Tributary of Kakamatua Stream crossed by Farley Track (not shown in topo map, refer to GPS coords) approx. 15m upstream from track	2651314	6467146	93	8
16	Kakamatua*	3	Tihihana Stream	2651310	6468059	174	7
17	Karekare	1	Basket Stream	2643021	6466827	144	4
18	Karekare	2	Seepage that crosses Zion Hill Tk	2642056	6466864	83	5
19	Karekare	3	Tributary of Company Stream,	2643757	6467641	190	?

			Para Gully				
20	Karekare*	5	Ocean View Stream	2642067	6468392	33	13
21	Karekare*	6	Karekare Stream	2644344	6469098	229	20
22	Lower Huia Dam	1	Nugget Stream	2648487	6469292	103	6
23	Lower Huia Dam	2	Tributary of Huia Stream	2649338	6469339	76	35
24	Lower Huia Dam	3	Tributary of Smiths Stream	2650122	6469079	110	14
25	Lower Nihotupu Dam	1	Stream that runs under the pipeline & Pipeline Rd. (true left branch)	2653374	6470915	72	15
26	Lower Nihotupu Dam	2	Rata Paddock Stream	2653643	6470949	52	15
27	Lower Nihotupu Dam	3	Wood Stream	2654368	6471048	102	8
28	Mill Bay*	1	Healy Stream	2653235	6466804	20	?
29	Opanuku	1	Stream that flows parallel to Opanuku Pipeline Tk	2649365	6477101	90	9
30	Opanuku*	2	Opanuku Stream	2649210	6476721	87	5
31	Opanuku	3	Tributary of Fairy Falls Stream	2649245	6475307	147	16
32	Pararaha	1	Waihuna Stream	2643008	6465229	139	8
33	Pararaha	2	Seepage that crosses Buck Taylor Tk	2643476	6465035	242	6
34	Pararaha	3	Tyree Stream	2645671	6465910	267	11
35	Pararaha	4	Tributary of Cowan Stream	2645687	6466198	253	9
36	Piha	1	Glen Esk Stream	2644243	6469780	181	7
37	Piha	2	Seepage that crosses Centennial Tk just North of Piha Stream	2644430	6471550	127	17
38	Piha	3	Stream in Mead Gully	2642706	6470698	47	10
39	Piha*	4	Wekatahi Creek	2641917	6472151	31	11
40	Piha	5	Marawhara Stream	2643612	6473849	229	10
41	Swanson	1	Swanson Stream	2649242	6478284	70	10

42	Upper Huia Dams	1	Tributary of Snowy Stream	2646843	6471540	313	15
43	Upper Huia Dams	2	Snowy Stream	2646639	6471291	266	24
44	Upper Nihotupu Dam	1	3rd stream after the bridge when walking down Upper Nihotupu Dam Rd.	2649397	6471830	229	7
45	Upper Nihotupu Dam	2	6th stream after the bridge when walking down Upper Nihotupu Dam Rd.	2649591	6471547	227	8
46	Wainamu	1	Plum pudding Stream	2641754	6477697	54	15
47	Whatipu	1	Tributary of Gibbons Stream	2643910	6462232	188	11
48	Whatipu	2	Tributary of Whatipu Stream	2645273	6462525	33	10
49	Whatipu	3	Seagull Stream	2646588	6464777	310	6
50	Whatipu*	4	Baker Stream	2647229	6463419	212	5

Appendix III. Waitakere Ranges site descriptions and observations

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Site ID: 1
Canopy Cover: 50-74%
Stream Order: 2 **Stream Width:** 2.1m
Stream Flow: continuous-moderate/fast
Vegetation: Paratanìwha, Nikau, tree fern, moss.
Dates Surveyed: 10/12/2008, 14/12/2008
Observations: Not many rocks, but lots of refugia in moss, logs and leaves. Water was silted first visit due to rain in previous day. Second visit the water was clear. Signs of flooding.
Other species: Weta, landhoppers and other invertebrates.

Site ID: 2
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 1.5m
Stream Flow: continuous-moderate
Vegetation: Young forest. Tea tree, tree fern, small ferns alongside the stream, Nikau.
Dates Surveyed: 26/09/2008, 30/09/2008
Observations: Site is crossed by track with 3-4m with no vegetation and some silt. Clear water, not many loose rocks, rock bed covered with moss. Dead frog found at 15m (1m downstream from track).
Other species: Spiders, weta, Koura, many invertebrates.

Site ID: 3
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.2m
Stream Flow: continuous-moderate/fast
Vegetation: Nikau, tree fern, supplejack, broadleaf trees, epiphytes, moss covered rocks. No Parataniwha.
Dates Surveyed: 10/12/2008, 14/12/2008
Observations: Very few loose rocks, most refugia searched was moss, leaves, and roots. Rock bed stream and relatively steep. Leaf litter.
Other species: Many invertebrates (landhoppers and others).

Site ID: 4
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.7m
Stream Flow: continuous-slow
Vegetation: Parataniwha, Nikau, tea tree, tree fern, 7 fingers, supplejack.
Dates Surveyed: 11/12/2008, 15/12/2008
Observations: Sandy, muddy stream, with some mudslides in the sides (steep slopes). Lots of driftwood debris, leaves and vegetation. Relatively closed stream. Not many loose rocks but plenty of refugia in vegetation.
Other species: Weta, landhoppers, spiders, Koura.

Site ID: 5
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.5m
Stream Flow: continuous-moderate
Vegetation: Lots of parataniwha alongside the stream, tree ferns, lots of Nikau (many seedlings), broadleaf trees, some Kauri.
Dates Surveyed: 26/10/2008, 29/10/2008

Observations: Clear water, many good sized rocks, plenty of good refugia. Moss covered rocks. Site is close to Project K house, and is good candidate for any long-term studies. 4 (additional) frogs were found downstream from site (within 5m, 1 swabbed WR34).
Other species: Many invertebrates (landhoppers, weta).

Site ID: 6
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 1.7m
Stream Flow: continuous-moderate
Vegetation: Abundant parataniwha, very high tree ferns, some supplejack, moss covered rocks.
Dates Surveyed: 8/11/2008, 12/11/2008
Observations: Few good sized rocks, however some refugia among the moss covered rock bed. Many small sized rocks. Some small waterfalls. Small waterfall and pool (3m diameter) at the end of the site.
Other species: Many weta, very few landhoppers and small invertebrates.

Site ID: 7
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.7m
Stream Flow: continuous-slow
Vegetation:
Dates Surveyed: 16/05/2008, 23/05/2008
Observations: Site finished at 30m because of a pool, very narrow, with few rocks. Deep gully stream with 2-3 m high walls, small number of refugia. Flooding signs, unstable walls and streambed. Would recommend changing this site for the other tributary instead (looks more favourable).
Other species:

Site ID: 8
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.6m
Stream Flow: continuous-moderate
Vegetation:
Dates Surveyed: 16/05/2008, 23/05/2008
Observations: Not many rocks, few moss covered rocks.
Other species:

Site ID: 9
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.7m
Stream Flow: continuous-moderate
Vegetation: Few parataniwha. Good mature forest; Nikau, tree fern and Kauri.
Dates Surveyed: 8/11/2008 (2 surveys only)
Observations: This site is the same as EcoQuest frog survey site 1D and others every 20m of stream (flagging tape). Many rock piles, however rocks are rather small, good refugia.
Other species: Weta, invertebrates (landhoppers).

Site ID: 10
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.5m
Stream Flow: continuous-slow
Vegetation: Abundant supplejack, parataniwha, tree fern, epiphytes.
Dates Surveyed: 8/11/2008, 12/11/2008
Observations: No rocks at this site, refugia searched were leaves, logs, and roots. Streambed is slightly silted/sandy. Pool from 3-13m with unstable streambed and walls (section not searched). Very shady site. Not best habitat for frogs, however stream might have better refugia elsewhere, but it was not possible to explore (and sample) upstream from Lower Kauri track crossing because access through supplejack was

impossible. Downstream from finish point (23m) was also too difficult to sample. This site was searched downstream.
Other species: Few invertebrates, Koura, snails.

Site ID: 11
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 1m
Stream Flow: continuous-slow
Vegetation:
Dates Surveyed: 18/05/2008, 25/05/2008
Observations: Site finishes at pool
Other species:

Site ID: 12
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 2.5m
Stream Flow: continuous-moderate
Vegetation: Abundant vegetation surrounding the stream: parataniwha, Nikau.
Dates Surveyed: 18/05/2008, 25/05/2008
Observations: Good habitat, small pools. Relatively open stream at some places. Many rocks. We started 7m from track, 4m upstream from K. Bradfield site.
Other species: Weta, invertebrates.

Site ID: 13
Canopy Cover: 50-74%
Stream Order: 2 **Stream Width:** 1.4m
Stream Flow: continuous-moderate
Vegetation: Parataniwha, tea tree, tree fern, Nikau.
Dates Surveyed: 16/06/2008, 21/06/2008
Observations: Site starts 40m downstream from the 4th bridge on Farley Track (coming from Huia). Stream runs parallel to track for a while looking suitable along the way. Not many loose rocks to search in the transect, but big boulders might serve as good refugia. A small tributary joins the stream about 1m downstream from site, which looks suitable for frogs as well.
Other species:

Site ID: 14
Canopy Cover: 50-74%
Stream Order: 3 **Stream Width:** 2.5m
Stream Flow: continuous-fast
Vegetation: Tree fern, Nikau, tea tree, parataniwha on the sides.
Dates Surveyed: 5/10/2008
Observations: 0m mark is 15m upstream from Parau Tk (bridge). Open stream, wide streambed, and light spots. Big boulders with good refugia. Only 2 visits to this site due to heavy rain during the sampling period.
Other species: Eels, spiders.

Site ID: 15
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.9m
Stream Flow: continuous-moderate
Vegetation: Parataniwha, Nikau, tree fern.
Dates Surveyed: 15/07/2008, 20/07/2008
Observations: Search finished at 30m to protect habitat (too difficult to search further). Site was slightly silted and muddy, some disturbance (paths crossing stream -not sure if they are animal or people). Not many searchable refugia (not many loose rocks, most were embedded in the mud. Some landslides on the

sides. Site was moderately flooded (rainy period) provoking landslides and silting the water. Perhaps more suitable for small frogs rather than big ones (?).
Other species: Spiders.

Site ID: 16
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.6m
Stream Flow: continuous-moderate
Vegetation: Parataniwha, Nikau, tree fern.
Dates Surveyed: 5/10/2008
Observations: Site starts approximately 5m upstream from Parau Tk (bridge). Many logs and big boulders with good refugia, but impossible to search. Water is clear. Streambed is relatively open. Only 2 visits to this site due to heavy rain during sampling period.
Other species: Weta, spiders, and many landhoppers.

Site ID: 17
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.6m
Stream Flow: continuous-slow
Vegetation: Secondary forest. Nikau, tree fern, tea tree, Kauri. No lower vegetation (no parataniwha).
Dates Surveyed: 16/07/2008, 21/07/2008
Observations: Site has few rocks, most refugia searched were leaves and crevices. Site is slightly silted because of erosion. Stream is in a gully with walls 2m high at some point, and narrow -1,5 width. Some landslides. No retreat sites when flooded. Few good refugia for adults (maybe suitable for juveniles). Leaf litter on the sides of the stream is relatively dry, as forest is not dense. Bait station 20m downstream from site, another bait station (labelled OP5B) at 25m.
Other species: Koura, small invertebrates, spiders.

Site ID: 18
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 0m
Stream Flow: isolated pools
Vegetation: Tea tree, very few tree ferns and Nikau. No low vegetation. Regenerating forest 10-15m high (not dense).
Dates Surveyed: 16/07/2008, 21/07/2008
Observations: Very dry, only few isolated pools, no surface flow, water just filtrating very slow through rocks and soil. Site fairly exposed to sunlight and wind at some points. Some leaf litter, abundant at some points. Some unsearchable potential refugia (beneath big boulders where it might be wet and cold enough for frogs). Good rocks, but not enough water (?).
Other species: Spiders, landhoppers.

Site ID: 19
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.6m
Stream Flow: continuous-moderate
Vegetation: Ferns, tea tree, Rimu, 7 fingers, no parataniwha.
Dates Surveyed: 5/12/2008, 11/12/2008
Observations: Some sandy spots, not many loose rocks, some metal wires and plastic in the stream. Peter King took us here with his dog. Pest control area (La Trobe mainland island).
Other species: Koura.

Site ID: 20
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.7m
Stream Flow: continuous-slow

Vegetation: Teatree, Nikau, tree fern, some Kauri. No parataniwha.
Dates Surveyed: 14/11/2008, 16/11/2008
Observations: Relatively open stream, many good-sized rocks. Some evidence of flooding, some disturbance upstream (moss is turned by some animal probably looking for small invertebrates).
Other species: Koura, spiders, landhoppers, weta, earthworms.

Site ID: 21
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 2m
Stream Flow: continuous-moderate
Vegetation: Abundant parataniwha, tree ferns, broadleaf trees, some supplejack.
Dates Surveyed: 14/11/2008, 16/11/2008
Observations: Shady stream, some fallen trees in the site. Many good refugia including abundant good-sized rocks.
Other species: Many weta, spiders, landhoppers and invertebrates.

Site ID: 22
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 1.1m
Stream Flow: continuous-moderate
Vegetation: Parataniwha on the sides. Tree ferns, Nikau.
Dates Surveyed: 24/10/2008, 28/10/2008
Observations: Few rocks, but many good refugia on Nikau and tree fern roots, which are difficult to search. Rocky bed. Perfect spot: wet, shady, clear water, all sorts of refugia.
Other species: Fish.

Site ID: 23
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.4m
Stream Flow: continuous-moderate
Vegetation: Nikau, tree fern, tea tree, parataniwha, Kauri.
Dates Surveyed: 6/12/2008
Observations: Rocky stream, excellent refugia. Only 2 visits to this stream to protect habitat and small frogs (many juveniles here).
Other species: Weta, Koura, many invertebrates.

Site ID: 24
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 1.7m
Stream Flow: continuous-moderate
Vegetation: Lots of big parataniwha. Huge tree ferns, tea tree, ferns, Nikau, broadleaf trees.
Dates Surveyed: 24/10/2008, 28/10/2008
Observations: Many rocks, many unsearchable refugia (under big logs). Big landslide at 40m. High/open canopy. Open stream: streambed is 4m wide. Big waterfall after site.
Other species: Fish

Site ID: 25
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.8m
Stream Flow: continuous-moderate
Vegetation: Parataniwha, Nikau, tree fern.
Dates Surveyed: 3/10/2008, 6/10/2008
Observations: Site not searchable between 13-20m due to fallen tree. Small stream very eroded with plenty of landslides with very few retreat sites. Slightly muddy and silted due to erosion, water was clear but turned silted with the rain. Most rocks embedded in mud and impossible to search.

Other species: Koura and plenty of invertebrates (landhoppers), weta.

Site ID: 26
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.6m
Stream Flow: continuous-moderate
Vegetation: Nikau, tree fern, tea tree.
Dates Surveyed: 3/10/2008, 6/10/2008
Observations: Relatively open site (open stream bed), high canopy. Not many good sized rocks. Some inaccessible good refugia though.
Other species: Many landhoppers, weta, spiders, Koura.

Site ID: 27
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.7m
Stream Flow: continuous-slow (isolated pools the first meters)
Vegetation: Many tree fern and Nikau, ferns. Young tea tree forest (low canopy).
Dates Surveyed: 24/10/2008, 28/10/2008
Observations: Narrow (0.5m) streambed the first 10m with few refugia. At 25m stream widens and more refugia is available.
Other species: Many Koura, fish, weta**.**

Site ID: 28
Canopy Cover: 50-74%
Stream Order: 2 **Stream Width:** 2.1m
Stream Flow: continuous-moderate
Vegetation: Parataniwha, Nikau, tree fern, tea tree, vegetation is not dense and is relatively high/open.
Dates Surveyed: 6/12/2008, 11/12/2008
Observations: Few loose rocks, stream is slightly silted and sandy, streambed is soft. Relatively wide/open stream. 2 frogs were found (1 juvenile (9mm), 1 sub-adult (18mm) where small (1st order) tributary joins the stream in the TR about 40m upstream from culvert (Huia Road), downstream from site.
Other species:

Site ID: 29
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.5m
Stream Flow: continuous-moderate
Vegetation: Some parataniwha, tree fern, Nikau, tea tree, some supplejack.
Dates Surveyed: 17/07/2008
Observations: Rocky streambed however rocks are small sized. Stream is slightly silted, with plenty of landslides on the sides. Found 2 frogs outside the site (40m downstream) and 1 frog 50m upstream in tributary that joins stream at 0m.
Other species: Landhoppers, spiders.

Site ID: 30
Canopy Cover: 50-74%
Stream Order: 2 **Stream Width:** 2.5m
Stream Flow: continuous-moderate/fast
Vegetation: Parataniwha, tree fern, Nikau, Rimu, broadleaf trees, moss covered rocks.
Dates Surveyed: 9/11/2008, 13/11/2008
Observations: Not same site than K. Bradfield, changed due to accessibility. Site is just upstream from where Spragg Stream flows into Opanuku Stream. Wide streambed with good refugia, some signs of flooding (water level might have raised more than 50 cm). This site was visited in winter but was not searched because it was flooded (1 frog was found in this site in winter). There is a pool from 16-23m not searchable. Some big boulders.

Other species:

Site ID: 31
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 2.5m
Stream Flow: continuous-moderate/fast
Vegetation: Parataniwha, Nikau, tree fern, ferns.
Dates Surveyed: 8/12/2008, 13/12/2008
Observations: Excellent habitat, many good sized rocks, plenty of good refugia. Leaf litter. Pest control sign at the beginning of Fairy Falls track, but no bait stations were seen.
Other species: Eels, weta, many invertebrates.

Site ID: 32
Canopy Cover: 50-74%
Stream Order: 2 **Stream Width:** 1.9m
Stream Flow: continuous-moderate
Vegetation: Tea tree and broadleaf tree very abundant.
Dates Surveyed: 14/06/2008, 20/06/2008
Observations: Site has a pool at 15.2m (w/o rocks, no refugia on the sides). Last 5m is a pool (no searchable refugia). Not many loose rocks, but quite few big boulders (not able to search but good refugia). It is relatively dry beside the stream (and in the surroundings).
Other species:

Site ID: 33
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 0.1m
Stream Flow: isolated pools
Vegetation: Some supplejack. High canopy.
Dates Surveyed: 14/06/2008, 20/06/2008
Observations: It is a small seepage, water flowing very slowly, almost still. Isolated small pools (only 4cm deep). From 15 to 25m water runs underground with a dense leaf litter over, we did not search this litter to protect habitat and frogs, only discrete leaf packs were turned and searched for frogs. Damp under the litter. One additional frog was found just 1m downstream from the site, right where the track crosses the stream. It looks more wet downstream.
Other species:

Site ID: 34
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.4m
Stream Flow: continuous-moderate
Vegetation: High canopy (20m); Rimu, Kauri, tea tree, ferns, broadleaf tree. Few and small parataniwha.
Dates Surveyed: 22/10/2008, 27/10/2008
Observations: Good stream, moss covered rocks, some big boulders, clear water.
Other species: Koura, weta, spiders, many invertebrates.

Site ID: 35
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.3m
Stream Flow: continuous-slow/moderate
Vegetation: Close canopy (bushy) at the beginning of the site, then opens. Rimu, tree fern, Nikau.
Dates Surveyed: 22/10/2008, 27/10/2008
Observations: Site ends with waterfall at 40m, some sunny spots on the site. Plenty of good refugia. Water gets slightly silted when walking on streambed.
Other species: Weta, spiders, Koura, many invertebrates.

Site ID: 36
Canopy Cover: 50-74%
Stream Order: 2 **Stream Width:** 1.7m
Stream Flow: continuous-moderate
Vegetation:
Dates Surveyed: 15/05/2008, 22/05/2008
Observations: No disturbance observed, plenty of refugia (rocky bed). Found 2 additional frogs just 3m downstream (outside) the site (one of them was swabbed).
Other species:

Site ID: 37
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 0.3m
Stream Flow: isolated pools
Vegetation:
Dates Surveyed: 13/06/2008, 19/06/2008
Observations: Seepage/small stream, no surface water running at all from 2m to 16.9m, where there is a small pool. After the pool the stream is more wet, but no flowing water.
Other species:

Site ID: 38
Canopy Cover: 50-74%
Stream Order: 1 **Stream Width:** 0m
Stream Flow: isolated pools
Vegetation:
Dates Surveyed: 13/06/2008**,** 19/06/2008
Observations: No surface water, not even wet, very dry. Only a couple of small pools at the end but with no flowing water. After 1 week (3 days of rain) the stream was more wet with more surface water flowing slowly.
Other species:

Site ID: 39
Canopy Cover: 50-74%
Stream Order: 2 **Stream Width:** 2.7m
Stream Flow: continuous-moderate
Vegetation:
Dates Surveyed: 15/05/2008, 22/05/2008
Observations: Dry zones, open canopy areas, some signs of flooding.
Other species:

Site ID: 40
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.5m
Stream Flow: continuous-slow
Vegetation: Nikau, supplejack, tree fern, tea tree, broadleaf tree.
Dates Surveyed: 26/09/2008, 30/09/2008
Observations: Site was not searched from 18-25m because of pool. Clear water but gets easily silted when walking on steam bed. Not many good-sized rocks (loose) but plenty of moss-covered rocks, cracks, and roots which offers good refugia (unsearchable). Site finished at 33 due to dense vegetation. Leaf litter, relatively dry (no rain in the past days).
Other species:

Site ID: 41
Canopy Cover: 50-74%

Stream Order: 1 **Stream Width:** 1.5m
Stream Flow: continuous-slow/moderate
Vegetation: Nikau, tree fern, Kauri, Lancewood, some parataniwha on the sides, moss covered rocks.
Dates Surveyed: 8/12/2008, 13/12/2008
Observations: Stream gets silted easily when walking in it (sandy streambed). Some good rocks but not many, many refugia in moss-covered rocks/roots. Relatively open canopy. Not much refugia between 15-25m (pool). Some signs of flooding. Poison bait warning in the area.
Other species: Fish, weta, Koura, spiders and other invertebrates.

Site ID: 42
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.6m
Stream Flow: continuous-slow
Vegetation: Plenty of supplejack, parataniwha.
Dates Surveyed: 27/09/2008
Observations: K. Bradfield couldn't get GPS fix so it is not 100% certain that this site is the same as hers. She mentioned it was the 3rd stream going down in Huia Dam (upper) tk. This site is the 3rd 'big' tributary as many smaller (unclear) crossed the track. This site was searched only once as it was very difficult to search without disturbing the habitat, due to supplejack and pronounced slope. I wouldn't recommend this site for long-term monitoring (except site-occupancy). Found and collected the rear legs of a frog (probably predated) which was given to Amanda Haigh from DOC to determine the cause of death.
Other species:

Site ID: 43
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 2.1
Stream Flow: continuous-moderate
Vegetation: Some parataniwha, Nikau, many ferns (tree ferns and others), tea tree.
Dates Surveyed: 27/09/2008, 2/10/2008
Observations: Open streambed. Many rock banks (only top rocks were removed) abundant refugia, including big boulders impossible to search. Clear water. Small tributary joins stream at 20m. Streams bifurcates and joins after couple of meters (searched both branches). Steep walls.
Other species: Koura, weta, spiders.

Site ID: 44
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.4m
Stream Flow: continuous-slow
Vegetation:
Dates Surveyed: 17/05/2008, 24/05/2008
Observations: Steep and small stream, very low canopy. Possum poo. Lots of refugia. Not evidently disturbed (hard for a pig to get to). Hard to walk without disturbing habitat.
Other species:

Site ID: 45
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.2m
Stream Flow: continuous-slow
Vegetation: Plenty of parataniwha.
Dates Surveyed: 17/05/2008, 24/05/2008
Observations: Site finished at 30m because of landslide/fallen tree(stream goes underground). Small and narrow stream with unstable floor, hard to search. Many good refugia, very steep, easy to disturb habitat. Wouldn't recommend 4 visits (full search) to this site to prevent impact on the frogs, site occupancy should be OK. Many impossible to search crevices, unstable rocks.
Other species:

Site ID: 46
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.2m
Stream Flow: continuous-moderate
Vegetation: Young forest. Nikau, parataniwha, tea tree.
Dates Surveyed: 15/06/2008
Observations: Few good-sized rocks, slightly silted, signs of cattle. Only 2 visits due to heavy rain.
Other species: Spiders, landhoppers, invertebrates.

Site ID: 47
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 0.6m
Stream Flow: continuous-slow
Vegetation: Supplejack, tree fern, Nikau.
Dates Surveyed: 14/05/2008, 21/05/2008
Observations: Small tributary (headwaters), dry upstream from site. Flowing very slow. Pig signs in the area. The site is silted/muddy upstream. Streambed with moss. Few low vegetation. Perhaps too dry in summer.
Other species: Koura, few spiders.

Site ID: 48
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.6m
Stream Flow: continuous-moderate
Vegetation:
Dates Surveyed: 14/05/2008, 21/05/2008
Observations: Good site for frogs, many refugia, very dark. Site ends at 34m with a waterfall.
Other species:

Site ID: 49
Canopy Cover: 75-100%
Stream Order: 1 **Stream Width:** 1.8m
Stream Flow: continuous-moderate
Vegetation:
Dates Surveyed: 12/06/2008, 18/06/2008
Observations: Lots of good refugia, couple of small pools.

Site ID: 50
Canopy Cover: 75-100%
Stream Order: 2 **Stream Width:** 1.5m
Stream Flow: continuous-moderate
Vegetation: Few parataniwha, tea tree, Nikau, tree fern.
Dates Surveyed: 12/06/2008, 18/06/2008
Observations: Slightly silted, lots of driftwood debris. Site starts 1m upstream from culvert (Whatipu Rd). Site has a concrete dam at 28m.
Other species: Many snail shells.

Appendix IV. List of frogs found in the Waitakere Ranges

Table IV.1. List of frogs found in the Waitakere Ranges during sampling season (May-December, 2008). Frog nº: frog number in each visit. Time: time taken to find frog. Distance: position of frog in the transect (from the 0m mark). SVL: snout vent length. Age classes used are; juvenile <18mm, sub-adult 18-24mm, adult >24mm. Shaded rows represent possible re-sightings, using the established criteria.

Site ID	Date	Visit	Searcher	Frog nº	Time (min)	Distance (m)	Side of stream	Cover object	SVL (mm)	Age class	Nº of refugia	Notes
1	10/12/08	2	Claudio	1	43	34.5	left	leaves	35	adult	?	jumped, SVL estimated
1	14/12/08	3	Claudio	1	27	22	right	rock	40	adult	111	15cm from water, jumped
1	14/12/08	3	Claudio	2	30	22.8	right	rock	38	adult	117	15cm from water, jumped
1	14/12/08	3	Claudio	3	34	26.5	right	rock	35	adult	137	20cm from water
1	14/12/08	3	Claudio	4	46	34.5	right	rock	33	adult	182	20cm from water
1	14/12/08	3	Claudio	5	51	38.5	right	rock	28	adult	200	35cm from water
1	14/12/08	4	Virginia	1	19	25	right	rock	33	adult	98	flat rock, swabbed WR60
1	14/12/08	4	Virginia	2	34	34	right	rock	34	adult	158	light brown
1	14/12/08	4	Virginia	3	40	38	right	rock	29	adult	184	green, 0.3m from water, swabbed WR59
3	10/12/08	1	Virginia	1	15	10.8	right	leaves	35	adult	56	sleepy, light clor, 20cm from water
3	10/12/08	1	Virginia	2	49	21.8	right	leaves	13	juvenile	113	green, up 1m from flow
3	10/12/08	1	Virginia	3	63	25.5	right	leaves	14	juvenile	133	on mud
3	10/12/08	1	Virginia	4	73	26	left	leaves	40	adult	151	jumped into stream
3	10/12/08	2	Claudio	1	4	1.9	right	rock	35	adult	15	jumped, 30cm from water
3	10/12/08	2	Claudio	2	48	24.5	right	leaves	18	sub-adult	159	2m from main flow in wet spot
3	14/12/08	4	Virginia	1	11	5.5	left	roots/moss	30	adult	43	jumped into water

3	14/12/08	4	Virginia	2	30	10	right	rock	30	adult	66	jumped
3	14/12/08	4	Virginia	3	34	10.1	right	log	28	adult	71	jumped, size estimated
3	14/12/08	4	Virginia	4	39	14	left	leaves	10	juvenile	86	
3	14/12/08	4	Virginia	5	76	5.1	left	leaves/roots	15	juvenile	158	
4	11/12/08	1	Virginia	1	22	12.5	left	rock	39	adult	75	size estimated
4	11/12/08	1	Virginia	2	32	16.3	left/middle	rock	16	juvenile	105	yellowish, 10cm from water
4	11/12/08	1	Virginia	3	59	24	left	rock	38	adult	175	on water, size estimated
4	11/12/08	2	Claudio	1	18	12.4	left	rock	39	adult	80	30cm from flow
4	11/12/08	2	Claudio	2	50	23.5	left	rock	42	adult	202	swam away, underwater
4	15/12/08	3	Claudio	1	32	17	left	rock	16	juvenile	164	0.2m from water
4	15/12/08	4	Virginia	1	11	16.5	left	rock	16	juvenile	94	same than previous visit
5	26/10/08	1	Claudio	1	10	5.6	right	log	28	adult	50	18cm from water
5	26/10/08	1	Claudio	2	39	19.1	left	rock	30	adult	151	jumped into the stream, branch w/rocks
5	26/10/08	2	Virginia	1	11	5.85	right	rock	23	sub-adult	55	light brown
5	26/10/08	2	Virginia	2	16	6.6	right	rock	20	sub-adult	65	beautiful
5	26/10/08	2	Virginia	3	36	18.3	left	rock	27	adult	178	vertical, size estimated
5	29/10/08	3	Claudio	1	5	3.2	right	rock	29	adult	20	jumped, 5cm from water
5	29/10/08	3	Claudio	2	12	5.4	right	rock	23	sub-adult	35	jumped, 40cm from water
5	29/10/08	3	Claudio	3	24	9.9	right	rock	40	adult	95	jumped, 40cm from water
5	29/10/08	3	Claudio	4	30	14.3	left	rock	30	adult	115	5cm from water
5	29/10/08	3	Claudio	5	44	18.6	left	rock	29	adult	179	10cm from water, pool
5	29/10/08	3	Claudio	6	63	26.1	left	rock	30	adult	273	30cm from flow

5	29/10/08	3	Claudio	7	86	37	middle	rock	35	adult	358	jumped, 10cm from water
5	29/10/08	4	Virginia	1	8	1.9	right	rock	9	juvenile	37	under small rock (5cm diameter)
5	29/10/08	4	Virginia	2	26	5.5	right	leaf	23	sub-adult	93	
5	29/10/08	4	Virginia	3	55	12.6	left	rock	26	adult	220	
5	29/10/08	4	Virginia	4	74	17.7	left/middle	rock	28	adult	305	
5	29/10/08	4	Virginia	5	82	18.4	left	rock	31	adult	319	
5	29/10/08	4	Virginia	6	91	22.5	left	rock	18	sub-adult	353	
5	29/10/08	4	Virginia	7	96	22.7	left	rock	30	adult	369	
5	29/10/08	4	Virginia	8	103	21.6	right	rock	27	adult	395	
5	29/10/08	4	Virginia	9	110	26.1	left	rock	31	adult	433	30cm above
5	29/10/08	4	Virginia	10	126	39.5	left	rock	42	adult	522	skinny
13	16/06/08	3	Claudio	3	15	8.1	left	rock	40	adult	39	same rock, jumped, size estimated
13	16/06/08	3	Claudio	4	15	8.1	left	rock	30	adult	39	same rock, jumped, size estimated
13	16/06/08	3	Claudio	5	35	19.4	left	rock	24	sub-adult	146	
14	5/10/08	1	Virginia	1	45	27.2	left	rock	36	adult	177	on slow flow
14	5/10/08	1	Virginia	2	48	27.2	left	rock	34	adult	178	50cm from above
14	5/10/08	1	Virginia	3	53	30.5	left	rock	32	adult	187	
14	5/10/08	2	Claudio	1	26	12.8	right	rock	28	adult	123	same rock
14	5/10/08	2	Claudio	2	26	12.8	right	rock	33	adult	123	same rock
15	15/07/08	2	Claudio	1	16	8	left	rock	25	adult	50	2cm from water
15	20/07/08	4	Virginia	1	4	1.9	right	leaves	12	juvenile	15	on damp ground 1m from stream
15	20/07/08	4	Virginia	2	23	5.4	left	leaves	22	sub-adult	55	20cm above water level
15	20/07/08	4	Virginia	3	28	6.4	left	leaves	11	juvenile	62	under Nikau leaf

15	20/07/08	4	Virginia	4	67	28.7	right	moss	12	juvenile	222	
15	20/07/08	4	Virginia	5	72	29.5	right	moss	9	juvenile	228	up
16	5/10/08	1	Virginia	1	19	16	left	rock	24	sub-adult	77	light brown
16	5/10/08	1	Virginia	2	33	20	left	rock	37	adult	117	below 20m mark
16	5/10/08	1	Virginia	3	56	32	right	rock	40	adult	200	together, jumped
16	5/10/08	1	Virginia	4	56	32	right	rock	38	adult	200	together, jumped
16	5/10/08	2	Claudio	1	20	16	left	rock	21	sub-adult	108	30cm from water
16	5/10/08	2	Claudio	2	33	20	left	rock	40	adult	183	1.2m from water on wet spot
16	5/10/08	2	Claudio	3	44	22.8	middle	rock	42	adult	224	
19	5/12/08	1	Claudio	1	4	1.5	right	rock	40	adult	20	50cm from water
19	5/12/08	1	Claudio	2	27	14.9	right	rock	38	adult	122	2cm from water, jumped
19	5/12/08	1	Claudio	3	47	26.7	right	rock	35	adult	179	on water, moved 10cm
19	5/12/08	2	Virginia	1	4	1.3	right	rock	40	adult	9	
19	11/12/08	3	Virginia	1	6	3	right	rock	37	adult	23	same refugia
20	16/11/08	4	Virginia	1	37	39.9	left	rock	33	adult	312	40cm from water, size estimated. Swabbed WR52
21	14/11/08	1	Claudio	1	48	34	left	rock	26	adult	297	10cm from water
21	14/11/08	2	Virginia	1	48	27	right	rock	22	sub-adult	281	jumped
21	14/11/08	2	Virginia	2	54	27.3	left	rock	29	adult	299	
21	14/11/08	2	Virginia	3	74	34	left	rock	25	adult	445	flat rock, 10cm from water
21	14/11/08	2	Virginia	4	80	37	left	rock	18	sub-adult	483	
21	14/11/08	2	Virginia	5	82	36	left	rock	30	adult	484	jumped, size estimated
21	16/11/08	3	Virginia	1	10	3	left	rock	31	adult	50	60cm from water, light brown, swabbed WR51

21	16/11/08	3	Virginia	2	26	7	right	rock	35	adult	125	at the beginning of big fallen tree fern, beneath tree, 10cm from water. Swabbed WR50
21	16/11/08	3	Virginia	3	59	20	right	rock	30	adult	265	jumped, size estimated
21	16/11/08	3	Virginia	4	94	29	right	rock	22	sub-adult	389	light brown, swabbed WR48
21	16/11/08	3	Virginia	5	117	36	left	rock	19	sub-adult	542	flat rock 50cm from water
21	16/11/08	3	Virginia	6	120	35.8	left	rock	30	adult	551	40cm above water
21	16/11/08	4	Claudio	1	11	3.2	left	rock	30	adult	41	90cm from water in semi-wet spot
21	16/11/08	4	Claudio	2	26	8	right	rock	39	adult	108	10cm from water
21	16/11/08	4	Claudio	3	63	28	right	rock	32	adult	339	5cm from water, underwater
21	16/11/08	4	Claudio	4	67	29	right	rock	24	sub-adult	354	40cm from water
21	16/11/08	4	Claudio	5	81	29.5	right	rock	20	sub-adult	408	20cm from water
21	16/11/08	4	Claudio	6	101	36.5	left	rock	19	sub-adult	579	60cm from water
22	24/10/08	2	Claudio	1	9	4.65	right	rock	35	adult	34	jumped to the flow
22	24/10/08	2	Claudio	2	15	4.7	left	rock	36	adult	52	same rock, jumped
22	24/10/08	2	Claudio	3	15	4.7	left	rock	33	adult	52	same rock, jumped
22	24/10/08	2	Claudio	4	17	4.7	left	rock	32	adult	53	jumped
22	28/10/08	3	Virginia	1	16	8.5	left	rock	30	adult	59	same rock, jumped
22	28/10/08	3	Virginia	2	16	8.5	left	rock	30	adult	59	same rock, jumped
22	28/10/08	3	Virginia	3	27	16.2	right	roots	12	juvenile	77	
22	28/10/08	3	Virginia	4	37	27	right	leaves	10	juvenile	102	
22	28/10/08	3	Virginia	5	48	37	right	roots	34	adult	117	together
22	28/10/08	3	Virginia	6	48	37	right	roots	12	juvenile	117	together
22	28/10/08	3	Virginia	7	50	36.8	right	moss/leaf	30	adult	118	swabbed WR41

22	28/10/08	4	Claudio	1	28	16.1	right	roots	10	juvenile	105	tree fern roots
23	6/12/08	1	Virginia	1	5	2.2	right	roots	23	sub-adult	22	0.5m up on steep wall, jumped into stream
23	6/12/08	1	Virginia	2	13	5.1	left	rock	25	adult	33	SVL estimated
23	6/12/08	1	Virginia	3	21	5.7	right	rock	20	sub-adult	55	SVL estimated
23	6/12/08	1	Virginia	4	24	6.6	right	rock	23	sub-adult	64	on slow flow, swabbed WR53
23	6/12/08	1	Virginia	5	35	8.9	right	roots	25	adult	86	SVL estimated, jumped, swabbed WR54
23	6/12/08	1	Virginia	6	52	17.5	left	rock	8	juvenile	124	under 5cm diameter rock, 5cm from water
23	6/12/08	1	Virginia	7	67	25.4	right	leaf	13	juvenile	172	40cm up and from water
23	6/12/08	1	Virginia	8	74	27	left	rock	28	adult	193	jumped into pool, size estimated, on isolated pool 1m away from main flow
23	6/12/08	1	Virginia	9	78	29	right	rock	10	juvenile	200	green
23	6/12/08	1	Virginia	10	82	31	left	roots	9	juvenile	210	up 0.8m rock
23	6/12/08	1	Virginia	11	85	31	middle/r	rock	25	adult	215	size estimated
23	6/12/08	2	Claudio	1	9	6.8	right	rock	28	adult	40	40cm from water, over flow
23	6/12/08	2	Claudio	2	25	17.2	left	rock	9	juvenile	112	5cm from water
23	6/12/08	2	Claudio	3	46	29.1	right	rock	11	juvenile	206	5cm from water
23	6/12/08	2	Claudio	4	52	31	left	moss	10	juvenile	218	80cm from water
23	6/12/08	2	Claudio	5	55	31.2	left	moss	15	juvenile	221	80cm from water
24	24/10/08	1	Claudio	1	2	0.3	right	rock	30	adult	2	jumped to water
24	24/10/08	2	Virginia	1	26	8.5	middle/l	rock	34	adult	130	close to next 2 frogs, skinny
24	24/10/08	2	Virginia	2	28	8.5	middle/l	rock	37	adult	131	
24	24/10/08	2	Virginia	3	30	8.6	middle/l	rock	34	adult	133	underwater
24	24/10/08	2	Virginia	4	62	27.8	right	rock	33	adult	295	
24	28/10/08	3	Claudio	1	51	15.9	right	rock	32	adult	220	jumped

24	28/10/08	3	Claudio	2	53	15.9	right	leaf	16	juvenile	221	10cm from previous frog
24	28/10/08	3	Claudio	3	84	32.5	right	rock	19	sub-adult	325	mini pool
24	28/10/08	4	Virginia	1	27	9.1	right	rock	39	adult	137	jumped
24	28/10/08	4	Virginia	2	48	16	right	rock	26	adult	212	vertical position, size estimated, swabbed WR40
24	28/10/08	4	Virginia	3	80	32.5	right	rock	16	juvenile	318	1m from flow
33	14/06/08	2	Claudio	2	43	28.5	middle	rock	20	sub-adult	129	almost no water nearby
33	20/06/08	3	Claudio	1	9	3.4	middle	rock	45	adult	20	same rock
33	20/06/08	3	Claudio	2	9	3.4	middle	rock	40	adult	20	same rock, jumped
33	20/06/08	3	Claudio	3	26	14.3	middle/l	rock	24	sub-adult	99	middle, left fork
33	20/06/08	3	Claudio	4	45	25.4	middle	rock	30	adult	125	same rock, brighter colour
33	20/06/08	3	Claudio	5	45	25.4	middle	rock	35	adult	125	same rock
33	20/06/08	3	Claudio	6	50	28.6	middle	rock	18	sub-adult	139	
33	20/06/08	3	Claudio	7	54	29	middle	rock	18	sub-adult	142	
33	20/06/08	4	Virginia	1	11	3.1	right	leaves	37	adult	49	jumped into water
33	20/06/08	4	Virginia	2	16	3.2	right	rock	42	adult	52	same rock
33	20/06/08	4	Virginia	3	16	3.2	right	rock	39	adult	52	same rock
33	20/06/08	4	Virginia	4	17	3.25	right	leaves	35	adult	53	size estimated
33	20/06/08	4	Virginia	5	55	13.4	middle	rock	24	sub-adult	158	swabbed ? Light brown
33	20/06/08	4	Virginia	6	68	25.4	middle	rock	30	adult	194	same rock
33	20/06/08	4	Virginia	7	68	25.4	middle	rock	35	adult	194	same rock
34	22/10/08	1	Virginia	1	10	8.7	left	rock	31	adult	33	same rock, jumped, size estimated
34	22/10/08	1	Virginia	2	10	8.7	left	rock	31	adult	33	same rock, jumped
34	22/10/08	1	Virginia	3	33	36.5	right	rock	40	adult	71	fat or gravid, beside parataniwha

34	22/10/08	1	Virginia	4	37	37	left	rock	35	adult	73	on the water
34	22/10/08	2	Claudio	1	17	37	right	rock	45	adult	69	2cm from water
34	27/10/08	3	Claudio	1	47	38	left	rock	36	adult	194	same rock, swabbed WR37
34	27/10/08	3	Claudio	2	48	38	left	rock	40	adult	195	same rock, swabbed WR36
34	27/10/08	4	Virginia	1	42	38	left	rock	40	adult	190	underwater
35	22/10/08	1	Virginia	1	42	32	left	log	30	adult	157	size estimated, jumped into the flow
35	27/10/08	4	Virginia	1	13	8.55	right	rock	35	adult	71	jumped, size estimated
35	27/10/08	4	Virginia	2	19	9.3	left	rock	43	adult	99	on water (flow), swabbed WR39
36	15/05/08	1	Virginia	1	19	9.7	left	rock	33	adult	89	on flow
36	15/05/08	1	Virginia	2	41	33	left	rock	41	adult	167	big rock
36	15/05/08	2	Claudio	1	22	9.8	left	rock	43	adult	90	escaped SVL estimated
36	15/05/08	2	Claudio	2	49	33	left	rock	42	adult	271	
36	22/05/08	3	Claudio	1	36	15	right	rock	28	adult	195	
36	22/05/08	3	Claudio	2	66	29	left	rock	30	adult	375	
36	22/05/08	4	Virginia	1	20	5.5	right	rock	40	adult	116	swabbed WR06
36	22/05/08	4	Virginia	2	28	5.7	left	rock	32	adult	129	swabbed WR07
36	22/05/08	4	Virginia	3	76	32.5	left	rock	39	adult	418	
36	22/05/08	4	Virginia	4	80	34	left	rock	40	adult	430	
37	13/06/08	1	Claudio	1	10	1.7	middle	rock	29	adult	16	together
37	13/06/08	1	Claudio	2	10	1.75	middle	rock	20	sub-adult	17	together
37	13/06/08	1	Claudio	3	13	1.75	middle	rock	30	adult	18	escaped, size estimated
37	13/06/08	1	Claudio	4	13	1.73	middle	rock	21	sub-adult	19	
37	13/06/08	2	Virginia	1	3	1	left	rock	28	adult	8	jumped, size estimated
37	13/06/08	2	Virginia	2	8	1.5	middle	rock	30	adult	23	sleeping

37	13/06/08	2	Virginia	3	12	1.75	left	rock	35	adult	24	same rock, one frog over the other
37	13/06/08	2	Virginia	4	12	1.75	left	rock	35	adult	24	same rock, maybe smaller, it was under the previous frog couldn't measure
37	13/06/08	2	Virginia	5	16	1.85	right	rock	33	adult	28	jumped, *
37	13/06/08	2	Virginia	6	19	1.95	middle	leaves	22	sub-adult	30	together
37	13/06/08	2	Virginia	7	19	1.95	middle	leaves	33	adult	30	together, might be the same frog than *
37	13/06/08	2	Virginia	8	40	25.8	right	leaves	39	adult	102	
37	13/06/08	2	Virginia	9	60	31	middle	rock	28	adult	130	same rock, all together
37	13/06/08	2	Virginia	10	60	31	middle	rock	35	adult	130	same rock, all together
37	13/06/08	2	Virginia	11	60	31	middle	rock	25	adult	130	same rock, all together, size estimated
37	13/06/08	2	Virginia	12	60	31	middle	rock	25	adult	130	same rock, all together, size estimated
37	13/06/08	2	Virginia	13	65	32	middle/r	rock	29	adult	134	same rock
37	13/06/08	2	Virginia	14	65	32	middle/r	rock	30	adult	134	same rock
37	13/06/08	2	Virginia	15	69	33.5	middle	rock	38	adult	137	size estimated
37	19/06/08	3	Virginia	1	9	1.5	left	log	27	adult	27	swabbed WR24, on the water
37	19/06/08	3	Virginia	2	12	1.8	middle/r	log	32	adult	33	swabbed WR23, on flowing water
37	19/06/08	3	Virginia	3	18	2	left	rock	6	juvenile	42	
37	19/06/08	3	Virginia	4	21	2.4	middle	leaves	7	juvenile	44	
37	19/06/08	3	Virginia	5	61	27	right	rock	10	juvenile	174	
37	19/06/08	3	Virginia	6	72	32	middle	rock	20	sub-adult	198	underwater
37	19/06/08	3	Virginia	7	73	32	middle	crevice	40	adult	199	size estimated
37	19/06/08	3	Virginia	8	79	33	middle	rock	22	sub-adult	204	green coloration, jumped to next rock
37	19/06/08	3	Virginia	9	80	33	middle	rock	41	adult	204	same rock, (all 4 together)
37	19/06/08	3	Virginia	10	80	33	middle	rock	41	adult	204	same rock

37	19/06/08	3	Virginia	11	80	33	middle	rock	31	adult	204	same rock
37	19/06/08	3	Virginia	12	80	33	middle	rock	10	juvenile	204	same rock, green coloration
37	19/06/08	3	Virginia	13	87	34.5	middle	rock	30	adult	206	same rock, size estimated, in a hole
37	19/06/08	3	Virginia	14	87	34.5	middle	rock	30	adult	206	same rock, size estimated, in a hole
37	19/06/08	3	Virginia	15	91	38	middle	leaves	9	juvenile	213	
37	19/06/08	4	Claudio	1	5	1.6	left	log	25	adult	16	size estimated
37	19/06/08	4	Claudio	2	11	2	middle	log	33	adult	28	
37	19/06/08	4	Claudio	3	15	2.44	left	leaves	12	juvenile	36	
37	19/06/08	4	Claudio	4	50	17.4	left	none	13	juvenile	151	
37	19/06/08	4	Claudio	5	64	20.9	middle	rock	30	adult	189	
37	19/06/08	4	Claudio	6	79	26.7	middle	rock	41	adult	247	
37	19/06/08	4	Claudio	7	79	26.8	middle	rock	35	adult	248	same rock, size estimated
37	19/06/08	4	Claudio	8	79	26.8	middle	rock	38	adult	248	same rock, size estimated
37	19/06/08	4	Claudio	9	82	27	right	rock	12	juvenile	250	
37	19/06/08	4	Claudio	10	104	32	middle	rock	30	adult	291	same rock, size estimated
37	19/06/08	4	Claudio	11	104	32	middle	rock	30	adult	291	same rock, size estimated
37	19/06/08	4	Claudio	12	105	32	middle	rock	20	sub-adult	292	
37	19/06/08	4	Claudio	13	109	33	middle	rock	40	adult	298	same rock, all together
37	19/06/08	4	Claudio	14	109	33	middle	rock	40	adult	298	same rock, all together
37	19/06/08	4	Claudio	15	109	33	middle	rock	30	adult	298	same rock, all together
37	19/06/08	4	Claudio	16	109	33	middle	rock	20	sub-adult	298	same rock, all together
37	19/06/08	4	Claudio	17	109	33	middle	rock	10	juvenile	298	same rock, all together, green
37	19/06/08	4	Claudio	18	120	35	middle	rock	30	adult	301	
39	15/05/08	2	Virginia	1	13	34	left	rock	32	adult	52	swabbed WR04, open place

39	15/05/08	3	Virginia	1	48	34.5	left	rock	33	adult	263	
39	15/05/08	4	Claudio	1	53	35	left	rock	33	adult	343	
40	30/09/08	3	Virginia	1	38	33	right	leaves	26	adult	167	among roots
42	27/09/08	1	Virginia	1	6	2.5	right	rock	33	adult	17	jumped
42	27/09/08	1	Virginia	2	34	15.8	right	rock	33	adult	49	jumped
42	27/09/08	1	Virginia	3	34	15.8	right	rock	35	adult	49	jumped
43	27/09/08	1	Virginia	1	14	4	left	rock	35	adult	38	skinny, jumped
43	27/09/08	1	Virginia	2	16	4.1	left	rock/leaves	35	adult	69	close to frog 1
43	27/09/08	1	Virginia	3	50	18	middle	rock	39	adult	202	together
43	27/09/08	1	Virginia	4	50	18	middle	rock	35	adult	202	together, jumped into water
43	27/09/08	1	Virginia	5	56	19.5	right	rock	37	adult	219	where small tributary joins stream
43	27/09/08	1	Virginia	6	62	23.7	middle	rock	38	adult	277	jumped
43	27/09/08	1	Virginia	7	93	38	left	rock	35	adult	359	jumped
43	27/09/08	2	Claudio	1	6	4.1	left	rock	44	adult	38	awake
43	27/09/08	2	Claudio	2	41	18	middle	leaves	40	adult	235	
43	27/09/08	2	Claudio	3	47	21.7	left	rock	31	adult	256	big rock
43	27/09/08	2	Claudio	4	52	23.9	middle	rock	30	adult	285	awake, size estimated
43	27/09/08	2	Claudio	5	67	31	right	rock	40	adult	329	2cm from water, size estimated
43	2/10/08	3	Claudio	1	8	0.1	left	rock	33	adult	30	size estimated
43	2/10/08	3	Claudio	2	16	5.5	right	rock	36	adult	80	jumped, size estimated
43	2/10/08	3	Claudio	3	41	15	left	rock	23	sub-adult	205	
43	2/10/08	3	Claudio	4	55	19.8	right	rock	36	adult	279	jumped, size estimated
43	2/10/08	3	Claudio	5	62	23.5	middle	rock	40	adult	295	jumped, size estimated
43	2/10/08	3	Claudio	6	71	24.2	right	rock	42	adult	345	

43	2/10/08	3	Claudio	7	75	26.1	right	rock	30	adult	349	
43	2/10/08	3	Claudio	8	88	32	left	rock	34	adult	427	2m from stream
43	2/10/08	3	Claudio	9	91	32.1	left	rock	31	adult	437	30cm from stream
43	2/10/08	3	Claudio	10	94	33	left	rock	40	adult	444	2cm f water, big square
43	2/10/08	4	Virginia	1	3	0	left	rock	31	adult	4	swabbed WR31
43	2/10/08	4	Virginia	2	20	4.2	left	rock	38	adult	88	jumped
43	2/10/08	4	Virginia	3	26	6	right	rock	47	adult	106	jumped
43	2/10/08	4	Virginia	4	61	14.9	left	rock	26	adult	277	swabbed WR28
43	2/10/08	4	Virginia	5	71	19.8	right	rock	33	adult	322	in small tributary, swabbed WR29
43	2/10/08	4	Virginia	6	73	20	right	rock	36	adult	323	in small tributary
43	2/10/08	4	Virginia	7	85	25.5	right	rock	30	adult	363	
43	2/10/08	4	Virginia	8	92	31.5	left	rock	40	adult	389	
45	24/05/08	4	Virginia	5	33	3.5	middle/l	rock/leaves	8	juvenile	73	
45	24/05/08	4	Virginia	6	33	3.5	middle/l	rock/leaves	7	juvenile	73	found when swabbing
45	24/05/08	4	Virginia	7	53	14	right	rock	39	adult	140	same rock
45	24/05/08	4	Virginia	8	53	14	right	rock	20	sub-adult	140	same rock, swabbed WR09
45	24/05/08	4	Virginia	9	73	16.2	right	rock/hole	35	adult	153	size estimated
45	24/05/08	4	Virginia	10	86	20.2	left	rock	8	juvenile	190	
50	12/06/08	1	Virginia	3	30	21.1	right	rock	35	adult	183	
50	12/06/08	1	Virginia	4	41	24	right	rock	40	adult	252	jumped into water
50	12/06/08	1	Virginia	5	48	25.6	right	rock	35	adult	274	light spotted
50	12/06/08	2	Claudio	1	56	20.05	middle	none	42	adult	270	over the measure tape, active
50	12/06/08	2	Claudio	2	62	20.9	left	none	12	juvenile	278	over rock, acive
50	12/06/08	2	Claudio	3	91	36	right	rock	44	adult	382	under rock

50	18/06/08	3	Claudio	1	15	21.2	left	rock	25	adult	317	under big heavy rock, jumped
50	18/06/08	3	Claudio	2	25	22.2	left	rock	30	adult	350	jumped
50	18/06/08	3	Claudio	3	35	21.9	right	rock	36	adult	375	same rock, big rock, frog jumped, size estimated
50	18/06/08	3	Claudio	4	35	21.95	right	rock	36	adult	375	same rock, big rock, frog jumped, size estimated
50	18/06/08	3	Claudio	5	51	35	right	none	22	sub-adult	434	swabbed WR19, no cover object, good shadow
50	18/06/08	4	Virginia	1	4	0.3	left	rock	40	adult	18	swabbed WR18
50	18/06/08	4	Virginia	2	8	0.2	middle/l	log	38	adult	24	
50	18/06/08	4	Virginia	3	34	8	right	rock	38	adult	121	same rock
50	18/06/08	4	Virginia	4	34	8	right	rock	30	adult	121	same rock, jumped, size estimated
50	18/06/08	4	Virginia	5	60	14.1	left	rock	38	adult	232	swabbed WR17
50	18/06/08	4	Virginia	6	88	19.9	right	rock	36	adult	357	
50	18/06/08	4	Virginia	7	100	21.8	right	rock	30	adult	403	same rock, size estimated
50	18/06/08	4	Virginia	8	102	21.7	right	rock	40	adult	403	same rock, size estimated
50	18/06/08	4	Virginia	9	131	37.5	right	rock	40	adult	532	on the water
50	18/06/08	4	Virginia	10	136	38	left	leaves	30	adult	537	underwater

Appendix V. Relative abundance of frogs in Waitakere Ranges sites

Table V.1. Distance searched, counts at each visit and relative abundance of frogs found at each site (MNA: Minimum Number Alive; n_{s-r} = total nº frogs sighted – nº of possible resights).

SITE ID	Distance searched	SURVEY OCCASION				MNA	n_{s-r}	Frogs/100 m
		1	2	3	4			
1	40	0	1	5	3	5	5	12.5
2	40	0	0	0	0	0	0	0
3	40	4	2	0	5	5	9	22.5
4	40	3	2	1	1	3	3	7.5
5	40	2	3	7	10	10	16	40
6	40	0	0	0	0	0	0	0
7	30	0	0	0	0	0	0	0
8	40	0	0	0	0	0	0	0
9	40	0	0	-	-	0	0	0
10	23	0	0	0	0	0	0	0
11	36	0	1	1	1	1	2	5.6
12	40	4	2	5	2	5	9	22.5
13	40	1	1	5	0	5	5	12.5
14	40	3	2	-	-	3	5	12.5
15	30	0	1	0	5	5	6	20
16	35	4	3	-	-	4	5	14.3
17	40	0	0	0	0	0	0	0
18	40	0	0	0	0	0	0	0
19	40	3	1	1	0	3	3	7.5
20	40	0	0	0	1	1	1	2.5
21	38	1	5	6	6	6	11	28.9
22	40	0	4	7	1	7	11	27.5
23	40	11	5	-	-	11	12	30
24	40	1	4	3	3	4	9	22.5
25	33	0	0	0	0	0	0	0
26	40	1	1	0	1	1	1	2.5
27	40	0	1	2	1	2	2	5
28	40	0	0	0	0	0	0	0(*)
29	40	0	0	0	0	0	0	0(*)
30	40	0	0	0	0	0	0	0(*)
31	40	10	6	4	6	10	11	27.5
32	40	1	1	0	1	1	1	2.5
33	32	1	2	7	7	7	9	28.1
34	40	4	1	2	1	4	4	10
35	40	1	0	0	2	2	3	7.5
36	40	2	2	2	4	4	7	17.5
37	40	4	15	15	18	18	29	72.5

38	40	0	0	0	0	0	0	0
39	40	0	1	1	1	1	1	2.5
40	33	0	0	1	0	1	1	3
41	40	0	0	0	0	0	0	0
42	30	3	-	-	-	3	3	10
43	40	7	5	10	8	10	18	45
44	40	3	7	4	9	9	16	40
45	30	1	2	3	10	10	14	46.7
46	40	0	0	-	-	0	0	0
47	40	0	0	0	0	0	0	0
48	34	1	0	1	3	3	5	14.7
49	40	12	5	7	7	12	18	45
50	40	5	3	5	10	10	17	42.5
TOTAL	**1904**	**93**	**89**	**105**	**127**	**184**	**272**	**-**
AVERAGE	**38.08**	**1.86**	**1.82**	**2.39**	**2.89**	**3.7**	**5.4**	**14.2**

(*): Frogs were detected outside the site or sampling season.

Appendix VI. Comparison of relative abundance of Waitakere Ranges sites with previous surveys

Table VI.1 Table of estimated relative abundance expressed as count indices (frogs/100m) for each site obtained by Ziegler (1999), Bradfield (2004/05), and Moreno (2008, this study). Some sites are not exactly the same section of stream, but represent the same close area. (*): Frogs detected near the site. (**): Net number of frogs found, no transect sampling, only a couple of metres searched.

SITE ID	NAME		1999	2004/05	2008
1	Anawhata	1	0	0	12.5
2	Anawhata	2	-	0	0
3	Anawhata	3	-	0	22.5
4	Arataki	1	-	-	7.5
5	Nutts Stream	1	-	-	40.0
6	Cascade	1	0	0	0
7	Cascade	2	-	0	0
8	Cascade	3	-	1.6	0
9	Cascade	4	-	0	0
10	Cascade	5	-	-	0
11	Huia	1	24	5.3	5.6
12	Huia	2	6	13.8	22.5
13	Huia	3	-	-	12.5
14	Kakamatua	1	-	-	12.5
15	Kakamatua	2	-	-	20.0
16	Kakamatua	3	-	-	14.3
17	Karekare	1	-	0	0
18	Karekare	2	-	0	0
19	Karekare	3	-	0	7.5
20	Karekare	5	-	-	2.5
21	Karekare	6	-	-	28.9
22	Lower Huia Dam	1	-	16.4	27.5
23	Lower Huia Dam	2	-	25.0	30.0
24	Lower Huia Dam	3	-	10.5	22.5
25	Lower Nihotupu Dam	1	-	4.9	0
26	Lower Nihotupu Dam	2	-	0	2.5
27	Lower Nihotupu Dam	3	-	0	5.0
28	Mill Bay	1	-	-	0(*)
29	Opanuku	1	-	3.6	0(*)

30	Opanuku	2	0	-	0(*)
31	Opanuku	3	16	0	27.5
32	Pararaha	1	-	0	2.5
33	Pararaha	2	-	30.0	28.1
34	Pararaha	3	4	16.7	10.0
35	Pararaha	4	10	10.0	7.5
36	Piha	1	4	0	17.5
37	Piha	2	-	7.4	72.5
38	Piha	3	-	0	0
39	Piha	4	-	-	2.5
40	Piha	5	0	0	3.0
41	Swanson	1	-	0	0
42	Upper Huia Dams	1	-	9.1	10.0
43	Upper Huia Dams	2	18	10.8	45.0
44	Upper Nihotupu Dam	1	8**	32.5	40.0
45	Upper Nihotupu Dam	2	2**	16.1	46.7
46	Wainamu	1	-	-	0
47	Whatipu	1	-	0	0
48	Whatipu	2	-	60.0	14.7
49	Whatipu	3	24	11.1	45.0
50	Whatipu	4	-	-	42.5
	AVERAGE			**7.9**	**14.2**

Appendix VII. Location and description of Miners Cove sites

Table VII.1. Location of Miners Cove sites (NZMG).

Site ID	Easting	Northing	Elevation (m)	Accuracy (+/-)
MC1	2723211	6566544	61.6	10
MC2	2723328	6566539	54	9
MC3	2723310	6566703	47.5	13
MC4	2723661	6566704	87.4	20
MC5	2723453	6566732	72.5	20
MC6	2722785	6566701	26.8	28
MC7	2722695	6566704	66.7	9
MC8	2722562	6566704	49.6	8
MC9	2722718	6566217	94.1	14
MC10	2723669	6566373	63.1	12
MC11	2724040	6566242	124.6	8

List of Miners Cove sites descriptions.

Site ID: MC1
Stream order: 1 **Stream width:** 0.5m
Observations: Steep. Leaf litter. Slow water flow. Not many refugia.

Site ID: MC2
Stream order: 2 **Stream width:** 2.5m
Observations: Rocky bed, clear water. High canopy.

Site ID: MC3
Stream order: 2 **Stream width:** 1.2m
Observations:

Site ID: MC4
Stream order: 2 **Stream width:** 1m
Observations: Steep, with many waterfalls.

Site ID: MC5
Stream order: 2 **Stream width:** 1.8m
Observations: Slow flow, clear water. Tree fern, Nikau, Manuka.

Site ID: MC6
Stream order: 1 **Stream width:** 0.6m
Observations: Small tributary not on the map. Tree fern, Nikau. Relatively open, with many logs.

Site ID: MC7
Stream order: 3 **Stream width:** 3m
Observations: Small arm of the main stream (north), still water away from main flow. Close to where a very small tributary (seepage) flows into MC stream. Completely shaded. Good sized rocks. High canopy. Close to where the track crosses the stream where it is very disturbed by cattle (footprints) and people.

Site ID: MC8
Stream order: 1 **Stream width:** 0.8m
Observations: Small tributary, with low vegetation (regenerating scrub), manuka, kanuka. Not many loose rocks for refugia.

Site ID: MC9
Stream order: 1 **Stream width:** 0.5m
Observations: Same tributary than MC8 but at higher altitude. Trees are taller (older), canopy higher. Many fallen trees and driftwood debris. Many refugia available (rocks). Water looks a little silted.

Site ID: MC10
Stream order: 2 **Stream width:** 2m
Observations: High canopy, clear water. Small waterfall. Plenty of rocks all sizes.

Site ID: MC11
Stream order: 2 **Stream width:** 2m
Observations: Steep site, many small waterfalls and pools. Only 11 metres were searched due to waterfall at end.

Table VII.2. Frogs found at each site.

Site ID	Survey 1	Survey 2	Total frogs
MC1	0	0	**0**
MC2	0	0	**0**
MC3	2	1	**2**
MC4	0	0	**0**
MC5	1	0	**1**
MC6	0	0	**0**
MC7	1	0	**1**
MC8	0	0	**0**
MC9	2	1	**2**
MC10	0	0	**0**
MC11	2	1	**3**

Appendix VIII. Location of swab samples

Table VIII.1. Swab samples taken from the Waitakere Ranges population of Hochstetter's frog.

Swab ID	Date	Easting	Northing	Elevation	GPS Accuracy	S.V.L. (mm)
WR01	19/05/08	2648828	6465504	50	8	23
WR02	21/05/08	2645256	6462504	25	13	45
WR03	21/05/08	2645240	6462502	28	10	22
WR04	22/05/08	2641882	6472124	49	16	33
WR05	22/05/08	2641818	6472216	54	8	20
WR06	22/05/08	2644243	6469788	181	5	32
WR07	22/05/08	2644243	6469787	177	6	40
WR08	22/05/08	2644233	6469775	152	6	34
WR09	24/05/08	2649563	6471543	246		20
WR10	24/05/08	2649591	6471547	227	7	22
WR11	24/05/08	2649399	6471839	241	7	20
WR12	24/05/08	2649396	6471847	238	8	25
WR13	25/05/08	2648823	6465497	20	6	38
WR14	25/05/08	2647929	6465709	167	15	31
WR15	25/05/08	2647924	6465729	165	24	25
WR16	25/05/08	2647930	6465741	164	24	32
WR17	18/06/08	2647196	6463427	206	20	38
WR18	18/06/08	2647206	6463414	199	19	40
WR19	18/06/08	2647211	6463453	198	20	22
WR20	18/06/08	2646591	6464764	286	18	30
WR21	18/06/08	2646591	6464764	286	18	32
WR22	18/06/08	2646589	6464767	285	19	37
WR23	19/06/08	2644424	6471560	120	16	32
WR24	19/06/08	2644426	6471560	118	14	27
WR25	20/06/08	2643474	6465037	230	10	45
WR26	20/06/08	2643474	6465027	234	7	35
WR27	20/06/08	2643475	6465037	230	10	24
WR28	2/10/08	2646662	6471305	227	23	26
WR29	2/10/08	2646661	6471304	226	35	33
WR30	2/10/08	2646654	6471288	227	37	30
WR31	2/10/08	2646656	6471285	230	33	31
WR32	6/10/08	2653657	6470960	53	9	42
WR33	22/10/08	2645644	6465951	262	13	42
WR34	26/10/08	2648141	6464341	70	8	38
WR35	27/10/08	2645448	6466060	228	4	26

WR36	27/10/08	2645694	6465879	265	7	40
WR37	27/10/08	2645697	6465873	264	8	36
WR38	27/10/08	2645546	6466151	252	9	29
WR39	27/10/08	2645685	6466196	264	20	43
WR40	28/10/08	2650130	6469077	115	11	26
WR41	28/10/08	2648462	6469254	98	24	30
WR42	28/10/08	2654383	6471073	104	16	36
WR43	28/10/08	2654379	6471052	104	16	36
WR44	29/10/08	2648135	6464386	83	18	35
WR45	29/10/08	2648129	6464387	77	7	39
WR46	9/11/08	2649339	6477081	92	20	30
WR47	9/11/08	2649386	6477065	95	14	30
WR48	16/11/08	2644375	6469098	243	29	22
WR49	16/11/08	2644377	6469125	245	22	
WR50	16/11/08	2644364	6469128	246	31	35
WR51	16/11/08	2644362	6469127	247	35	31
WR52	16/11/08	2642045	6468434	25	15	33
WR53	6/12/08	2649328	6469336	79	11	23
WR54	6/12/08	2649329	6469342	81	12	25
WR55	11/12/08	2643754	6467630	182	7	42
WR56	12/12/08	2649232	6475307	132	11	42
WR57	12/12/08	2649242	6475298	133	18	30
WR58	12/12/08	2649235	6475307	132	16	25
WR59	14/12/08	2644162	6474899	170	10	29
WR60	14/12/08	2644157	6474884	167	12	33
WR61	14/12/08	2645235	6473277	262	17	30

Table VII.2. Swab samples taken from Great Barrier Island Hochstetter's frog population

Swab ID	Date	Easting	Northing	Elevation	GPS Accuracy	S.V.L. (mm)
F1	12/01/08	2722693	6566719	23	7	38
F2	12/01/08	2722693	6566719	23	7	36
F5	14/01/08	2723469	6566738	75.8	23	22
F6	16/01/08	2722707	6566244	88.3	16	42
F7	16/01/08	2722709	6566232	86.2	13	42
F8	17/01/08	2723642	6566339	64.8	20	40
F9	17/01/08	2723994	6566234	115	62	17
F10	17/01/08	2724033	6566258	127.5	19	34

F11	17/01/08	2724062	6566233	122	11	24
F12	17/01/08	2724052	6566239	120.3	20	12
GB1	16/03/09	2724648	6565200	332.3	15	33
GB2	16/03/09	2724672	6565175	324.6	12	30
GB3	16/03/09	2724656	6565135	335.9	12	17
GB4	16/03/09	2724642	6565147	337.3	8	12
GB5	16/03/09	2724634	6565147	326.5	25	25
GB6	16/03/09	2724619	6565162	331.1	15	25
GB7	17/03/09	2722518	6566761	60	9	28
GB8	17/03/09	2722646	6566735	42.7	9	31
GB9	17/03/09	2722657	6566734	40.5	7	17
GB10	17/03/09	2722636	6566758	45.1	8	30
GB11	17/03/09	2722644	6566741	29.7	10	31
GB12	17/03/09	2722810	6566812	52.8	16	31
GB13	17/03/09	2722813	6566823	59.2	16	28
GB14	17/03/09	2722810	6566835	62.1	20	15
GB15	17/03/09	2723366	6566720	39.3	9	38
GB16	17/03/09	2723378	6566804	56.6	20	40
GB17	17/03/09	2723371	6566744	46	15	38
GB18	18/03/09	2725912	6563839	168.6	18	33
GB19	18/03/09	2725883	6563729	149.4	9	28
GB20	18/03/09	2725888	6563726	144.6	8	30
GB21	18/03/09	2725896	6563702	140.5	11	33
GB22	18/03/09	2725891	6563685	138.3	8	11
GB23	18/03/09	2725901	6563665	136.4	10	25
GB24	18/03/09	2726003	6563684	156.1	13	25
GB25	18/03/09	2725993	6563678	162.3	12	20
GB26	18/03/09	2726009	6563683	162.1	15	26
GB27	18/03/09	2726018	6563708	167.6	21	33
GB28	18/03/09	2726042	6563708	172	17	32
GB29	19/03/09	2724940	6566839	464.2	8	30
GB30	19/03/09	2724950	6566847	463.5	11	40
GB31	19/03/09	2724950	6566847	467.1	12	30
GB32	19/03/09	2724953	6566833	466.6	8	30
GB33	19/03/09	2724981	6566807	461.3	12	30
GB34	19/03/09	2724981	6566808	461.3	12	20
GB35	19/03/09	2724947	6566841	468	10	35
GB36	19/03/09	2724951	6566831	467.8	13	22
GB37	19/03/09	2724985	6566819	461.3	10	29
GB38	19/03/09	2724950	6566834	468	9	21

GB39	19/03/09	2724950	6566834	466.6	10	37
GB40	19/03/09	2724960	6566836	466.1	12	27
GB41	19/03/09	2724977	6566814	464	13	15
GB42	19/03/09	2724971	6566820	464.4	11	25
GB43	19/03/09	2724971	6566821	464	11	18
GB44	19/03/09	2725000	6566834	461.6	10	33
GB45	19/03/09	2724974	6566817	461.8	15	27
GB46	19/03/09	2724976	6566824	459.2	17	20
GB47	19/03/09	2724974	6566817	461.6	17	26
GB48	19/03/09	2724967	6566823	463.5	12	32
GB49	20/03/09	2726257	6554570	246.2	12	28
GB50	20/03/09	2726266	6554569	254.2	8	22
GB51	20/03/09	2726269	6554565	260.6	7	16
GB52	20/03/09	2726264	6554555	285.9	7	23
GB53	20/03/09	2726268	6554548	280.8	8	30

Table VIII.3 Swab pooling and testing.

Test	Batch 1	Batch 2	Batch 3	Batch 4
1	WR01+WR13	WR56+WR57	(GBI) F1+F2	GB41+GB42
2	WR02+WR03	WR08	(GBI) F6+F7	GB43+GB45
3	WR04+WR05	WR16	(GBI) F9+F10	GB46+GB47
4	WR06+WR07	WR19	(GBI) F11+F12	(GBI) F5
5	WR09+WR10	WR22	GB1+GB2	(GBI) F8
6	WR11+WR12	WR26	GB3+GB4	GB7
7	WR14+WR15	WR32	GB5+GB6	GB14
8	WR17+WR18	WR33	GB8+GB9	GB17
9	WR20+WR21	WR34	GB10+GB11	GB18
10	WR23+WR24	WR35	GB12+GB13	GB23
11	WR25+WR27	WR38	GB15+GB16	GB28
12	WR28+WR29	WR39	GB19+GB20	GB33
13	WR30+WR31	WR40	GB21+GB22	GB38
14	WR36+WR37	WR41	GB24+GB25	GB44
15	WR42+WR43	WR52	GB26+GB27	GB48
16	WR44+WR45	WR55	GB29+GB30	GB49
17	WR46+WR47	WR58	GB31+GB32	GB50
18	WR48+WR49	WR59	GB34+GB35	GB51
19	WR50+WR51	WR60	GB36+GB37	GB52
20	WR53+WR54	WR61	GB39+GB40	GB53