Conservation Biology of the goldstripe gecko (*Hoplodactylus chrysosireticus*) and interactions with Duvaucel's gecko (*Hoplodactylus duvaucelii*) on Mana Island, Cook Strait, New Zealand.
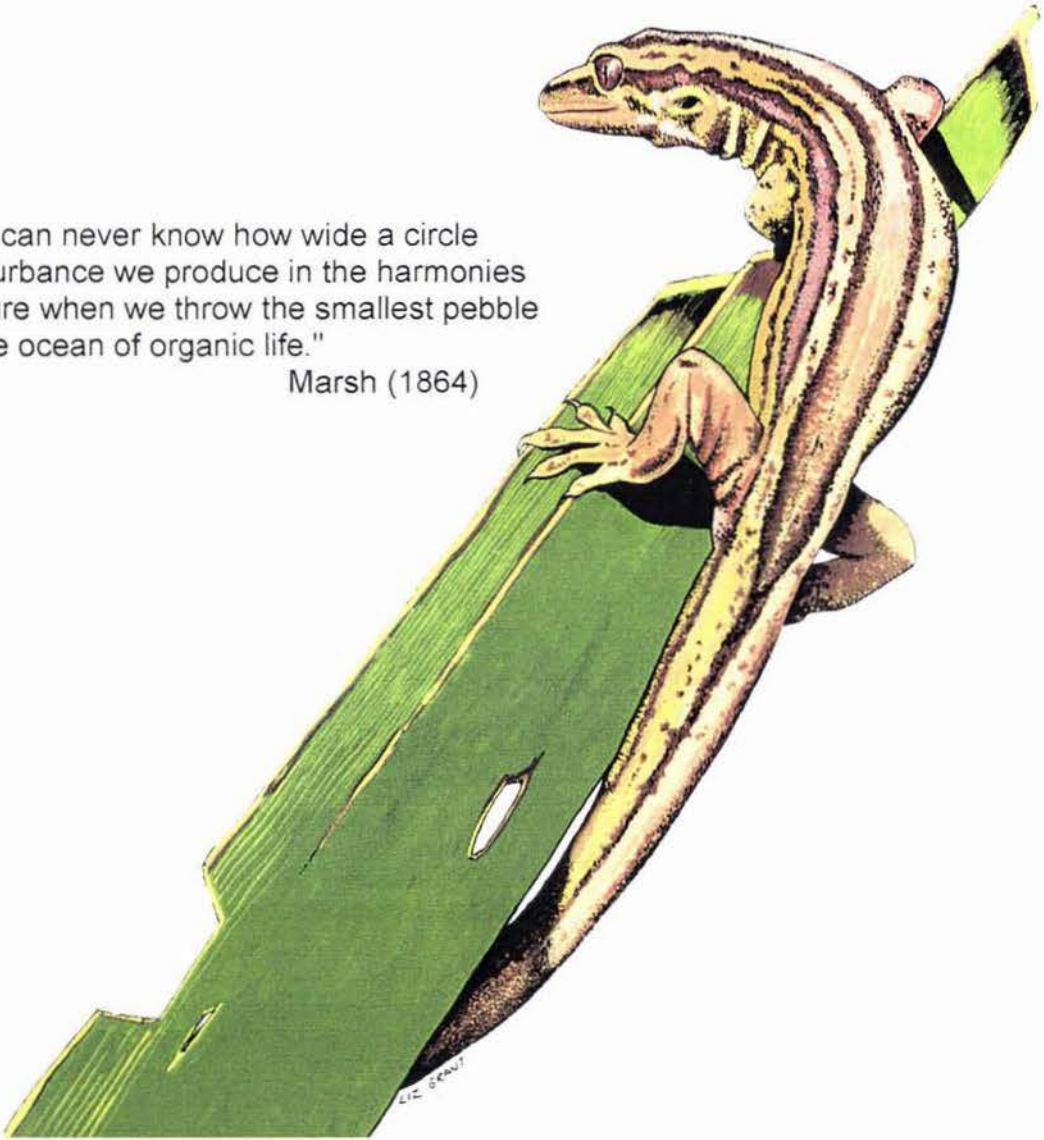
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"... we can never know how wide a circle
of disturbance we produce in the harmonies
of nature when we throw the smallest pebble
into the ocean of organic life."
                                    Marsh (1864)

Abstract

The conservation biology of goldstripe geckos (*Hoplodactylus chrysosireticus*) on Mana Island was considered in two ways. First, by studying the ecology, behaviour and population dynamics of *H. chrysosireticus* on Mana Island and in Taranaki and second, by assessing their behaviour in the presence of newly introduced Duvaucel's geckos (*Hoplodactylus duvaucelii*) on Mana Island.

The activity patterns of *H. chrysosireticus* were observed at night and during the day on Mana Island between November 1996 and October 1997. *H. chrysosireticus* were found to exhibit higher levels of diurnal behaviour than previously thought, with over two-thirds of all animals caught during daylight hours (170 out of 257 individuals; mean catch rate = 2.59 per person hour), a behaviour uncharacteristic of the genus. A female-biased sex ratio (0.53:1 male: female) was found among adult *H. chrysosireticus* on Mana Island but a male bias (1:0.5 male: female) was observed in the Taranaki population. This could be due either to a female-specific behaviour making them more catchable and hence taken more frequently by predators on the mainland, or to the effect of stochastic processes working on a small population. Growth curve estimations showed *H. chrysosireticus* is slow growing and long-lived, reaching breeding age at around five years. Population size estimates for the main sub-population on Mana Island generated an estimate of 90 (95%C.I 70-136) animals, less than half (200-300) that arising from a survey of the same area in 1993 (200-300) using different survey and calculation methods. Juvenile mortality was high (63% estimate) in the first year and overall population growth slow. The geckos showed high site fidelity with over 90% moving less than 5m from their original point of capture. Population growth on Mana Island is slow despite the absence of mammalian predators, raising serious questions about the security of the remaining mainland populations.

Two sets of simultaneous cage and enclosure experiments, designed to observe interactions between *H. chrysosireticus* and *H. duvaucelii* were conducted on Mana

Island between December 1997 and February 1998. *H. chrysosireticus* were observed to increase their activity during the day in flax ($F_{2,13}$ P=0.0040) and climb more in manuka ($F_{2,5}$ P=0.0450) when in the presence of *H. duvaucelii*. *H. duvaucelii* also appear to have preyed upon young *H. chrysosireticus* when in close contact. The implications of introducing *H. duvaucelii* to Mana Island and future conservation measures for *H. chrysosireticus* are discussed.

Preamble

Thesis organisation

This research was designed primarily to provide essential base-line data on the behaviour and activity of the threatened *H. chrysosireticus* to aid in the successful conservation of the species on Mana Island. This involved first identifying aspects of the basic ecology of *H. chrysosireticus* through comparisons with another population of the species on the mainland and then estimating the status and potential growth of the main Mana Island population through growth models and population estimates. Following from this, a significant component of this work was to investigate the potential for competitive interactions between *H. chrysosireticus* and *H. duvaucelii* on Mana Island and included carrying out a translocation of *H. duvaucelii* from North Brother Island to Mana Island.

This thesis has a general introduction and discussion with three separate 'data' chapters in-between. References have been collated at the end to reduce replication. Two appendices containing data on permanently marked *H. chrysosireticus* from Mana Island and all *H. duvaucelii* caught on North Brother Island, are included at the back. The general organisation of this thesis and an outline of each chapter is provided below:

A general introduction with background information on *H. chrysosireticus* and the situation on Mana Island is given in **Chapter 1**. **Chapter 2** deals with the temporal and spatial behaviour of *H. chrysosireticus* on Mana Island, including a comparison with gecko behaviour from a Taranaki population. **Chapter 3** covers the general ecology of *H. chrysosireticus* on Mana Island in terms of population structure and density. The transfer of *H. duvaucelii* from North Brother Island to Mana Island forms part of **Chapter 4** along with the experimental investigation of interactions between *H. chrysosireticus* and *H. duvaucelii* on Mana Island. **Chapter 5** provides a general discussion and recommendations concerning the continued conservation of *H. chrysosireticus* on Mana Island, given the island's current restoration focus.

Acknowledgements

This thesis may yet take the record as the most drawn out M.Sc. from this department, however, the length of time this has taken and the adventures it has led me to would not have been possible without the help of so many people! Firstly I must thank Associate Professor Robin Fordham and Dr. Stephen Sarre, my remarkable supervisors, for being supportive and understanding when others would have long but given up. Thank you also, for indulging me and putting up with my constant absences from my thesis to run a round on islands and play with endangered species.

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Finally, I should thank the beautiful goldstripe geckos for letting me watch them in their world.

Dedicated to my best friend and companion
Krissy   ??.09.1992 - 29.12.1999

Contents

Chapter one: Introduction

Chapter two: Activity and movements of *H.chrysosireticus*

Chapter three: Age structure and population biology of *H. chrysosireticus* on Mana Island

Chapter four: Restoring a component of Mana Island's reptile fauna: Will the introduction of *H. duvaucelii* compromise the resident *H. chrysosireticus* population?

Chapter five: Conservation of *H. chrysosireticus*: summary and recommendations

List of Figures

List of Tables

List of Plates

Chapter One

Introduction

Chapter one:

Introduction

1.1 Translocations for ecosystem restoration

Like most of New Zealand's endemic fauna, many of our lizard species have become extinct or restricted on the mainland in recent times (Towns and Daugherty 1994). These declines are usually attributed to habitat destruction and the impacts of introduced mammalian predators (eg. Whitaker 1973; Towns 1991; Towns and Daugherty 1994; Christmas 1995). Many species owe their continued survival to the refuge provided by a handful of small offshore islands. The persistence of rodents on many of these islands has, however, put even these populations at risk. However, with the recent successful eradication of rodents from an increasing number of islands, translocations are becoming a popular means of increasing the area of safe available habitat for threatened lizard species (Towns 1999).

Translocation is defined here according to the IUCN (1987) definition as "the movement of living organisms from one area with free release in another". Often these translocations are part of a larger restoration programme and ideally are re-introductions of species thought to have occurred in the area in the past but have since become extinct (IUCN 1987). Island restorations, in particular, have several goals. As well as attempting to restore a functioning pre-human ecosystem, they also have a strong conservation role for threatened species (Towns *et al.* 1990). Restoration of whole ecosystems is a complex process but is gaining popularity over the more conventional, but expensive, single species approach (Towns and Williams 1993). Often, however, the exact composition of the pre-human community is unknown and informed guesses based on relict distributions and sketchy sub-fossil remains are required. 'Re-introduction', implies that the historic range is known. For this reason, the terms 'introduction', 'translocation' or 'transfers' are used here instead of 're-introduction' as

it is not enough to assume that all species within a historic range will have lived in the same areas in the past. Inter-species interactions are innately complicated and the issues surrounding interspecific competition and the processes shaping ecological communities have been hotly debated for many years (Schoener 1977, 1983; Rummel and Roughgarden 1983; Toft 1985; Taper 1993). Changes to the structure of a community range from the impacts of an introduced predator, such as rats on many New Zealand offshore islands (Towns and Daugherty 1994), to an imbalance in a natural community resulting in one native species threatening the continual survival of another. For example, the removal of rats from Lady Alice Island, New Zealand, encouraged prolonged nesting by winter-breeding little shearwaters *(Puffinus assimilis haurakiensis)*, in turn, preventing the occupation of burrows by summer-breeding Pycroft's petrel *(Pterodroma pycrofti)* (Dr R.J. Pierce, pers. comm.).

Competitive displacement from newly introduced but similar species is also an issue (Losos *et al.* 1993). In Hawaii, the common house gecko *(Hemidactylus frenatus)* introduced around 1945 has increased in numbers to the point where it has displaced at least three other gecko species (Case and Bolger 1991). A similar pattern was observed in *Anolis* lizards by Losos *et al.* (1993), where *A. sagrei* on Grand Cayman appeared to cause a habitat shift in the resident *A. conspersus* within 10 years of being introduced. Although these examples relate to animals not historically known from the introduction area, they illustrate the potential for community wide changes following the introduction of a new species into the existing community.

Despite their importance for conservation, many restoration introductions fail (Griffith *et al.* 1989; Short *et al.* 1992). The reasons for this are poorly understood but are often attributed to a failure to recognise and remove the factor(s) that caused the initial decline (Short *et al.* 1992). A bias exists in the literature because failed introductions and their reasons for failure are seldom recorded or published (Simberloff 1990; Short *et al* 1992). Predation consistently appears in the literature as the single most important factor in the failure of introductions (Short *et al.* 1992; Towns and Ballantine 1993; Towns and Daugherty 1994). However, other factors such as competition and community dynamics may be just as important but less often reported because they are harder to identify (Simberloff 1990).

Armstrong *et al.* (1995a) emphasised the need to design translocations as experiments. Several experimental translocations dealing with founder groups, familiarity and habitat quality (mostly with birds) have since been done (Armstrong *et al.* 1995b; Castro 1995; Perrott 1997; Armstrong and Perrott 2000). Despite this, experimental assessment of the potential for conflict with a resident species has not been attempted in New Zealand (Armstrong and McLean 1995). Before any predictions can be made about the suitability of a translocation, a good understanding of the fundamental ecology of the species being introduced, and of the resident species at the release site, is essential (IUCN 1998). Using this information, plus carefully conducted trials with both species to test for negative interactions, can help to provide a more informed approach to translocations for restoration purposes.

Looking at how animals differ in their use of space, time and food resources can give an indication of how ecologically similar two species are to each other. By then assessing the resources available to them we can begin to estimate which factors, if any, may be limiting and in turn be the source of competitive interactions. The habitat in restoration areas is usually patchy and undergoing constant and rapid change. Therefore, predictions of how recently transferred organisms will interact and change with the existing community are difficult to ascertain. The *New Zealand guidelines for transfers of indigenous terrestrial fauna and flora* (DoC 1990) make special note that habitat use by transferred species may differ considerably between source and release sites and includes the following suggestions for preparing a transfer proposal:

> "State whether the species being released is likely to directly compete with any species already occurring at the site of release.

[and]

> Outline any other impacts the new species is likely to have on existing species at the release site, This includes species which may be potential food items."

A fundamental knowledge of the natural history of the organism being introduced and the source community are essential for addressing both of these points.

1.2 Thesis aims

In this thesis I aim to assess the potential for negative interactions between resident and introduced species using an element of the current restoration programme for Mana Island, Cook Strait, New Zealand. The proposed restoration of the island's reptile fauna will bring several species together that currently are not sympatric elsewhere (Miskelly 1997). One of these new sympatries will arise from the introduction of Duvaucel's gecko *(Hoplodactylus duvaucelii)* with the resident goldstripe gecko *(Hoplodactylus chrysosireticus)*. *H. duvaucelii* has featured in several ecological studies (Whitaker 1968; Barwick 1982; Thompson *et al* 1992; Christmas 1995; Cree 1994), however, little is known about the ecology and behaviour of *H. chrysosireticus,* making the potential impact of the introduction unclear. In order to ascertain the impact of introducing *H. duvaucelii* on the resident *H. chrysosireticus* population, adequate background information on the ecology and status of *H. chrysosireticus* was essential. For this reason, the activity, behaviour and population dynamics of *H. chrysosireticus* were investigated first and an experimental investigation of interactions between the two species followed.

1.3 Mana Island

Mana Island (41°05'S 174°47'E, 217 ha, 121m a.s.l.), is a Scientific Reserve administered by the Department of Conservation and is one of three island reserves in the Wellington Ecological Region, along with Kapiti Island and Matiu/Somes Island. It is situated off the lower west coast of the North Island of New Zealand, 21 km north of Wellington and 4 km west of Titahi Bay (Fig 1.1). The island is characterised by a flat plateau bordered on the west by steep cliffs. On the eastern side, it is deeply dissected by several valleys which open into a flat, coastal wetland area (Waikoko wetland) (Fig 1.2).

The island is highly modified having undergone 154 years of intensive pastoral farming following a strong Maori presence spanning several centuries (Jones 1987). Despite deforestation and a high level of human occupation, mice *(Mus musculus)* were the only mammals remaining on the island after farming ceased in 1986. In the absence of stock, rank pasture provided ideal conditions for the expanding mouse population (Newman
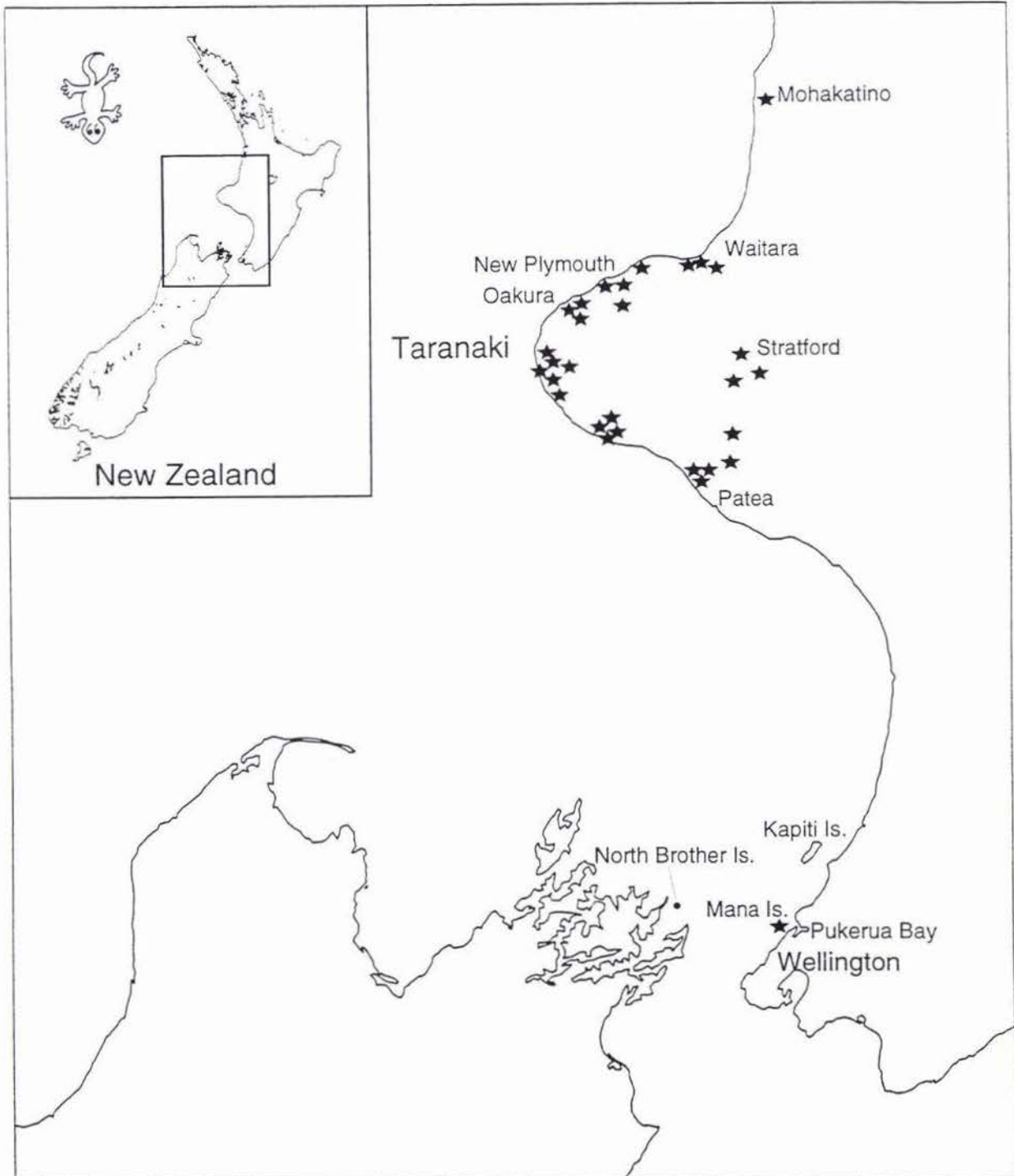
Fig 1.1 Approximate known distribution of *H. chrysosireticus* (★) and locations mentioned in the text. Data from Pickard and Towns (1988), D. Wilkinson, NMNZ and H. Flannagan. Actual records are held by the New Zealand Department of Conservation.

▲121 m

Tauhinu Valley

Forest Valley

House Valley

Shingle Point

Aston's Valley

A

Weta Valley

Waikoko Flat

G

Southern Valley

South Point

0   500 m
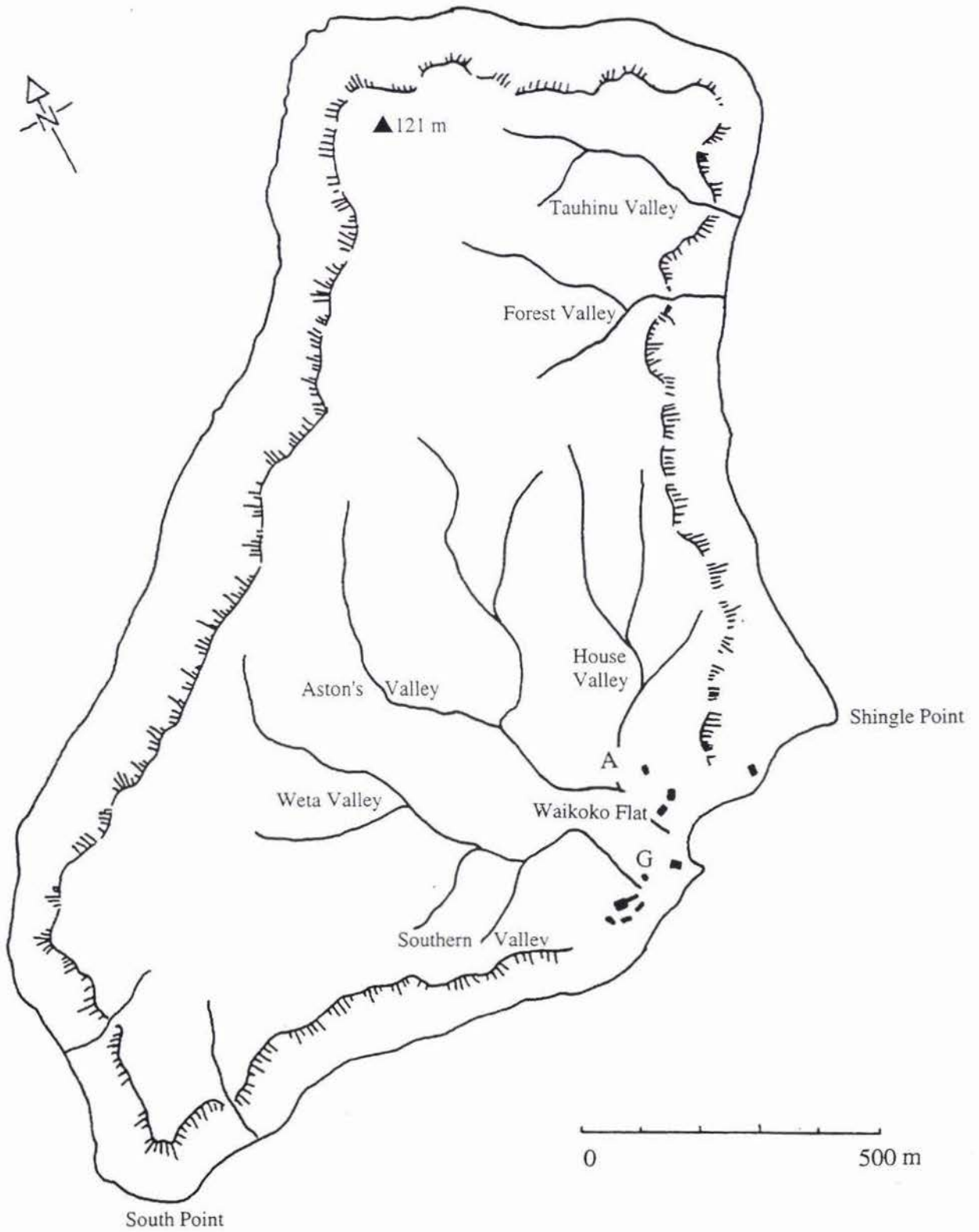
Fig 1.2 Map of Mana Island showing locations mentioned in the text.

1994). By 1989, mouse numbers were said to be of plague proportions (Hutton 1990). An intense poisoning and trapping programme eradicated the mice by February 1990 leaving the island free from all introduced mammalian predators (Newman 1994).

The original vegetation of Mana Island is unknown although palynological research by Chester and Raine (1990) suggest that a kohekohe – kaikomako (*Dysoxylum spectabile – Pennantia corymbosa*) mixed broadleaf community covered most of the island prior to human arrival. This is likely to have been replaced by a seral kanuka-manuka community after early fires (Chester and Raine 1990). The present vegetation of Mana Island was described in detail by Timmins *et al.* (1987a) based on two surveys between 1984 and 1986. At the time, rank pasture grasses dominated due to the island's disruptive agricultural history. Restoration plantings were initiated in 1987. Since then over 250,000 trees have been planted consisting mainly of ngaio (*Myoporum laetum*), kanuka (*Kunzea ericoides*) and manuka (*Leptospermum scoparium*) which now cover most of the eastern valleys and Waikoko flat. Scattered shelter belts of flax (*Phormium tenax* and *P. cookianum*), pampas (*Cortaderia sp.*) and karo (*Pittosporum crassifolum*), planted by the Ministry of Agriculture and Fisheries in the early 1970s still remain on the plateau and Waikoko flat. Kanuka-manuka and tauhinu (*Ozothamnus leptophylla*) occur on the cliffs and down some of the valleys.

As part of the restoration of Mana Island, three lizard species (Spotted skink *Oligosoma lineoocellatum*, Wellington green gecko *Naultinus elegans punctatus* and *H. duvaucelii*) were released in early 1998. Prior to this, the island was home to six of the 14 reptile species known from the Wellington region: common skink (*Oligosoma nigriplantare polychroma*), brown skink (*O. zelandicum*), copper skink (*Cyclodina aenea*), McGregor's skink (*C. macgregori*), common gecko (*Hoplodactylus maculatus*) and *H. chrysosireticus*. As both *C. macgregori* and *H. chrysosireticus* are threatened and of national significance (Timmins *et al* 1987b), the Mana Island Management plan made special note that "future introductions of birds and reptiles to Mana Island, as part of an ecological restoration programme, must not compromise the continued survival and expansion of these two resident species" (Miskelly 1997).

Mana Island supports other species of rare and threatened plants and animals such as Cook's scurvy grass (*Lepidium oleraceum*) and the Cook Strait giant weta (*Deinacrida*

rugosa). It is also managed for the conservation of nationally threatened birds such as the little spotted kiwi (*Apteryx owenii*) and the takahe (*Porphyrio mantelli*), both of which are introductions to the island (Miskelly 1997).

1.4 The goldstripe gecko *Hoplodactylus chrysosireticus*

H. chrysosireticus is a medium sized (SVL 75-80 mm), endemic New Zealand gecko (Plate 1.1). It is an agile and alert lizard with a prehensile tail and an aptitude for climbing. Typical of New Zealand gekkonids, *H. chrysosireticus* is ovoviviparous giving birth to two live young around February/March (Wilkinson 1977, 1981; Rowlands 1987). Individual base colour varies from dark tan to olive green with two well-defined parallel longitudinal stripes, usually of alternate light and dark shades of the basic body colour, running down the dorsum. The ventral surface is generally a lighter shade of the dorsal colour, often with fine black flecks. Some animals also exhibit a distinctive salmon pink colour on the underside of the tail (Robb 1980a).

Despite suggestions as early as the mid 1960s (Sharell 1966), that this distinctively striped gecko could be a separate species, *H. chrysosireticus* was not formally described until 1980 (Robb 1980a). Until then it had been considered to be a local variant of the pacific gecko (*H. pacificus*) (Wilkinson 1977; Robb 1980a, 1980b;).

1.4.1 Distribution, history and conservation status of H. chrysosireticus

H. chrysosireticus have a curious disjunct distribution including Mana Island and the Taranaki region between Mohakatino[1] and Patea and inland as far as Stratford[1]. (Fig 1.1). To date, no *H. chrysosireticus* have been found on the mainland south of Patea despite large areas of apparently suitable habitat. They have also never been found on Kapiti Island. Mana Island, therefore, is significant as the location of the only secure population of *H. chrysosireticus*, and the known southern limit for the species. Their historical range is unknown as they are osteologically indistinguishable from the similar

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[*] These locations extend the current published northern and inland limits for the distribution of *H. chrysosireticus* in Taranaki and are based on records from SRARNZ (Society for Research on Amphibians and Reptiles in New Zealand) notes # 12, 1994 and the personal records of Mr. D. Wilkinson (New Plymouth).

sized but more widespread *H. maculatus*, from midden deposits on Mana Island (Miskelly 1997).

H. chrysosireticus were unrecorded on Mana Island until 1972 when Tony Whitaker captured the first specimen in Weta Valley (Daniel *et al* 1972) (Fig 1.2). In the following 20 years only three further *H. chrysosireticus* were seen on the island despite occasional searches for them by experienced herpetologists (Whitaker 1993). In 1993, a Department of Conservation survey team led by Tony Whitaker uncovered the first significant numbers on the island. Sightings of at least 112 individual *H. chrysosireticus* were made over four nights. All except three of these were found during night searches, and over 80% of the animals found were on flax (Whitaker 1993). Ten geckos were found in forested habitats, 760 m from the main population in the flax on Waikoko flat (Whitaker 1993). No *H. chrysosireticus* found during the survey were permanently marked.

H. chrysosireticus were originally listed as 'Indeterminate' in the New Zealand Red Data Book (Williams and Given 1981) and then assigned to Category B (second priority for conservation) under the New Zealand Conservation Priority ranking system (Molloy and Davis 1992). They were later downgraded to Category C, being restricted but locally abundant, following the relatively large numbers found during Whitaker's 1993 Mana Island Survey (Molloy and Davis 1994). Their IUCN listing as 'Vulnerable' has not changed (IUCN 1996).

1.4.2 Behaviour and ecology of H. chrysosireticus

Like many New Zealand reptiles, little is known of the habits and ecology of *H. chrysosireticus* outside of captivity. Flax appears to be an important habitat for the lizards and is certainly where they are most numerous (Plate 1.2). The factors that make it a preferred cover type have not yet been identified. Whitaker (1993) recorded *H. chrysosireticus* foraging high on flax inflorescences within half an hour of dusk. This, together with my own observations of geckos taking flax nectar, suggests that the nectar may be an important seasonal food for the geckos.

In Taranaki, many *H. chrysosireticus* have been found close to human habitation in sheds, woodpiles and houses (Robb 1980b; Wilkinson 1981, however, this behaviour has not been recorded on Mana Island. Published accounts of the habits of *H. chrysosireticus* vary from nocturnal and ground dwelling (Wilkinson 1977; Robb 1980a, 1980b;) to nocturnal and arboreal (Whitaker 1993; Gill and Whitaker 1996;). Most authors mention basking behaviour and the apparent agility and alertness of the gecko, especially when held (Robb 1980a, 1980b).

1.5 *H. duvaucelii* and its introduction to Mana Island

Despite the lack of information concerning the ecology of *H. chrysosireticus*, a proposal to establish a population of *H. duvaucelii*, sourced from North Brother Island (section 1.5; Fig 1.1; Plate 1.4), on Mana Island, was put forward in the Mana Island Ecological Management Plan (Miskelly 1997). *H. duvaucelii* are thought to have once been widespread throughout much of the North (Worthy 1987) and South Islands (Worthy and Holdaway 1994; Worthy 1998). They are now restricted to 36 offshore islands off the northeast of the North Island and three island groups in the Marlborough Sounds (Trio Islands and Sentinel Rock) and Cook Strait area (North Brother Island) (Towns 1991). Although Mana Island is within the historic range for *H. duvaucelii*, there is no hard evidence that *H. duvaucelii* was ever extant on the island. An archaeological dig (Horwood 1991) uncovered bones from a large gecko in midden deposits on Mana Island (Miskelly 1997), however, Worthy and Holdaway (1994) suggest caution in interpreting all large gecko bones as *H. duvaucelii* given the recent discovery of several cryptic species within the *H. maculatus* complex. In contrast to *H. chrysosireticus*, *H. duvaucelii* has been recognised as a separate species since its first collection in 1836 (McCann 1955). As a result the natural history of New Zealand's largest gecko is well-documented (Robb 1980b, Barwick 1982, Christmas 1995). Typical of the *Hoplodactylus* genus, *H. duvaucelii* are nocturnal. They are habitat generalists and are considered to be both arboreal and ground dwelling (Robb 1980b). They are known to inhabit coastal forest and rocky shorelines (Christmas 1995) and have been observed to take flax nectar (Whitaker 1987a, 1987b).

There are no areas where *H. duvaucelii* and *H. chrysosireticus* are sympatric. Accordingly, there is no direct evidence to suggest how they may interact on Mana

Island. Indirect evidence lies in Eifler's (1995) work on nectarivory in New Zealand geckos which suggested that *H. duvaucelii* displaced the smaller *H. maculatus* over nectar resources on Korapuki Island, in the Mercury Islands group. Adult *H. duvaucelii* can grow up to 160mm SVL (Whitaker 1968) and are considerably larger than *H. chrysosireticus* (cf. 75mm SVL). As both species may be attracted to the same limited resource, there is a possibility that displacement could occur. *H. duvaucelii* are also known predators of the young of other gecko species (Barwick 1982).

Although restricted to offshore islands, *H. duvaucelii* is not considered threatened and is not listed under the Conservation Priority ranking system, as outlined by Molloy and Davis (1994). Under the IUCN system they are considered 'Lower risk' (IUCN 1996). All of New Zealand's herpetofauna are protected under the Wildlife Order (No2) 1996 (Anon 1996) and can only be kept under permit. They can not be collected from the wild or sold.

1.6 North Brother Island

North Brother Island (41°06'S 174°26'E) is a small island (4ha, 73m a.s.l.) in the Cook Strait about 39 km north-west from Wellington, and is the northern-most island in the Brother Islands group (Thompson 1977). The exposed rocky island has steep windswept cliffs making it difficult to access. It supports only low growing vegetation and is predominantly covered with taupata (*Coprosma repens*), pohuehue (*Muehlenbeckia complexa*) and Koromiko (*Hebe spp*) along with some small herbs and succulents (Barwick 1982; Thompson *et al* 1992). The island has never been exposed to mammalian predators although a manual lighthouse and weather station were run on the island until 1987 with live-in lighthouse keepers. The lighthouse still remains but is controlled remotely, as are the meteorological devices. North Brother Island supports populations of diving petrels (*Pelecanoides urinatrix*), fairy prions (*Pachyptila turtur*) and little blue penguins (*Eudyptula minor*) and is has the only wild population of the Brothers Island tuatara (*Sphenodon guntheri*) (Wilson and Freeman 1993). Four other reptile species, *H. maculatus*, *H. duvaucelii*, *O. lineoocellatum* and *O. nigriplantare polychroma* are also known from the island (Wilson and Freeman 1993).

Plate 1.1 Goldstripe gecko *Hoplodactylus chrysosireticus*

Plate 1.2 Typical flax habitat (*P. tenax*) of *H. chrysosireticus* on Mana Island (area A).

Plate 1.3 Duvaucel's gecko *Hoplodactylus duvaucelii*

Plate 1.4 North Brother Island

Chapter Two

Activity and movements of
H. chrysosireticus

Chapter two:

Activity and movements of *H. chrysosireticus*

2.1 Introduction

New Zealand geckos are presently grouped in two genera, *Naultinus*, the green, arboreal, diurnal geckos, and *Hoplodactylus*, the brown, ground dwelling, nocturnal geckos (Robb 1980b). Although *Hoplodactylus* geckos are generally considered nocturnal, there are two exceptions to this. Both the forest gecko (*H. granulatus*) and the harlequin gecko (*H. rakiurae*) are more active during daylight hours than other members of the genus (Thomas 1982, Gill and Whitaker 1996). Also, despite usually seeking ground-based retreat sites, *Hoplodactylus* geckos are frequently reported climbing into vegetation to forage or avoid predators (Whitaker 1968; Christmas 1995).

Little is known about the behaviour and habits of *H. chrysosireticus*. In published accounts, this gecko is often described as nocturnal (Robb 1980a and b; Whitaker 1993; Gill and Whitaker 1996) or crepuscular (Wilkinson 1977). On Mana Island Whitaker (1993) reported that of a minimum of 112 individuals all except three were found at night. The three found by day were wedged deep in the bases of flax bushes in sites considered to be near to their daytime retreats. Nevertheless, *H. chrysosireticus* are known to bask and sometimes move about in daylight (Robb 1980b). This, coupled with anecdotal reports and personal observations, suggested that *H. chrysosireticus* might be more active during the day than previously thought. *H. chrysosireticus* have also been described as ground dwelling, being frequently found under wood and in close proximity to human habitation in Taranaki (Wilkinson 1977, 1981; Robb 1980a). However, all *H. chrysosireticus* found during Whitaker's survey on Mana Island (1993) were climbing on some form of vegetation from grass (20cm) up to flax inflorescences (>3m). Over 80% were found on flax, yet none were found around the houses or sheds

on the island. Despite flax being identified as the vegetation in which *H. chrysosireticus* are most abundant (Wilkinson 1981; Whitaker 1993), no information is available on their movements within or between flax bushes.

Fundamental to understanding the ecology of any animal species is determining what they do and when. The aims of this study therefore, were to identify when *H. chrysosireticus* are most active in flax and to establish their movements within and between flax bushes. This baseline understanding is vital if monitoring of a species for conservation purposes is to be successful (Read 1999). In a restoration scenario, it allows future management decisions to be made with a more informed idea of their consequences for the species involved.

2.2 Methods

2.2.1 Study sites

Observations of *H. chrysosireticus* were made at two sites on Mana Island and one in Taranaki. In all places, flax (*P.tenax*) was the dominant vegetation cover. On Mana Island, both sites were located at Waikoko flat on the eastern side of the island. A detailed description of Mana Island is included in section 1.2. Area A (Fig 1.2 and Plate 1.2) at the base of House Gully, consists of two close rows of flax planted on the banks of a small stream up to a dam at the northern end. Poroporo (*Solanum aviculare*), inkweed (*Phytolacca octandra*), cutty grass (*Carex geminata*) and umbrella sedge (*Cyperus ustulatus*) occur in and around the flax. It is bordered on the western side by 5-10yr old plantings of mahoe (*Melicytus ramiforus*), ngaio, (*Myoporum laetum*), taupata (*Coprosma repens*) and karaka (*Corynocarpus laevigatus*) and to the south and east by mown grass access tracks. Area G (Fig 1.2) was located at what is now Waikoko wetland. The main vegetation at this site consisted of two close rows of flax planted as a shelter belt from the flat grass landing area near the beach, along the side of the generator shed and up to the sewerage ponds adjacent to the southern access track. The flax rows were surrounded by rank pasture grasses and interspersed with poroporo and New Zealand spinach (*Tetragonia trigyna*). Adjacent to the landing area end was a

pocket of 5-10 year old plantings of mature ngaio, cabbage trees (*Cordyline australis*), and mahoe.

The Taranaki site is located at Matekai Park, Oakura, 15km west of New Plymouth. Matekai Park is a small wetland reserve (4.844ha) in a valley less than 100m from the Oakura coast and is administered by the New Plymouth District Council (NPDC) Parks Division (Plate 2.1). The area is surrounded by residential housing and comprises Matekai stream, a wetland of native flax, cabbage trees and carex (*Carex secta*), and an island of mown grass and plantings, both exotic and native (Anon 1999).

Matekai Park was formally a leased grazing area until the formation of the Oakura Park Development Society in 1984. The Society set about restoring the wetland area and creating a 'passive recreation' park through public and council involvement. *H. chrysosireticus* was first found in the park in 1986 (Daily News 1986) which led to the protection of the area. Since then, local groups have been involved in the planting of native vegetation including flax. The wetland is maintained by the NPDC through weed control and the removal of species such as tree ferns (*Cyathea* spp) and mahoe, which may lead to successional change. No herbicide is sprayed in the wetland area. Rats (*Rattus* spp.) and domestic cats (*Felis catus*) are often seen in the park but no form of organised predator control is undertaken (H. Flannagan pers. obs).

2.2.2 Activity

After a preliminary search in July 1996, timed and untimed searches were made of flax bushes in these areas over three to five days each month from November 1996 to October 1997 (excluding January and February 1997) on Mana Island and August 1997 to November 1997 at the Taranaki site. Lizard activity was measured by comparing catch rate (number of geckos caught per person hour) and encounter rates (number of geckos caught plus those seen but not caught per person hour) in flax at various times during the day and night. Activity is defined here as any behaviour where the gecko moved out from its retreat site and therefore became available for capture. This included basking, foraging, sitting and walking amongst the vegetation. Animals that were in retreat sites, wedged into the bases of the flaxes or curled up under vegetation or other

cover objects, were not used in the analysis. To maintain a consistent search effort, searches were made by myself and occasionally one other person. Care was taken to ensure disturbance to the habitat was kept to a minimum. During the day, geckos were located by sight and at night with a spotlight to detect eye-shine. Where possible, geckos were caught by hand, weighed (to nearest 0.5g) and assigned to an age/sex class (section 2.2.4). Their snout to vent length (SVL), tail length (TL) and amount of tail regeneration were measured with a ruler (to nearest 1 mm).

On initial capture, the geckos were given a unique and permanent identity mark by clipping the tips of two toes as described by Whitaker (1994). Only two toes per gecko could be clipped in accordance with the permit issued by the Department of Conservation, allowing a total of 150 unique combinations. The combinations were sequential, counting toes from the inside out and starting with the left front foot (LF), then the right front foot (RF), the left rear foot (LR), and finally the right rear foot (RR) when viewing the gecko from the dorsal side. This is a standard procedure that is permanent and causes little, if any, apparent distress to the animal (Dunham *et al* 1988). The toes were preserved in 70% ethanol and refrigerated for future genetic analysis. All toeclipped *H. chrysosireticus* and any caught in addition to the initial 150 were given a temporary field identification mark on the dorsum using a non-toxic, xylene-free, silver ink pen. This mark has been shown to remain on the skin until the animal sloughs its skin up to 160 days later (section 3.3.1).

Vegetation or substrate type and the time of each encounter were recorded. Lizards that were seen but not caught were also noted. The height above ground of geckos within the vegetation when first encountered were recorded as general height classes (0 = ground or base of flax, 0-0.5m above base, 0.5-1m, 1-1.5m, 1.5-2m, >2m). Ambient temperature, humidity, wind direction and intensity, cloud cover and precipitation were also measured at the time of each search.

To see if any diurnal behaviour observed could be considered within the 'normal' range for a nocturnal gecko, day and night catch rates for *H. chrysosireticus* were compared to those for *H. maculatus*, also resident on Mana Island. *H. maculatus* are similar-sized (adult SVL 55-60mm) nocturnal geckos (McIvor 1973; Robb 1980b) that are also often

encountered in flax (Eifler 1995). They are perhaps New Zealand's most widely studied gecko species and hence much is known about their ecology (Whitaker 1982), physiology (Werner and Whitaker 1978), reproduction (Cree 1994), and behaviour (Hardy 1971; Tocher 1992).

Differences in night and daytime activity and monthly variations were investigated by comparing catch rates for each of the age/sex classes using SAS® version 6.12 General Linear Models (GLM) procedure for ANOVA and Duncan's multiple range test (SAS Institute 1989). All results are for type III sums of squares unless otherwise stated. The relationship between gecko activity and weather variables was determined using forward stepwise multiple regression analysis in SYSTAT® version 6.0 (SPSS Inc. 1996). Significance for all tests was set at $P < 0.05$. Only searches greater than or equal to one person hour were included in the analyses, unless otherwise stated, to overcome biased catch rates through extrapolation.

2.2.3 Movements

Between July 1996 and December 1997 movements were determined by labelling and recording the location where toeclipped geckos were found. Subsequent recaptures of these geckos over the following months provided information about how far they had moved between captures. Distances were classified in terms of "flax bushes moved" and calculated based on the average width of a mature flax bush of c.1.5m.

2.2.4 Sexing and ageing

When caught, all geckos were assigned to an age class (juvenile <45mm, sub-adult 45-60mm or adult >60mm) based on the arbitrary categories proposed by Whitaker (1993). These were then reclassified according to age estimations from growth curve data (section 3.2.3). Therefore, only the new categories are used in this chapter. Sexing was only possible on adults as it relies on the observation of secondary sexual characteristics. Adult male geckos are easily distinguished from females by the swollen hemipenal sacs at the base of the tail, 1 enlarged blunt scale on either side, and a triangular patch of preanal pores (Robb 1980b). As females are difficult to distinguish

from immature males, only animals that were the same size or bigger than the smallest gravid female caught (62mm SVL) were considered females.

2.3 Results

Although both catch rates and encounter rates were recorded in this study, they were highly correlated with each other during both day and night searches ($R^2 = 0.7724$, Fig 2.1). Individual identification of geckos ensured that animals were not counted more than once in a search period. Therefore, catch rate is used for all of the analyses unless otherwise stated.
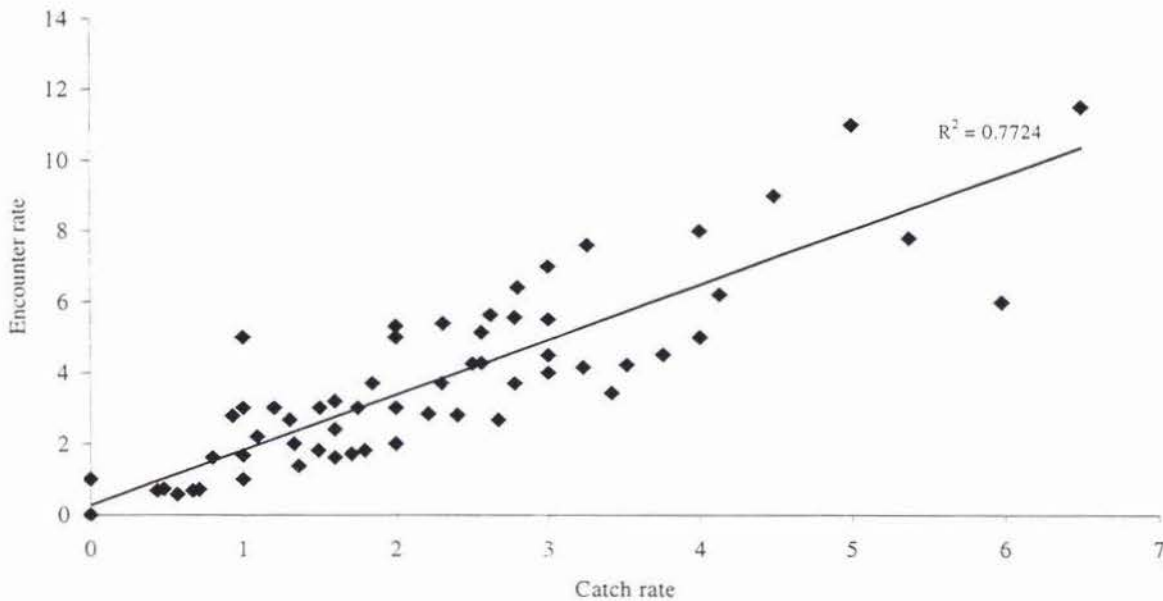
Fig 2.1 Correlation between catch rates and encounter rates of *H. chrysosireticus* on Mana Island between July 1996 and October 1997.

Search efficiency improved after the first three months of sampling with the average catch rate per hour increasing from an initial rate equivalent to Whitaker (1993) to a mean level of 2.08 ($\pm$ 0.17 SE) (Fig 2.2).
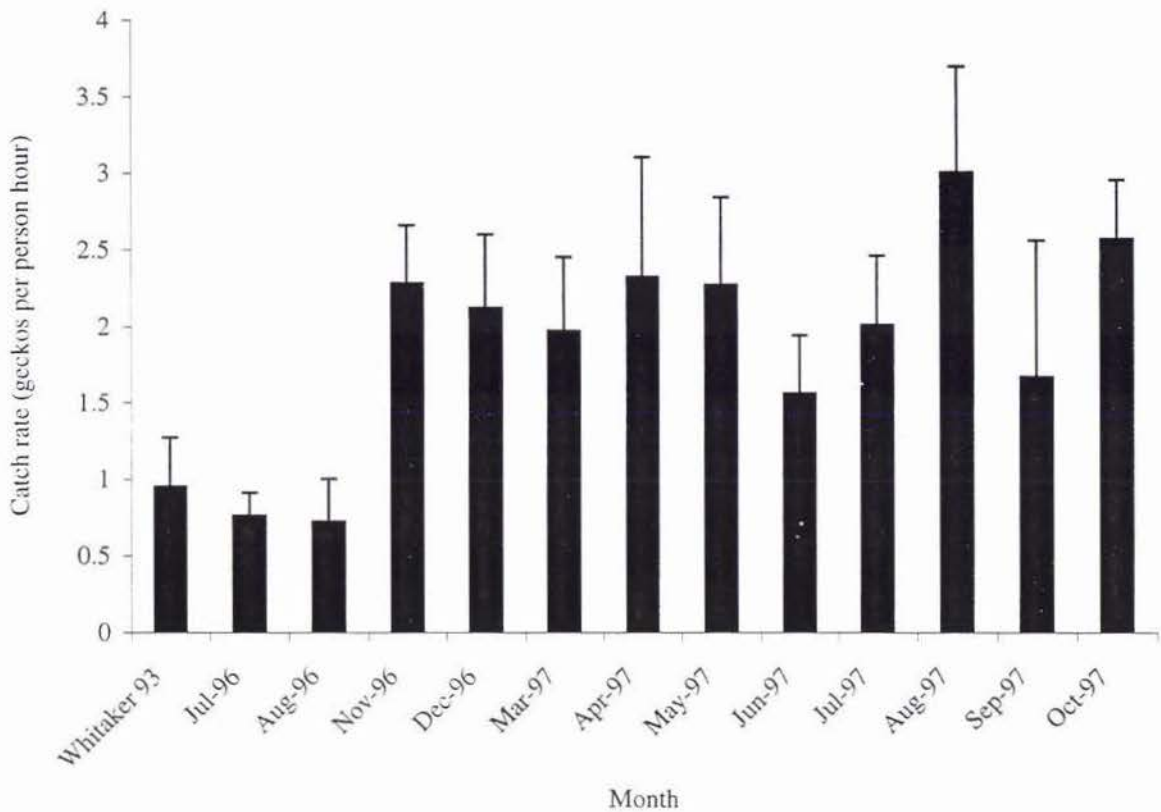
Fig 2.2 Mean monthly catch rates ($\pm$ SE) of *H. chrysosireticus* in flax on Mana Island.

2.3.1 Activity

In contrast to previous observations (Whitaker 1993), *H. chrysosireticus* were found out and active both day (Plate 2.2) and night (Fig 2.3). They were caught at all times of the day from dawn (approx. 0600 – 0800h), midday, dusk (approx. 1700 – 1900h) and dark (up to latest search time of 0300h), with peaks in captures between 0800 – 1600h in daylight, and after dark from approximately 1900h. Dawn and dusk were the periods of least activity.

Plate 2.1 *H. chrysosireticus* habitat at Matekai Park, Oakura, Taranaki.

Plate 2.2 *H. chrysosireticus* as found on flax during the day

Although many *H. chrysosireticus* were seen basking during the day, several were observed moving about in the flaxes actively foraging for small flies, mites, moths and craneflies[2]. At night they were also observed foraging, often in a "sit-and-wait" posture across the leaves or, in December, climbing to the tops of flax inflorescences to take nectar from new flowers. Geckos were observed on flax inflorescences after flowering in early autumn (March) possibly attracted by large numbers of small flying invertebrates.
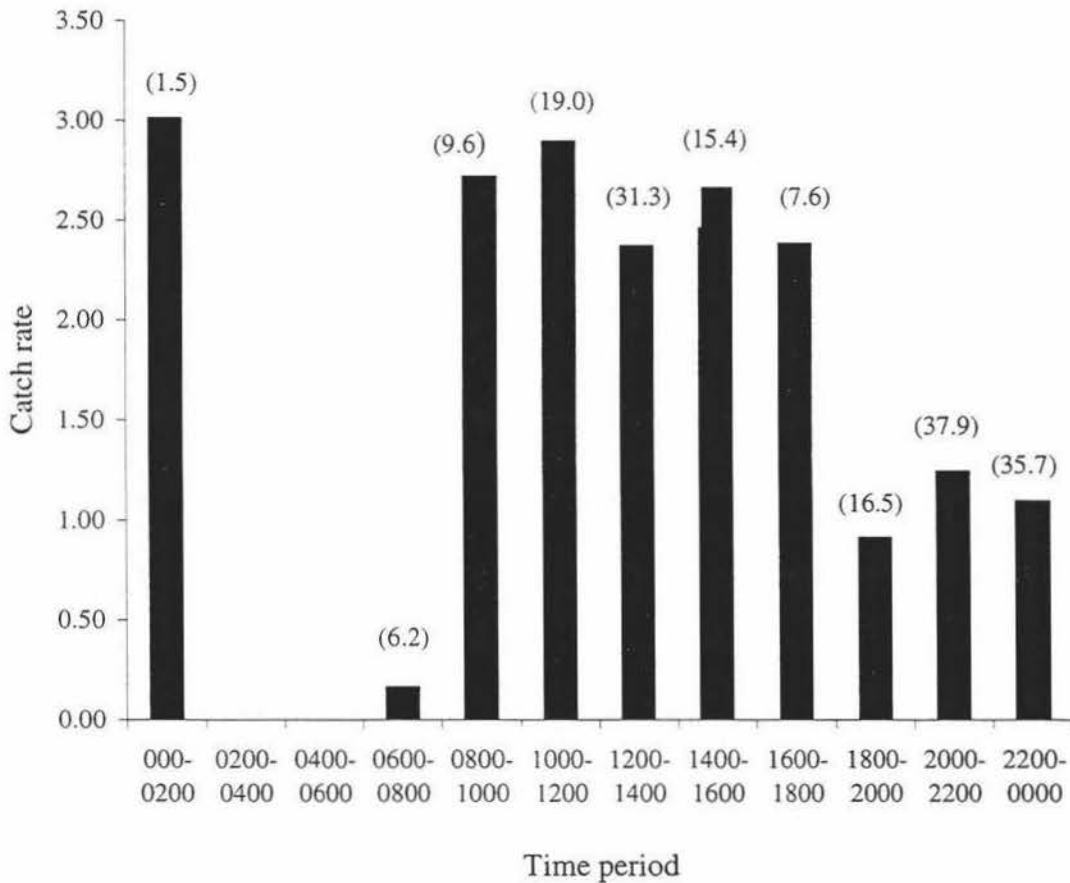
Fig 2.3 Overall catch rates for *H. chrysosireticus* in flax on Mana Island in relation to time of day (No searches took place between 0300 and 0600). Number of hours spent searching are in brackets and include searches < one person hour.

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[2] Craneflies, moths and mites were pulled from mouths of *H. chrysosireticus* soon after they were caught. *H. chrysosireticus* were often also seen chasing small flies up the flax leaves.

H. chrysosireticus were consistently caught ($F_{1,35}$ =6.42 P=0.016) and encountered ($F_{1,35}$ = 10.04 P=0.003) more often during the day than at night. Slightly more time was spent on night searches than day searches (Table 2.1) yet 66.1% of *H. chrysosireticus* were found during the day. Catch rates for males, females, sub-adults and juveniles are shown in Table 2.2. Female catch rates were higher than all other age/sex classes ($F_{3,211}$ = 8.57, P=0.0001) but there was no significant difference between night and day time catch rates for any of the classes ($F_{1,211}$ = 0.73, P=0.3955). The male to female ratio based on these catch rates was 0.53:1 showing a strong female bias (G = 17.514; P>0.05, 1df)

Table 2.1 Comparison of mean ($\pm$ SE) catch rate and encounter rate for *H. chrysosireticus* during day and night searches in flax on Mana Island. Total search hours only include searches > one person hour.

	Day	Night	Total
Total search hours	64.38	79.67	144.05
Total geckos caught	170	87	257
Mean caught	2.59 ($\pm$ 0.24)	1.42 ($\pm$ 0.20)	2.08 ($\pm$ 0.17)
Total geckos encountered	289	132	421
Mean encounter rate	4.46 ($\pm$ 0.44)	2.26 ($\pm$ 0.28)	3.50 ($\pm$ 0.30)

Table 2.2 Comparison of catch rate (mean $\pm$ SE) for each age/sex class for *H. chrysosireticus* during day and night searches in flax on Mana Island.

Age/sex class	Day	n	Night	n	Total n
Male	0.22 ($\pm$ 0.04)	37	0.25 ($\pm$ 0.05)	26	63
Female	0.42 ($\pm$ 0.05)	84	0.31 ($\pm$ 0.06)	35	119
Sub-adult	0.14 ($\pm$ 0.04)	22	0.16 ($\pm$ 0.05)	13	35
Juvenile	0.17 ($\pm$ 0.04)	27	0.11 ($\pm$ 0.04)	13	40

Activity of *H. chrysosireticus* did not appear to change between months (Fig 2.4) with no significant difference observed for overall monthly catch rates ($F_{1,35}$ = 0.52,

P=0.8497) or age/sex catch rates ($F_{9,211}$ = 0.25, P=0.9871). However, catch rates during the day in August and September were notably higher than night catch rates when compared to other months (Fig 2.4). There was also no significant difference in *H. chrysosireticus* activity between the two Mana Island study sites.
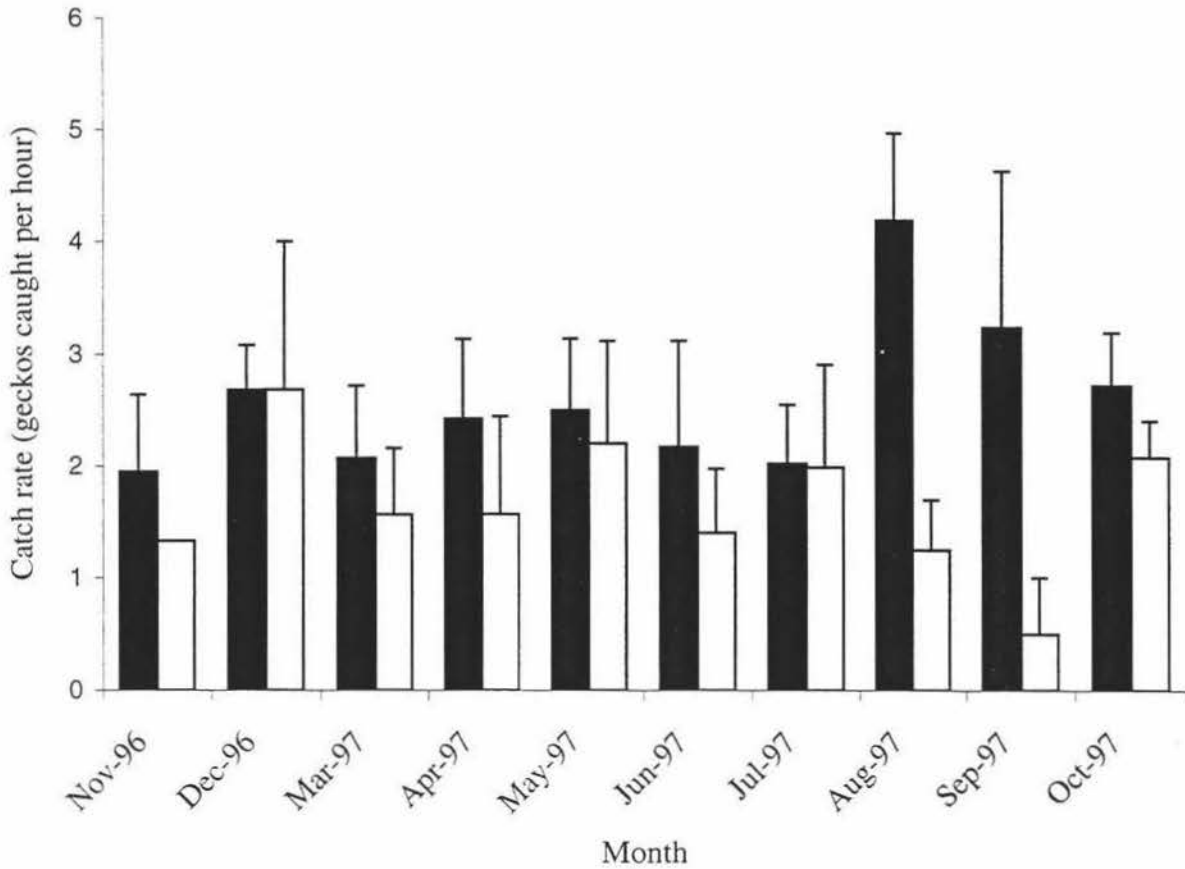
Fig 2.4 Monthly catch rate (mean ± SE) of *H. chrysosireticus* during the day (■) and at night (❑) on Mana Island (November 1996 – October 1997). No searches were made in January or February 1997.

2.3.2 Comparisons with Taranaki H. chrysosireticus and Mana Island H. maculatus

Timed searches for *H. chrysosireticus* were made during the day and night at Matekai Park, Oakura, Taranaki, during September and October 1997. Difficult search conditions (swamp and blackberry) meant that not all of the swamp area was searched, therefore these results relate only to a sub-set of the population at Matekai Park. A total of 21 *H. chrysosireticus* were caught with the majority (82%) caught during the day

(Table 2.3). All captured animals were on flax. The ratio of males to females, from overall catch rates, were the reverse of those on Mana Island at 1:0.5 male (n=12) to female (n=6) (c.f. 0.53:1 on Mana Island) although this was not a significant male bias (G = 2.0388; P>0.05, 1df).

In contrast, to the activity patterns of *H. chrysosireticus*, *H. maculatus* were seldom active during the day on Mana Island but were frequently encountered after dark (Table 2.3). They tended to be in very low numbers in the two flax areas where *H. chrysosireticus* were most numerous but were more abundant along the rocky shoreline. On the beach *H. maculatus* were easily detected by eye-shine after dark (11.2 per person hour). Large numbers were found during the day under old farming debris and in wooden rat bait boxes along the shore; occasionally there were more than 20 in one box. These animals were considered to be in their retreat sites and therefore not "active" for the purposes of this study. Only geckos found in flax were used for the comparisons.

Table 2.3 Comparison of day and night catch rates (mean $\pm$ SE) between Mana Island *H. chrysosireticus*, Taranaki *H. chrysosireticus*, and Mana Island *H. maculatus* in flax.

	Catch rate day	n	Catch rate night	N
Mana Island *H. chrysosireticus*	2.59 (0.25)	289	1.59 (0.22)	132
Taranaki *H. chrysosireticus*	1.86 (0.37)	29	0.62 (0.21)	6
Mana Island *H. maculatus*	0.76 (0.23)	3	1.56 (0.31)	45

Catch rates of *H. chrysosireticus* from Mana Island and Taranaki were not significantly different ($\chi^2 = 3.802$; P>0.05, 1df) although the overall numbers were lower. However, catch rates for *H. maculatus* and *H. chrysosireticus* from flax on Mana Island were significantly different with *H. maculatus* being far more active at night than during the day ($\chi^2 = 68.762$; P>0.05, 1df).

2.3.3 Influence of weather variables

Weather appeared to have little effect on *H. chrysosireticus* behaviour. Although most geckos were observed in temperatures of 12 to 18°C, they were also seen out and foraging in rain, strong winds and on generally bleak overcast days in temperatures as low as 7.5°C. One animal was caught at night 20 minutes prior to a cold snap down to 1.5°C. Statistically, temperature had the greatest influence on overall encounter rates (P = 0.012) but explained little of the variation (R^2 = 0.128). When regressed against day or night, no significant variable was apparent for daytime encounter rates. At night, temperature and humidity became the best predictors (P = 0.026 and 0.025 respectively; R^2 = 0.356). Tests using weather variables for catch rates failed to pick up any significant correlations.

2.3.4 Climbing

All *H. chrysosireticus* at the Mana Island and Taranaki study sites were found climbing on and amongst vegetation, with 98% on flax. The other two percent were found on poroporo, cutty grass and New Zealand spinach growing alongside and amongst the flax. The height within vegetation at which geckos were found did not vary significantly between day and night ($F_{1, 191}$ = 0.42, P=0.5172) or between months ($F_{1, 191}$ = 1.60, P=0.1187). The average height was 0.58m ($\pm$ 0.02) above the base of the flax. Generally, geckos were more frequently found at 0.5m or less at night (mean 00.48m $\pm$ 0.05) compared to 0.5 – 1m during the day (mean 0.61m $\pm$ 0.03).

2.3.5 Movements

Sixty-nine (37.7%) out of 183 marked animals were re-caught. Only animals caught more than 21 days after their initial capture were used for the analysis to reduce any effect of observer interference. This reduced the number of recaptured individuals to 55. Thirty-nine (70.9%) of these remained in the same flax bush where they were originally caught in (Fig 2.5). Of the 16 (29.1%) that shifted, four moved to an adjacent bush (1.5m), five moved two bushes over (3m), two went three (4.5m) and five went greater than four bushes away (>6m). Two geckos moved up to three bushes away but then

came back after 343d and 418d respectively since their initial capture. The greatest distances travelled were by two males who each travelled further than 25m away from their original point of capture. There did not appear to be any seasonal reason for these moves with one occurring in spring (July 1997 to October 1997) and the other over summer (November 1996 to April 1997). Movement was not related to the age or sex of the gecko (Table 2.4) or to the time between recaptures (Fig 2.6). Movement of geckos between bushes was not related to the number of times each gecko was caught, suggesting that the level of disturbance involved with searching was not enough to encourage them to move (Fig 2.7). Efforts were made to track individual geckos using transponders and harmonic radar, but were unsuccessful.
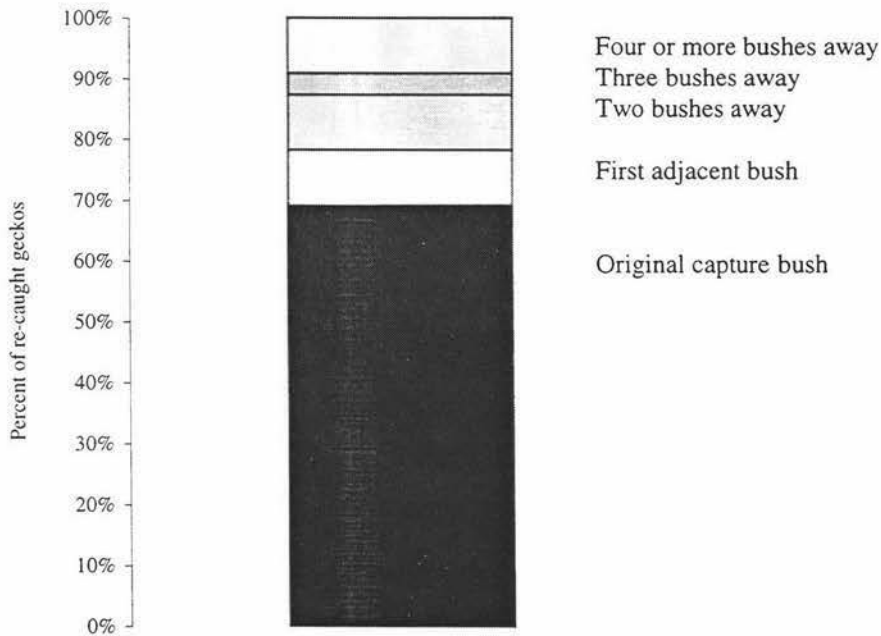
Fig 2.5 Percentage of re-caught *H. chrysosireticus* on Mana Island in relation to the number of flax bushes moved between captures.

Table 2.4 Number of flax bushes and distance (m) travelled by *H. chrysosireticus* between captures. The class 'young' includes juvenile and sub-adult geckos.

		Number of bushes moved						
	Number re-caught	0	1 (1.5m)	2 (3m)	3 (4.5m)	>4 (>6m)	Total moved	% moved
Female	28	19	3	3	1	1	9	29.6
Male	12	9	0	0	0	3	3	31
Young	15	10	1	2	1	1	5	30
Total	55	38	5	5	2	5	17	30.9
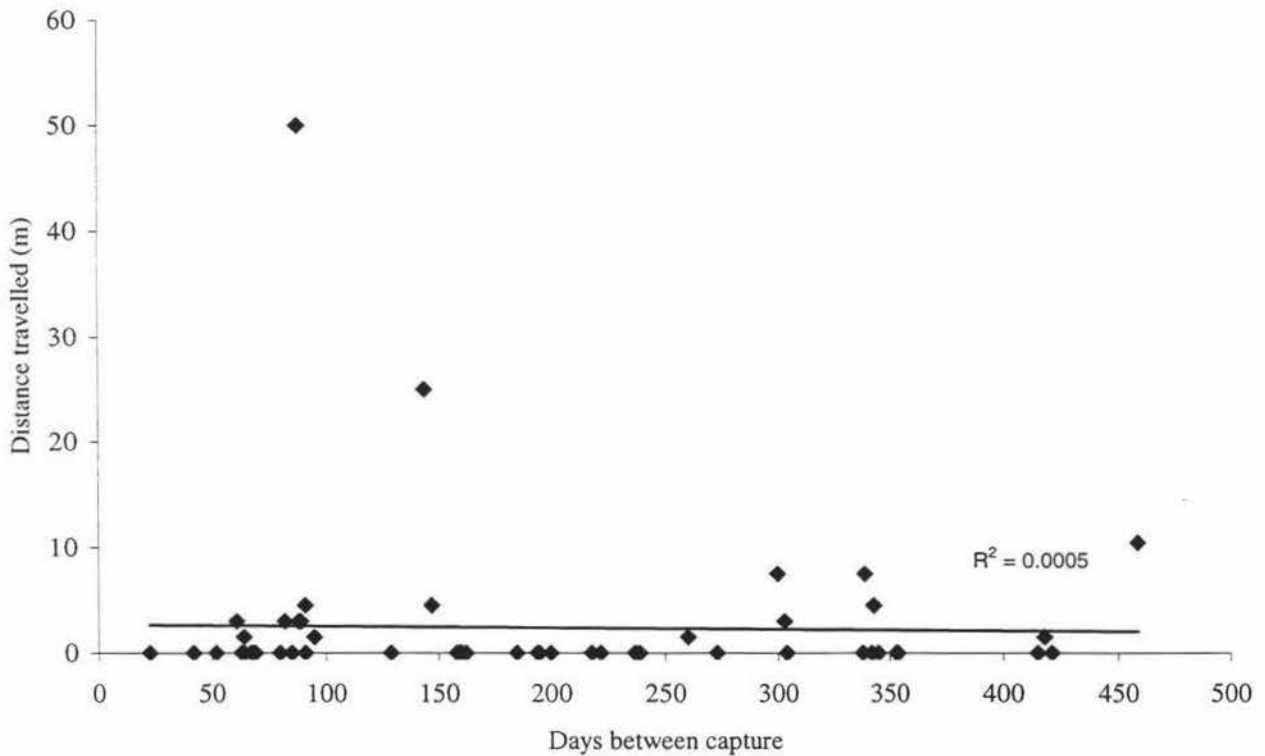
Fig 2.6 Distance travelled (m) by *H. chrysosireticus* on Mana Island in relation to the number of days between capture.
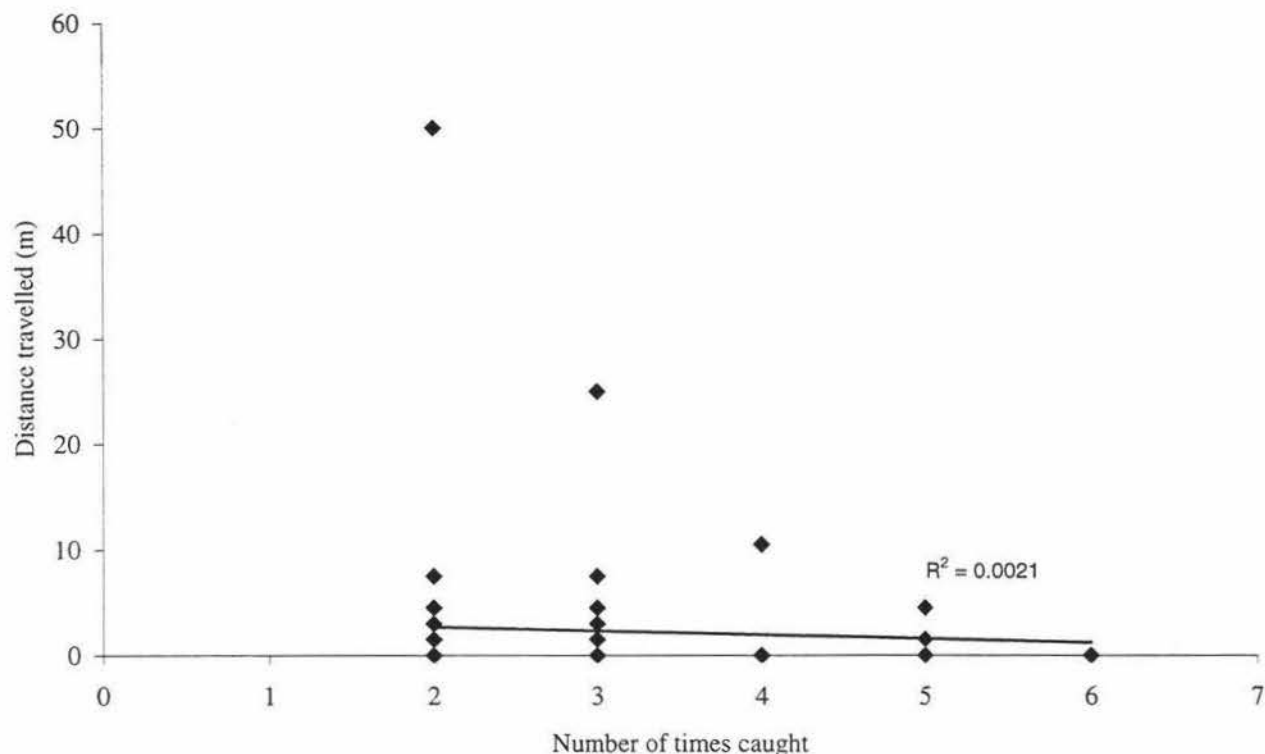
Fig 2.7 Distance travelled (m) by *H. chrysosireticus* on Mana Island in relation to number of times caught.

2.4 Discussion

2.4.1 Activity

H. chrysosireticus of all age/sex classes were consistently found during both day and night searches. Capture rates were similar for day and night and in many cases were higher during the day. This is an unusual observation for what has been described as a nocturnal species. Only three *H. chrysosireticus* were found during the day in Whitaker's survey (Whitaker 1993). This anomaly is difficult to explain and may be related to different search techniques by Whitaker (1993) and myself. Whitaker's team consisted of up to 10 people with varying experience during one month of the year. In comparison, the present study is the result of one searcher repeatedly sampling the same area over 12 months.

Alternatively, diurnal behaviour may have recently developed due to some external pressure. As has been shown in several lizard species on islands where rodents have been removed (Towns 1991), predators can sometimes cause changes in behaviour. Mana Island became free of rodents in 1990 after the successful eradication of large numbers of mice (Hutton 1990). The impacts mice may have had on the *H. chrysosireticus* population are largely unknown. However, circumstantial evidence suggests that high predation pressure and competition for food resources by the mice may have been responsible for only four animals being found on the island prior to 1993 (Whitaker 1993). Mice may also be responsible for the increased level of diurnal behaviour exhibited by *H. chrysosireticus* today. However, if this were true, one could expect *H. maculatus* to have adopted a similar strategy, but this is not the case since *H. maculatus* remain a strongly nocturnal species on Mana Island (Whitaker 1993, Gorman 1996). The natural predators of *H. chrysosireticus* on Mana Island are largely unknown although starlings (*Sturnus vulgaris*) (Anon 1977), kingfishers (*Halcyon sancta*) (Aanensen 1978), moreporks (*Ninox novaeseelandiae*) (Ramsey and Watt 1971) and possibly takahe (Atkinson 1990) are all known to prey on lizards. In Taranaki, *H. chrysosireticus* are found in areas where mammalian predators, such as cats and rats, are frequently seen (H. Flannagan pers. obs.). Their numbers may be low because of this but their behaviour is surprisingly similar to that on Mana Island.

Aside from predation, competition from a similar species may be influencing the activity patterns of *H. chrysosireticus*. Studies by Rummel and Roughgarden (1985) found that *Anolis wattsi* tended to change its time of activity when in the presence of *A. bimaculatus* in the Lesser Antilles, although they did remain essentially diurnal. In New Zealand, nocturnal *H. duvaucelii* have been reported to change their behaviour from ground to arboreal foraging when in the presence of *Oligosoma oliveri*, a similar sized nocturnal skink (Whitaker 1968). For *H. chrysosireticus*, increased diurnal behaviour may be a way of reducing dietary overlap with *H. maculatus*. However, this does not appear to be the case because, although *H. maculatus* occur at high densities on Mana Island, they are seldom found in the flax areas where *H. chrysosireticus* are most abundant. The diurno-nocturnal activity pattern of *H. chrysosireticus* was also seen in Taranaki where *H. maculatus* are absent.

Alternatively, the bimodal activity of *H. chrysosireticus* may just be a natural behaviour that for some reason has remained undetected until now. The motivation for such bimodal activity is unclear and may be the result of several factors working in conjunction such as photoperiod, temperature, light intensity, barometric pressure (Harker 1964) or hunger (Heatwole and Taylor 1987). Studies on the night lizard (*Xantusia henshawi*) showed that both photoperiod and temperature were important in stimulating activity, and that although most locomotor activity occurred in rock crevices during the day, the lizards only emerged from cover after dark (Lee 1974). The night emergence was suggested to be an opportunity for establishment or defence of territories. The phase of the moon has also been shown to influence diurno-nocturnal geckos, with *Ptyodactylus hasselquistii guttatus* observed to increase its level of activity on the waxing moon and decrease it on the waning moon (Frankenberg and Werner 1979).

Typically the main period of activity for nocturnal geckos commences around dusk (Whitaker 1968). However, many will emerge during the day to bask (Robb 1980b). Basking is an essential behaviour for increasing the body temperatures of nocturnal reptiles to assist basic metabolic processes such as digestion and is usually done under or close to cover (Waldschmidt *et al* 1986). As well as basking in the open, *H. chrysosireticus* were also observed walking around the flax leaves and actively foraging for small invertebrates during the day. They were also observed out in 'sit and wait' positions on overcast and damp days. Heatwole and Taylor (1987) have suggested that the diurnality shown in some New Zealand geckos has been a response to the cold environment creating more necessity to bask. However, if basking were the main reason for *H. chrysosireticus* activity during the day, one would expect temperature to be the most important factor influencing catch and encounter rates. This was not evident in the present study.

Adult female *H. chrysosireticus* on Mana Island were caught more often than other age/sex classes. They were more active during the day but not significantly so. This could either indicate a skewed sex ratio in favour of females or a tendency for adult females to be more active than other individuals hence making them more likely to be caught during a search period. The later may be responsible for the reversed sex ratio

observed in the catch rates at the Taranaki site. If females are out more often than males, they are likely to be more susceptible to predation. Like all New Zealand geckos, *H. chrysosireticus* are ovoviviparous, giving birth to live young (McCann 1955). Although basking was not compared to the females' reproductive state in this study, their diurnal behaviour may be related to a metabolic need to bask for that purpose. This would agree with Werner and Whitaker (1978) who found body temperatures taken from female *H. maculatus* from Motunau Island, New Zealand, were 2° C higher on average than males. Similarly, Schwarzkopf and Shine (1991) found that viviparous female *Eulamprus tympanum* skinks tended to bask more often when gravid than other members of the population, although in that study, no noticeable difference in body temperatures between individual skinks was observed.

2.4.2 Movements

H. chrysosireticus showed strong site fidelity with over 70% remaining in the same bush that they were originally captured in and over 90% moving less than $4.5m^2$. This is comparable to Whitaker's (1982) study of *H. maculatus* at Turakirae Head where 92% moved less than 5m from their original capture point. The flax rows on Mana Island are densely planted and the leaves of different bushes are frequently intermingled. Despite this, the majority of *H. chrysosireticus* tended to stay faithful to one flax bush. Whitaker (1982) also found that juvenile *H. maculatus* moved slightly more than the adults, possibly indicating a type of dispersal phase. This did not appear to be the case for juvenile *H. chrysosireticus* with all age/sex classes showing approximately the same amount of movement. Although they move very little between flaxes, *H. chrysosireticus* take full advantage of the three-dimensional nature of the bushes themselves, foraging to the extremities of the flax leaves and up to the flowers at the tops of the flax inflorescence stalks (>3m). The actual movements of *H. chrysosireticus* within the flaxes in a 24hr period are not clear. It is also not known whether the geckos stayed in the same bushes or perhaps moved away and returned.

2.4.2 Conclusion

This is the first study where *H. chrysosireticus* has been permanently marked and followed over time. From this work it can clearly be seen that *H. chrysosireticus* are just as active during the day as they are at night and therefore should be considered diurno-nocturnal in their habit. This will make them the third *Hoplodactylus* species to be considered as such after *H. granulatus* and *H. rakiurae* (Gill and Whitaker 1996). For accurate results, searches for *H. chrysosireticus* in new areas or for future population assessments should be done both during the day and at night. *H. chrysosireticus* also show strong site fidelity, hence the spread of these geckos into new habitats may be a slow process. This should be considered when making management decisions for the future of the species.

Chapter Three

Age structure and population biology of
H. chrysosireticus

Chapter three:

Age structure and population biology of *H. chrysosireticus* on Mana Island.

3.1 Introduction

Conservation biology has been described as a crisis discipline whereby its very existence has been borne out of necessity (Soule 1985). Ideally, a good understanding of the ecology and population dynamics of species before they become critical may highlight the warning signs and assist in their recovery. When dealing with already threatened or endangered species, this is essential. Without adequate data, monitoring results are meaningless and the implications of management practices can be difficult to predict or interpret accurately (Read 1999). Few studies have been done on the ecology and behaviour of New Zealand's gecko species and new species are still being discovered (Hitchmough 1997). This is mainly due to their cryptic, and in the case of *Hoplodactylus* species, nocturnal nature. Likewise, little is known about the behaviour and habits of *H. chrysosireticus*. With the exception of short descriptive accounts such as in Robb (1980a and b) and Gill and Whitaker (1996), there are only two published papers (Wilkinson 1977 and 1981) and one unpublished report (Whitaker 1993) that focus on the species.

Until 1980, *H. chrysosireticus* was considered a variation of *H. pacificus* (Robb 1980a and b). Like all New Zealand geckos, *H. chrysosireticus* belongs to the subfamily Diplodactylinae, a group restricted to Australia, New Caledonia and New Zealand. Both endemic New Zealand gecko genera (*Naultinus* and *Hoplodactylus*) are ovoviviparous and give birth to live young (Robb 1980b). Mating among *H. chrysosireticus* occurs in April and the young (usually twins) are born in February or March (Wilkinson 1977, 1981; Rowlands 1987). Adult size (around 140mm total length) is achieved after four

years (Wilkinson 1981). However, these demographic and growth records are for captive geckos and may not accurately represent the wild situation.

H. chrysosireticus is known only from Mana Island and a few locations in the Taranaki region (section 1.3.1). There are no data available on the status of the Taranaki populations of *H. chrysosireticus*, however, the largest group on Mana Island was estimated at 200-300 animals from a survey in February 1993 (Whitaker 1993). Whitaker concluded that the population was in a growth phase after the recent eradication of mice from the island in 1990 and that the potential population of *H. chrysosireticus* could number in the thousands. Accordingly, based on Whitaker's estimate, the conservation status of *H. chrysosireticus* was reduced from category B to C (Molloy and Davis 1994). However, no geckos during this survey were permanently marked and no growth data obtained. Recommendations from Whitaker's survey were to check the status of the Mana Island population and monitor their expansion at five-year intervals. This chapter re-assesses the status of the *H. chrysosireticus* population on Mana Island, four years after the initial survey, using mark-recapture techniques, population estimates and growth models from permanently marked individuals over one year. The main objectives were to estimate age in relation to size of individual geckos and to estimate the size of the largest known group of *H. chrysosireticus* on the island.

3.2 Methods

3.2.1 Study site

The work for this chapter was conducted on Mana Island Scientific Reserve (217 ha, 121m a.s.l.), Cook Strait, with some comparisons drawn from *H. chrysosireticus* from Matekai Park in Taranaki. Matekai Park is described elsewhere (section 2.2.1) and a more comprehensive description of Mana Island is detailed in section 1.2. Mana Island has been highly modified following several centuries of Maori occupation and intensive pastoral farming since the early 1800s (Jones 1987). It is currently managed by the Department of Conservation and has been undergoing ecological restoration since 1987 (Miskelly 1997). Mice were the only introduced mammal left on the island after farming

ceased in 1986 and were subsequently eradicated by 1990 (Hutton 1990). Although mostly covered by rank pasture grass, a large proportion of the lower eastern side has been replanted in native coastal forest and wetland species as part of the restoration programme. Remnant clumps and shelter belts of flax, pampas, ngaio and karo planted by the Ministry of Agriculture in the early 1970s still remain and are the main habitat for *H. chrysosireticus* (Whitaker 1993). The greatest number of *H. chrysosireticus* is found in area A (Whitaker 1993), which is situated at Waikoko flat on the eastern side of the island (Fig 1.2 and Plate 1.2). This area is composed predominantly of flax (*P. tenax*) planted either side of a small stream. *H. chrysosireticus* are also found in other clumps of flax around the island including a shelter-belt planted along side the generator shed on Waikoko flat (area G). Further descriptions of areas A and G are included in section 2.2.1.

3.2.2 Capture and marking methods

After a preliminary search in July 1996, timed and untimed searches were made of flax bushes on Mana Island over 3-5 days and nights each month from November 1996 to October 1997 (excluding January and February 1997). To maintain a consistent search effort, searches were made by myself and occasionally one other person. During searches, care was taken to ensure disturbance to the habitat was kept to a minimum. During the day, geckos were located by sight, and at night with a spotlight to detect eye-shine. Pitfall trapping proved ineffective for this agile species[3] (H.Flannagan pers obs.) so where possible, geckos were caught by hand. On initial capture, the first 150 *H. chrysosireticus* were given a unique four-digit toeclip combination by clipping the tips of two toes as described by Whitaker (1994) (section 2.2.2). The toes were preserved in 70% ethanol and refrigerated for future genetic analysis. In addition, all toeclipped animals were given a temporary field identification mark on the dorsum using a non-toxic, xylene-free, silver ink pen. Subsequent recaptures of the permanently marked individuals provided information on the timing of skin sloughing and the persistence and reliability of the temporary markings. All geckos caught were weighed (to nearest

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[3] Pitfall trapping was attempted around flax areas over four months but was unsuccessful. *H. chrysosireticus* seldom forage on the ground (Whitaker 1993) and are able to climb up vertical glass (Wilkinson 1981), making them difficult to trap.

0.5g) and sexed (section 2.2.3), and their snout to vent length (SVL) and tail length (TL) measured (to nearest 1 mm). Records were kept of geckos with broken tails and the length of tail regeneration measured (to nearest 1 mm). Vegetation or substrate type and the time of each gecko encounter were also recorded.

3.2.3 Reproduction and growth rates

Upon capture, female *H. chrysosireticus* were palpated (Cree and Guillette 1995) to assess reproductive state (gravid or not). If a large mass was palpated, females were considered gravid. The actual stage of vitellogenesis or pregnancy was not recorded nor any dissections made. Females were also weighed at this time. An ANOVA (PROC GLM; SAS Institute 1996) was used to determine if the average weight of females with unbroken tails changed throughout the year. The SVL frequency of juvenile *H. chrysosireticus* caught each month was also tested in this way to see if there was an influx of small juveniles at any particular time of the year indicating a 'birth pulse'. Repeated captures and measurements of permanently marked geckos provided information on growth rates of juveniles and adults. These data were used to estimate age in relation to SVL using three growth models frequently used for estimating lizard growth (Dunham 1978; Sarre 1998): Faben's method to estimate Von Bertalanffy growth curves and Schoener's method to estimate Logistic-by-length and Logistic-by-weight (with length substituted for weight) growth curves (Schoener and Schoener 1978). The growth curve models are expressed by the following interval equations:

Von Bertalanffy equation:

$$L_2 = a - (a - L_1)\, e^{-rD}$$

Logistic-by-length equation:

$$L_2 = aL_1 / L_1 + (a - L_1)\, e^{-rD}$$

Logistic-by-weight equation:

$$L_2 = \left[\frac{a^3 L^3}{L^3 + (a^3 - L^3)\, e^{-rD}} \right]^{1/3}$$

where a = an asymptotic value, r = intrinsic growth rate, L_1 and L_2 are SVL at initial capture and final capture, respectively, and D is the time interval between L_1 and L_2.

The mark-recapture data were fitted to each equation using a non-linear, least-squares regression procedure in SAS version 6.12 (PROC NLIN; SAS Institute 1996) to produce the growth model. All models were seeded with a 'best guess' growth rate of 0.03 based on the average growth rate of recaptured juveniles in the wild from this study and captive animals from Wilkinson (1981). The model with the lowest residual mean squares was then chosen as it indicates the best fit (Dunham 1978). The estimation of age in relation to SVL was then compared to the SVL frequency of captured geckos to identify likely cohorts in the population.

3.3.4 Population structure and size estimates

Areas A and G (Fig 1.2), as identified in Whitaker's (1993) survey on Mana Island, were searched repeatedly between November 1996 to October 1997, and approximately $90m^2$ of flax swamp at Matekai Park, Taranaki (section 2.2.1) between August 1997 and October 1997. Data from recaptures of permanently marked *H. chrysosireticus* caught between August and October 1997 were used to estimate population size for each area using CAPTURE (Otis *et al* 1978). Population estimation relies on several assumptions, all of which are difficult to achieve when sampling wild populations. Most importantly, all animals must have an equal chance of being caught on all occasions and must retain their marks throughout the study (Caughley 1977). To relax the necessity of equal catchability, CAPTURE tests the data against eight models that vary aspects of catchability and selects the one that best explains the mark-recapture history presented. Model Mt tests for capture probabilities that vary with time, Model Mb, for probabilities that vary with behaviour of the group as a whole and model Mh, for individual variation. All possible combinations of the above models (Mth, Mtb, Mhb and Mtbh) and a null model (Mo), where capture is constant with respect to all factors, are produced by CAPTURE. Recaptures of permanently marked (toeclipped) geckos between July 1996 and December 1997 provided information on the reliability of the temporary silver ink marks.

Another important assumption of mark-recapture population estimates is that the population must be closed, that is, there are no births, deaths, immigration or emigration. To reduce the likelihood of births and deaths occurring in the population, only data collected over two months (August 1997 to October 1997) were used. This period was outside the known birth range (February/March) for the species (Wilkinson 1977, 1981; Rowlands 1987). Movement data from section 2.3.5 showed *H. chrysosireticus* to be highly site-specific, with over 90 percent moving less than 5m, hence immigration and emigration was unlikely in this time period.

Overall population growth at area A was estimated by calculating a life table based on the population size estimate, using actual age distributions obtained from the growth data and sex ratios from section 2.3.1. Fecundity was maximised by assuming all females of breeding age produced two young.

3.3 Results

3.3.1 Sloughing rates and temporary mark retention

All *H. chrysosireticus* marked with silver ink pen in May 1997, and subsequently re-captured between June and October 1997 (29-160 days), had retained their marks (n= 41). No changes in measurements were recorded from these recaptures indicating that little if any growth had occurred during this period. Conversely, all geckos marked in December 1996 and re-captured in March 1997 (83 days) had sloughed their skin and lost their marks (n=3). Those marked in March/April and re-captured in May (36-61 days) had also sloughed (n=4). Therefore, the temporary marks can be relied upon to remain until the gecko sloughs its skin, which can be up to 160 days over winter or less than 36 days during the warmer months.

3.3.2 Growth rates and age estimation

Fifty-two individuals (24 females, 13 males and 15 sub-adult/juveniles) were caught and re-caught between July 1996 and December 1997, with time between recaptures varying from 23 - 421 days. Growth rates, therefore, may vary according to seasonal variation.

Comparison of the three growth models showed the Von Bertalanffy model to have lower residual mean squares than the Logistic-by-Length or Logistic-by-weight models (Table 3.1) and so was used for estimating the relationship between age and SVL.

Growth curve estimations were derived by substituting the values for a and r generated with the Von Bertalanffy growth model (Table 3.1) and b (see below) into the general Von Bertalanffy equation as expressed by Schoener and Schoener (1978):

$$L_t = a \, (1 - be^{-rt})$$

where L_t is SVL at time t. Variable b was calculated as 0.6069 based on the SVL of an individual of a known age (29mm, juvenile at birth) using the following equation:

$$b = e^{rt} \, (1 - h/a)$$

where h = SVL at birth.

Table 3.1 Residual mean square estimates and fitted values for asymptotic length (a) and intrinsic growth rate (r) for Von Bertalanffy, Logistic-by-length and Logistic-by-weight growth models. (95% confidence intervals are given in brackets).

Model	Residual mean squares	a	r
Von Bertalanffy	3.82	73.78 (68.20-79.36)	0.26 (0.18-0.35)
Logistic-by-Length	4.16	71.62 (68.30-74.93)	0.48 (0.36-0.60)
Logistic-by-Weight	4.63	70.89 (68.36-73.42)	0.72 (0.54-0.90)

The estimated age values in relation to SVL are given in Table 3.2. They show slow growth but are comparable to those of Bannock *et al* (1999) for *H. maculatus* on Motunau Island, east of Christchurch. The age classes agree with Whitaker's (1993) arbitrary age/size classes and show the sub-adult class to probably span two cohorts, also suggested by Whitaker (1993). Adults are distinguishable at year four, which agrees

with captive data from Wilkinson (1981). However, maximum size in the wild (79mm SVL) is unlikely to be attained until much later. The smallest male caught with recognisable secondary sexual characteristics was 57mm SVL and 5g weight (August 1997) and the smallest gravid female was 62mm SVL and 8g weight (July 1997). From the growth curve estimations, this female may have been over 5 years old. Looking at the frequency of individual geckos caught in each size/age class on Mana Island between May and October 1997, 12.2% were one year old or less (juvenile), 16.2% were between one and four years (sub-adult) and 71.6% were considered adults at four years or over.

Table 3.2 Comparison of age estimates in relation to SVL for *H.chrysosireticus* on Mana Island and *H.maculatus* on Motunau Island (Bannock *et al* 1999).

	H.chrysosireticus	*H.maculatus*
Birth	29.0*	
Year one	39.4	26.7*
Year two	47.4	40.9
Year three	53.5	50.5
Year four	58.2	57.5
Year five	61.8	61.5
Year six	64.6	64.5

* measured in field

3.3.3 Reproduction and birthing times

No dissections were permitted because of the species' conservation status, and although the stage of vitellogenesis and pregnancy in geckos can be determined by palpation (Cree and Guillette 1995), these stages were not distinguished in this study. If a large mass was palpated, females were considered gravid. Juveniles were caught at all times of the year with no difference in mean SVL ($F_{10, 35} = 1.0$, P= 0.4614) by month. Although the smallest juvenile (29mm SVL, 0.4g) was caught in March, one birth (apparently twins) was inferred by the recapture of a marked postpartum female with two unmarked newborns in November (both 31mm SVL, 0.8g). There was also no significant difference in female weights by month over one year, even after removing all females less than 62mm SVL (size of smallest gravid female caught) from the data set ($F_{9,21} = 0.51$, P=0.8584).
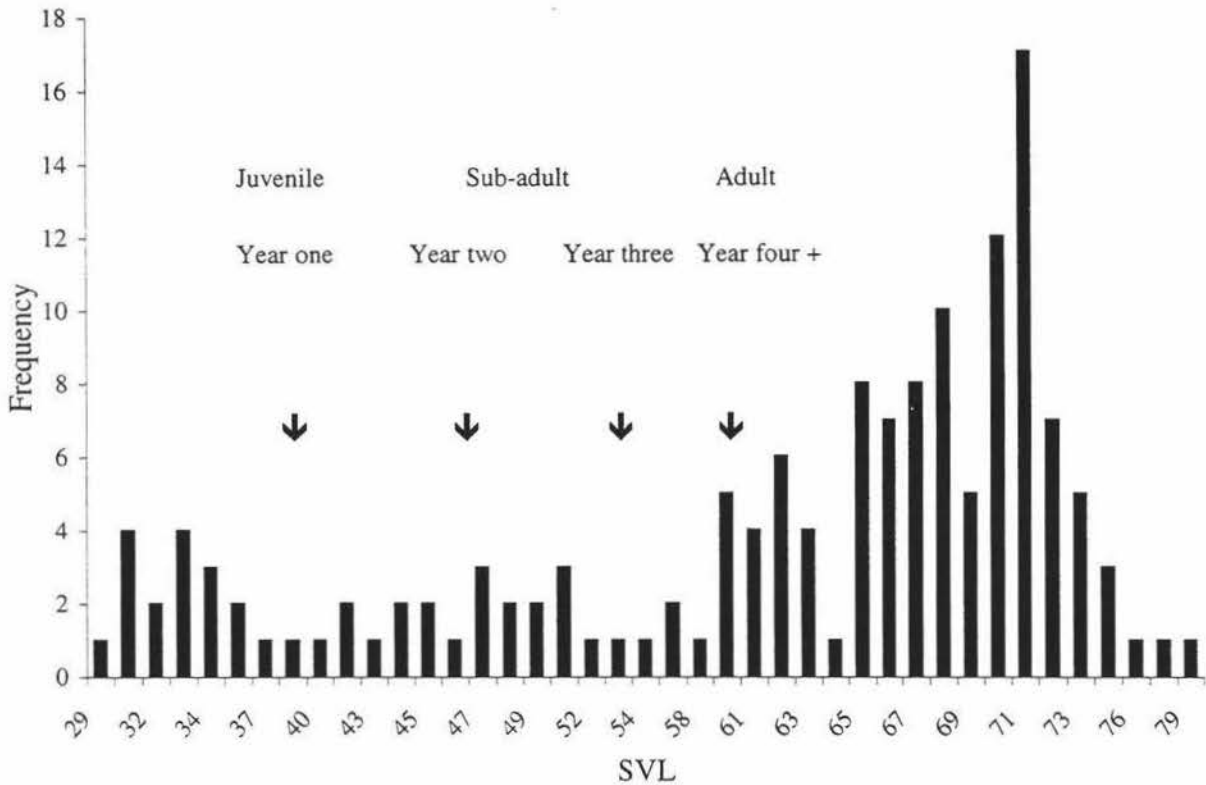
Fig 3.1 Age estimation and SVL frequencies for *H. chrysosireticus* on Mana Island caught between May 1997 and October 1997.

3.3.4 Population size estimates

In order to be considered reliable, the mean capture probability must be greater than 0.1 when using fewer than 11 trapping occasions (Otis *et al* 1978). In all cases, this requirement was satisfied (Table 3.3). The population estimate for area A was 90 (95% confidence limits (C.L) = 70-136) geckos (Table 3.3) using model M (th) where capture probabilities vary according to time and differences amongst individuals. This is lower than Whitaker's (1993) estimate of 200-300 animals for the same area four years earlier. In Whitaker's survey, recapture rates were lower, with only 15 out of 77 (19.5%) marked geckos re-captured, compared to 16 out of 51 (31.4%) marked animals during my searches. My estimates were based on six searches over two months with only one observer, thus reducing the chance of observer interference. Over 58 percent of the final catch were recaptures from the first month and over 85 percent were permanently marked individuals from the preceding 11 months of the study, suggesting that most of

the population was marked. Recapture data for area G between August and October 1997 were too sparse to generate population estimates with only two recaptures in this period. To overcome this, data from May to October were used, although the assumption of a closed population was less likely to be satisfied. The best model selected for area G using these data, was model (tbh), however, this model has no estimator associated with it, as capture probabilities vary with respect to all factors (behaviour, time and individual). The next best models were the null model M(o) and model M(bh). The null model produced an estimate of 77 (95% C.L = 57 - 125) and the model M(bh) gave a lower estimate of 50 (95% C.L = 43 - 81). Population estimates for this area, however, are unrepeatable due to extensive habitat modification following the formation of the Waikoko wetland in 1998 (section 1.2). The Taranaki population estimate was between 19 (95% C.L = 17 – 30) based on the null model, and was a lot lower than the two areas on Mana Island. Only 21 individual *H. chrysosireticus* (total of 35 captures) were caught in 32.24 hours of searching (section 2.3.2) and most were adult males (57%).

Based on Whitaker's (1993) assessment of $56m^2$ for area A, the population estimate provided here gives a density of 1.25 to 2.43 *H. chrysosireticus* per m^2. This is similar to the actual density per bush observed between August and October (not including recaptures). In area A there are 40-50 flax bushes (average of $1.5m^2$ in area for each flax plant), however, *H. chrysosireticus* were found in only 23 bushes. The average density of geckos per bush, was 1.4 geckos per bush over 40 to 50 bushes. However, the actual density (using only the 23 bushes containing geckos), would be closer to 2.61 ($\pm$ 0.51 SE) with a ratio of 0.47:1 males to females in each bush. A maximum of 13 *H. chrysosireticus* was found in one bush. This is not an absolute measure because the number of geckos not caught per bush remains unknown, but it does suggest the densities achievable by these geckos. A much lower density of 0.19 to 0.33 *H. chrysosireticus* per m^2 was found at the Taranaki site with a ratio of adult males to females of 1:0.5. No density estimates are available for area G. At present, it is unclear what attracts the geckos to particular bushes and not others. Further work is needed to establish the factors involved in habitat selection by *H. chrysosireticus*.

Table 3.3 Population estimates for *H. chrysosireticus* in areas A and G on Mana Island, and Matekai Park, Taranaki, for October 1997, generated using CAPTURE; SE = standard error, LCL = lower 95% confidence limit, UCL = upper confidence limit, Model = model selected to best explain the data, M_{t+1} = number of geckos captured, P-Hat = mean probability of capture.

Sample	Popn Est.	SE	LCL	UCL	Model	M_{t+1}	P-Hat
Area A	90	16.1507	70	136	M(th)	51	0.13
Area G*	77	16.4809	57	125	M(o)	40	0.14
Matekai Park	19	2.8309	17	30	M (o)	16	0.24

*The model best fitting the data for area G did not produce an estimate, therefore, the next best fitting model was used.

3.3.5 Mortality and population growth

The life table shows slow overall population growth for area A, with fewer than six animals joining the breeding population (> four years) a year (Table 3.4). Juvenile mortality was high in the first year (Table 3.4) but dropped during years two and three. After year four, mortality estimates were unable to be calculated, as the age classes became less distinguishable by size. The mortality figures show a 'U' shaped curve similar to mammals (Caughley 1977) and are also comparable to the lizard *Sceloporus graciosus* during their first four years (0.77,0.38,0.47,0.55 respectively) (Tinkle 1973).

Table 3.4 Life table for *H. chrysosireticus* up to four years of age at area A, Mana Island.

Age	Frequency	Survival	Mortality	Mortality rate	Survival rate
0	52	1.00	0.63	0.63	0.37
1	19	0.37	0.08	0.22	0.78
2	15	0.29	0.08	0.28	0.72
3	11	0.21	0.09	0.43	0.52
4	6	0.12			
5	39				

3.4 Discussion

The population estimate for area A was less than half that of Whitaker's estimate for the same area in 1993. Whitaker's estimate was based on recaptures over four nights by up to ten searchers. In comparison, the estimates in the present study were based on six searches over two months by only one observer, thus reducing the chance of observer interference but increasing the chance of violating the closed population assumption. If the length of time between these recapture periods were to have compromised the mark-recapture analysis then one would expect fewer marked animals to have been caught in the final sample making the current figure an over-estimate. The difference between this estimate and Whitaker's shows a substantial decline in the population at area A. This coupled with low recruitment rates, raises serious questions about the stability of *H. chrysosireticus* populations on Mana Island. However, the drop could also be the result of different search techniques and population estimate calculations between the two studies. Whitaker used the Lincoln-Petersen estimate described in Patterson (1992) which is calculated using the ratio of marked to unmarked animals in a second sample after an initial marking attempt at least 24 hours earlier. This estimate is susceptible to behavioural bias by the animals which can result in over-estimations brought about by "trap" or "capture shyness" (Patterson 1992). In comparison, CAPTURE allows for catchability to vary according to time or behaviour by the individual or group.

Typical of all New Zealand geckos, female *H. chrysosireticus* are capable of producing up to two live young each year (Robb 1980b). From the growth data presented here, it appears that these geckos are long lived and slow growing and may not reach sexual maturity in the wild until around four to five years old. At least 50 percent of *H. chrysosireticus* caught in 1997, and an even greater percentage of those (> 54mm SVL) caught during the 1993 survey, are likely to have been alive before the mice were eradicated in 1990. Habitat shifts and behavioural changes in response to the removal of rodents have been well documented for New Zealand lizards (Towns 1991, 1996; Newman 1994; Christmas 1995). Therefore, the discovery of greater numbers of *H. chrysosireticus* on Mana Island may also be the result of a behavioural change rather than just a population explosion.

Habitat destruction and predation are commonly identified as the main causes for the decline of reptile populations in New Zealand (Towns 1994; Towns and Daugherty 1994). *H. chrysosireticus* are widespread in the Taranaki region, however accurate mapping of the populations and their status has never been investigated. Their tendency to live close to built-up areas in residential gardens, woodsheds (Wilkinson 1977), and even letterboxes (D. Casky pers. comm.) is unusual in comparison to other native gecko species, and has led to the assumption that they are maintaining healthy populations on the mainland (Wilkinson 1977; Robb 1980b). However, this opinion should be viewed with caution, as no information is available on the sizes of the Taranaki populations, their structure or metapopulation dynamics.

Failure to detect substantial numbers of *H. chrysosireticus* on Mana Island prior to 1993 has been attributed to heavy mouse predation (Whitaker 1993). However, mice, rats, cats and other mammalian predators are abundant in Taranaki, which would suggest that these populations are far from secure. The population size estimate for the mainland site was considerably lower than the two sites on Mana Island, despite the area being greater. The sex ratio of animals caught was also the reverse of that on the island, with more males than females. On Mana Island, which has no mammalian predators, twice as many females than males were caught. This could indicate either a female-biased sex ratio or a behavioural difference between the sexes. If females are more active, then their predation risk is greater. Unless the pattern observed on Mana Island is peculiar to the island, it would appear that the population at Matekai Park is under threat from the loss of reproductive females. Alternatively, the biased sex ratios in both areas may be a stochastic effect of small population size. This, however, remains unclear due to the absence of information from other populations in the Taranaki area.

Currently there are no areas on the mainland that are protected for the conservation of *H. chrysosireticus*. Although they are easy to breed in captivity (Wilkinson 1981), release of captive-bred animals into the wild is not always desirable or effective (Griffith *et al* 1989) and is pointless if adequate predator control at the release site is not achieved (Short *et al* 1992). The Mana Island population is at present, the only secure population for the species. This makes little sense for the conservation of a species as it provides

minimal protection from stochastic perturbations in the environment such as natural disasters or the invasion of a mammalian predator (Shaffer 1981).

3.4.1 Conclusion

Even in apparently ideal habitat, *H. chrysosireticus* exhibit slow population growth in the absence of mammalian predators on Mana Island. Similar to other New Zealand gecko species, they are slow growing, long lived and can produce only two young per year at most. Although they appear to be widespread in Taranaki, the status of these wild populations is unknown and their current conservation priority status limits resources being allocated to rectify this. More information on the status and metapopulation dynamics of the Taranaki populations should be acquired and at least one area with effective predator control established in Taranaki for the future conservation of this species on the mainland.

Another survey of the Mana Island population should be conducted within the next year given the possibility that numbers in the main sub-population on the island have declined since 1993. Depending on the outcome, further surveys at five-year intervals as suggested by Whitaker (1993), should be appropriate. However, a standard search procedure should be established which includes permanently marking animals and uses comparable population estimate and survey techniques.

Chapter Four

Restoring a component of Mana Island's reptile fauna: Will the introduction of *H. duvaucelii* compromise the resident *H. chrysosireticus* population?

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4.1 Introduction

The translocation of a species into habitat within its former range has long been the desired management goal for endangered species (Conant 1988). Translocations have had a long history in New Zealand, dating back to Richard Henry in the late 1800s who initially used translocation as a tool to protect kakapo (*Strigops habroptilus*) and kiwi (*Apteryx* spp.) from predation on the mainland (Clout and Saunders 1995). With the successful eradication of rodents from many of New Zealand's offshore islands, restoration of pre-human communities through translocation has become an increasingly popular goal. However, given the highly modified nature of habitats in many restoration areas, careful thought is needed to decide which, and when, different organisms should be introduced (Gilpin 1987). Restorations often lead to the association of species that have not been sympatric for a long time and under different environmental conditions than in the past. The available habitat is often patchy and undergoing restoration itself. Special attention needs to be given to both the survival of the introduced organism in the restoration area as well as the potential impacts the organism may have on existing communities (IUCN 1998). The guidelines for New Zealand translocations make special note that habitat use by transferred species may differ considerably between the source and release sites (DoC 1990). However, the potential conflicts between resident species and the species being introduced are seldom investigated (Armstrong and McLean 1995).

The restoration of Mana Island, Cook Strait, New Zealand, provides a good example of where such considerations are essential. Following the eradication of mice in 1990

(Hutton 1990), the island has been the focus of a programme of ecological restoration (Miskelly 1997). Prior to February 1998 the island was home to six of the 14 reptile species known from the Wellington region. The subsequent transfer of three further lizard species in February 1998 brought several species together that are not sympatric elsewhere (Miskelly 1997). One of these sympatries arose with the resident *H. chrysosireticus* after the transfer of *H. duvaucelii* from North Brother Island. There are currently no known locations where *H. duvaucelii* and *H. chrysosireticus* are sympatric and also no hard evidence that *H. duvaucelii* ever did live on Mana Island. Today, *H. duvaucelii* is extinct on mainland New Zealand and is restricted to 36 offshore islands ranging from northern North Island to Cook Strait/Marlborough Sounds (Towns 1991). This disjunct distribution is shared with other large nocturnal reptiles such as tuatara (*Sphenodon. punctatus*) and thought to be the result of habitat destruction and predation from introduced mammalian predators (Towns and Daugherty 1994). Fossil deposits in various locations on the North Island, including Wairarapa (Worthy 1994), place Mana Island within the known range for *H. duvaucelii*. However, the bones of only one large gecko have been found in midden deposits on Mana Island itself. *H. duvaucelii* is currently the only gecko of its size still extant in New Zealand, however, Worthy and Holdaway (1994) suggest caution in labelling all large gecko bones as *H. duvaucelii*. After the recent re-assessment of the *H. maculatus* complex (Hitchmough 1997), it is unknown whether other large *Hoplodactylus* geckos may have existed in the past.

In contrast, *H. chrysosireticus* have a smaller and less easily explainable range that includes Mana Island and a few locations in the Taranaki region (Fig 1.1). The size and status of the Taranaki populations is largely unknown, therefore, Mana Island is particularly important for *H. chrysosireticus* as both the only secure island population and the known southern limit for the species (Whitaker 1993). Prior to the present study little was known about the ecology and behaviour of *H. chrysosireticus*. This, combined with the fact that there were no areas where both *H. duvaucelii* and *H. chrysosireticus* are sympatric, provided few clues as to how they may interact on Mana Island.

Being New Zealand's largest gecko species, adult *H. duvaucelii* can grow up to 160mm SVL (Whitaker 1968). Even though they are slightly smaller on North Brother island at up to 119mm SVL (Barwick 1982) this still makes them around 1.5 times the size of

mature *H. chrysosireticus* (75mm SVL) (Gill and Whitaker 1996). *H. duvaucelii* are known predators of the young of other lizard species (Barwick 1982) and have also been known to displace smaller gecko species (*H. maculatus*) around nectar sources (Eifler 1995). Flax appears to be an important cover type for *H. chrysosireticus* and is where they are most frequently found on Mana Island. In contrast, *H. duvaucelii*, are habitat generalists but are known to frequent flax, especially when it is in flower (Whitaker 1968). At present, flax is a rare vegetation type on Mana Island due to the highly modified nature of the island and its current state of restoration. Because both species may be attracted to the same limited resource and possibly occupy similar habitats, there is a chance that negative interactions between the two species may be an issue. Negative interactions such as competition for food or habitat resources could result in either the displacement of *H. chrysosireticus* from their presently marginal habitat or the failure of *H. duvaucelii* to establish on Mana Island.

North Brother Island (section 1.5) is somewhat different from Mana Island (section 1.2) being only c.4ha (c.f. 215ha) with a rocky surface, severe windswept cliffs and low-growing vegetation (<1m). Hence, direct comparisons of how *H. chrysosireticus* and *H. duvaucelii* use their native respective habitats are not appropriate for drawing conclusions as to how they may interact when placed together on Mana Island. To test for possible negative interactions between then two species, both geckos need to be observed in the same environment. The aim of this chapter, therefore, is to experimentally investigate the temporal and spatial behaviour of *H. duvaucelii* and *H. chrysosireticus* when placed in the same environment on Mana Island.

4.2 Methods

4.2.1 H. duvaucelii *transfer*

North Brother Island, was identified as the most suitable source population for *H. duvaucelii* because of its close proximity to Mana Island and the apparently healthy population of *H. duvaucelii* (750 geckos/ha, Barwick 1982) living on the island (Miskelly unpub). Searches for *H. duvaucelii* were made over all of the accessible land area on North Brother Island over three consecutive nights (November 21-23 1997).

Attempts were made to catch all *H. duvaucelii* seen in order to choose the 'best' geckos for transfer. Only healthy geckos with minimal external parasites and preferably complete tails were considered. Any geckos caught with recognisable toe-clip combinations from a survey on the island in 1982 (Thompson 1982) were recorded but left on the island. Geckos were located at night with the aid of a spotlight and caught by hand. The weight of each gecko was measured using a 30g Pesola™ spring balance (to nearest 1g) and snout to vent length (SVL), tail length (TL), and tail regeneration were measured using a ruler (to nearest 1mm). Notes on the substrate, vegetation type, and the height above ground at the point of capture were also recorded for each gecko. All geckos were given a temporary field identification mark on the dorsum using a xylene-free silver ink pen. Lizards chosen for transfer were held in individual cotton bags and transported in a partitioned polystyrene box by helicopter to Mana Island. All bags were individually labelled and sprayed with a light misting of water to prevent overheating. Geckos that were measured but not selected for transfer were returned to the place they were caught.

4.2.2 Experimental design

Two sets of simultaneous experiments to investigate interactions *between H. chrysosireticus* and *H. duvaucelii* were conducted on Mana Island between 01 December 1997 and 24 January 1998. To investigate habitat use and interactions between the two species, four large enclosures (each approximately 25m^3) were purpose-built around existing vegetation on Mana Island to simulate a natural situation. Direct interactions were investigated using a series of eight small (600 x 600 x 600mm) cages.

4.2.2.1 Large enclosure design

Although flax is the vegetation cover where the greatest numbers of *H. chrysosireticus* have been found on Mana Island, low numbers have also been caught in manuka (Whitaker 1993). Therefore these two vegetation types were chosen for the enclosure experiment in case gecko behaviour was related to habitat. Any negative interactions between the two gecko species may be more serious for the future of *H. chrysosireticus*

if they occur in flax. Two enclosures were built around flax on Waikoko flat and another two built around manuka at the top of Southern Valley (Fig 1.2). Each enclosure was constructed with a wooden frame covered with $1mm^2$ black fiberglass mesh. The mesh was dug into the soil around the cages to form a 'gecko-proof' seal with the ground. The tops of the enclosures were open to allow access of flying invertebrates and to reduce the effect of the enclosures on factors such as light, wind and rain. To prevent the geckos from escaping or outsiders from getting in, strips of aluminium, 40cm wide, were fixed to the top of the frames to form a 20cm overhang inside and outside the enclosures. Each enclosure was divided in half with a removable non-transparent partition so that an equal amount of vegetation was present on both sides (Plate 4.1). Each enclosure was treated as a separate experiment using an ABA experimental design. Three *H. chrysosireticus* were introduced into one half of each enclosure and three *H. duvaucelii* into the other (Table 4.1). One male and two female geckos were used in the adult enclosures to reduce the likelihood of adults of the same species fighting during the experiment.

Table 4.1 Distribution of geckos in large enclosures

	Flax enclosures		Manuka enclosures	
	Flax A	Flax B	Manuka A	Manuka B
H.chrysosireticus	1 male 2 female	1 male 2 female	1 male 2 female	1 male 2 female
H. duvaucelii	1 male 2 females	3 sub-adults	1 male 2 females	3 sub-adults

Each gecko was marked with a unique number written on its back with a xylene-free silver ink pen for identification at a distance. The lizards were then released into their respective sides and observed for up to five minutes. The experiments were run in three blocks of 10 days. During each 10-day block, each enclosure was searched from the outside, for up to 20 minutes, three times a day at 0900h, 1500h and just after dark at around 2130h. All enclosures were approached in random order and from different angles each day to reduce observer interference. The location of marked geckos within each enclosure, their choice of microhabitat, height amongst vegetation, and activity when seen, were recorded during these observation times. For the first 10-day block

each species was separated by the middle partition (part A of the experiment). After this time, the middle partition of each enclosure was removed to allow both species to physically interact with each other, and observations were continued for the following 10 days (part B). For the third and final 10-day block (part C) the partition was replaced, and all geckos caught and returned to their original sides. A further 10-day period of observations followed. At the end of the experiment, all animals were re-caught, weighed and measured and held in temporary housing until release.

Activity (day and night emergence) and habitat use (climbing or not, and location within each enclosure) were compared between the two gecko species, the enclosures, and each part of the experiment using SAS version. 6.12 General Linear Models ANOVA procedure (SAS Institute 1988). Residuals were checked in all cases and the data log-transformed when necessary. All ANOVA results are for Type III sums of squares unless otherwise stated.

4.2.2.2 Small cage experiment

Direct interaction between the two species was investigated in a series of paired cage trials. Eight small, purpose-built cages containing a small flax plant (*P. cookianum*), rocks, bark, leaf litter and old flax inflorescence stalks (Plate 4.2) were set up adjacent to the plant nursery on Mana Island. Lizards were maintained with a typical food supply of moths, small flies, wax-moth larvae and locusts and given a daily misting of water. Supplementary dishes of honey water were also provided every three to four days. The cages were arranged in pairs with each pair containing one of the various age/size combinations (Table 4.2). A total of eight *H. chrysosireticus* (two juvenile, two sub-adult and four adult male) and eight *H. duvaucelii* (two sub-adult and six adult male) were used in these experiments. Initially, the geckos were housed for five nights with up to four geckos of the same species in each cage. Notes were made of when geckos were active during day and night. Following these observations, the geckos were then paired together with a member of the other species according to table 4.2 and observed at 1500h and 2030h each day for 15 days. At these times the location of each lizard was recorded and their activity noted (ie. basking, active/alert, in retreat). Any direct encounters between both species were also recorded. Activity of both species in the

single and mixed species cages was compared using a log linear model in SAS (SAS Institute 1989).

Table 4.2 Age/size pairings of *H. duvaucelii* and *H. chrysosireticus* in small cages.

Cage

	A1	A2	B1	B2	C1	C2	D1	D2
H. chrysosireticus	Adult male	Adult male	Adult male	Adult male	Sub-adult	Sub-adult	Juvenile	Juvenile
H. duvaucelii	Sub-adult	Sub-adult	Adult male	Adult male	Adult male	Adult male	Adult male	Adult male

Plate 4.1 Large enclosure design (Flax B) showing removable partition. (Photo R.A.Fordham)
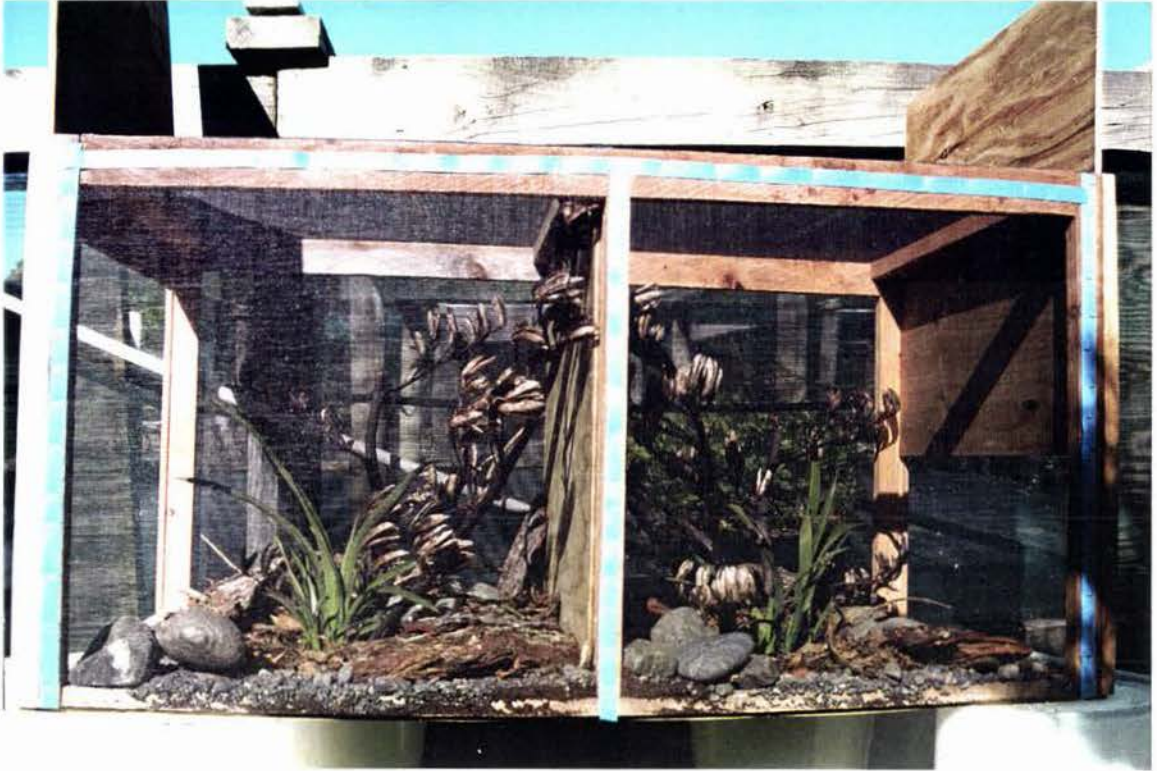
Plate 4.2 Small cage design.

4.3 Results

4.3.1 Transfer of H. duvaucelii

A total of 42 *H. duvaucelii* were caught and measured on North Brother Island between 21 and 23 November 1997 (*Appendix three*). Of those 42, nine were males, 20 females, 11 sub-adults and two juveniles. Ninety three percent (39/42) of the geckos caught were found foraging at night out in the open, on rocks or human-made structures. Five percent (2/42) were found climbing on vegetation, also at night. One was found under a sheet of aluminium during the day. Five females, eight males and eight sub-adult *H. duvaucelii* were selected for transfer as required by the experimental design. Two of the five females chosen were noticeably gravid at the time of transfer. Three of the geckos caught had recognisable toe-clip combinations (Appendix three) from the 1988 survey by Thompson *et al.* (1992) and were not considered for transfer.

4.3.2 Cage and enclosure experiments

When placed in the cages and enclosures for the first time, geckos of both species were observed investigating the boundaries of the new environment. To minimise the effect of this 'investigation phase' on the interpretation of the geckos' behaviour, observations from the first day of each trial were removed from the analyses. The sample size for observations in the large enclosures then became n = 18 during the day and n = 9 at night for each part of the experiment. Sample sizes for the small cages were n = 4 nights in the single species cages and n = 14 nights for the mixed species cages.

4.3.2.1 Temporal activity

H. chrysosireticus were seldom seen in the manuka enclosures during the day or at night (Fig 4.1). Those observed to be active at night were usually found climbing the fiberglass mesh on the sides or close to the sides on the ground as if looking for a means of escape. There was no difference in *H. chrysosireticus* activity between any of the daily observation periods ($F_{2,13}$ P=0.0769) or the two manuka enclosures ($F_{1,13}$ P=0.7243). There was also no noticeable change in their behaviour between the three stages of the experiment ($F_{2,13}$ P=0.6344) (Fig 4.1). By comparison, *H. chrysosireticus* were observed more frequently in flax ($F_{1,13}$ P=0.0034 Type I) and were more active in the afternoons compared to night or morning observation periods in these enclosures ($F_{2,13}$ P=0.0004). *H. chrysosireticus* activity varied between the three stages of the experiment (Fig 4.2) with observations increasing during the day for part B, where both species had free access to all parts of the enclosure ($F_{2,13}$ P=0.0040). When the partition was replaced, (part C), activity dropped back again to a level similar to that at the start of the experiment, (part A). There was however, a difference in activity between the two flax cages ($F_{1,13}$ P=0.0010) with more *H. chrysosireticus* observations in the enclosure housing sub-adult *H. duvaucelii*. In contrast, *H. duvaucelii* were most frequently encountered at night in both manuka ($F_{2,13}$ P=0.0032) and flax enclosures ($F_{2,13}$ P=0.0022) throughout the whole of the experiment. Although activity between the two vegetation types was not significantly different overall ($F_{1,13}$ P=0.5471), sub-adult *H. duvaucelii* were less active in flax than adult *H. duvaucelii* ($F_{1,13}$ P=0.0085). There was, however, no significant difference between parts of the experiment for any enclosure (Fig 4.3 and Fig 4.4).
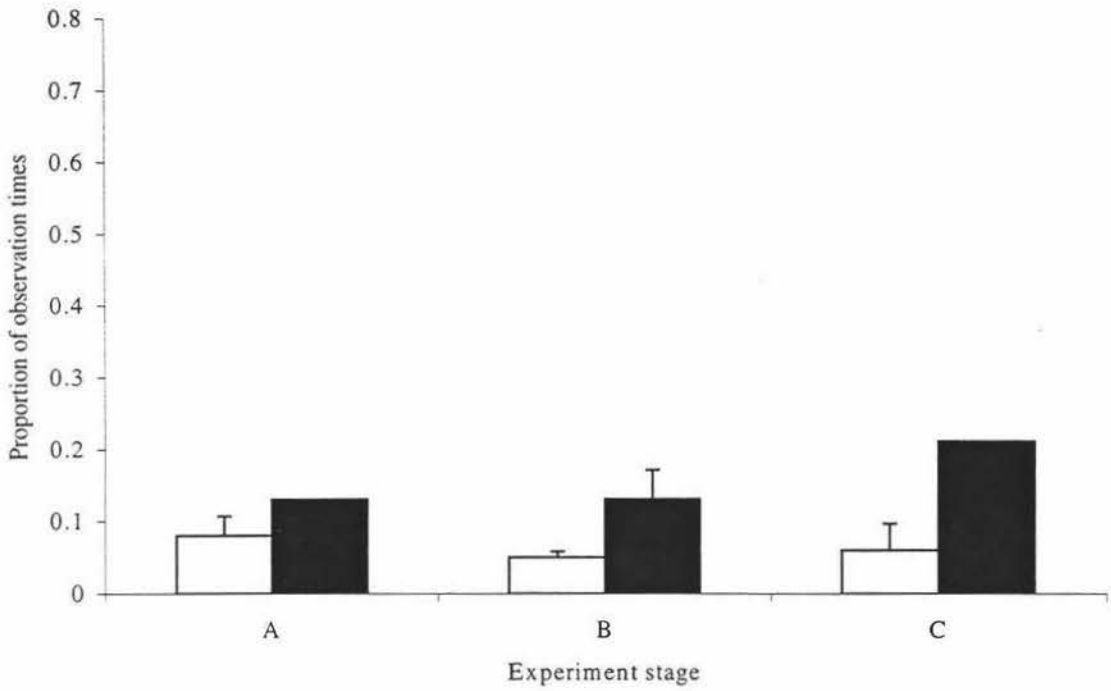
Fig 4.1 Proportion of observation times (mean ± SE) where *H. chrysosireticus* were seen active during day (▢) and night (■) in manuka enclosures.
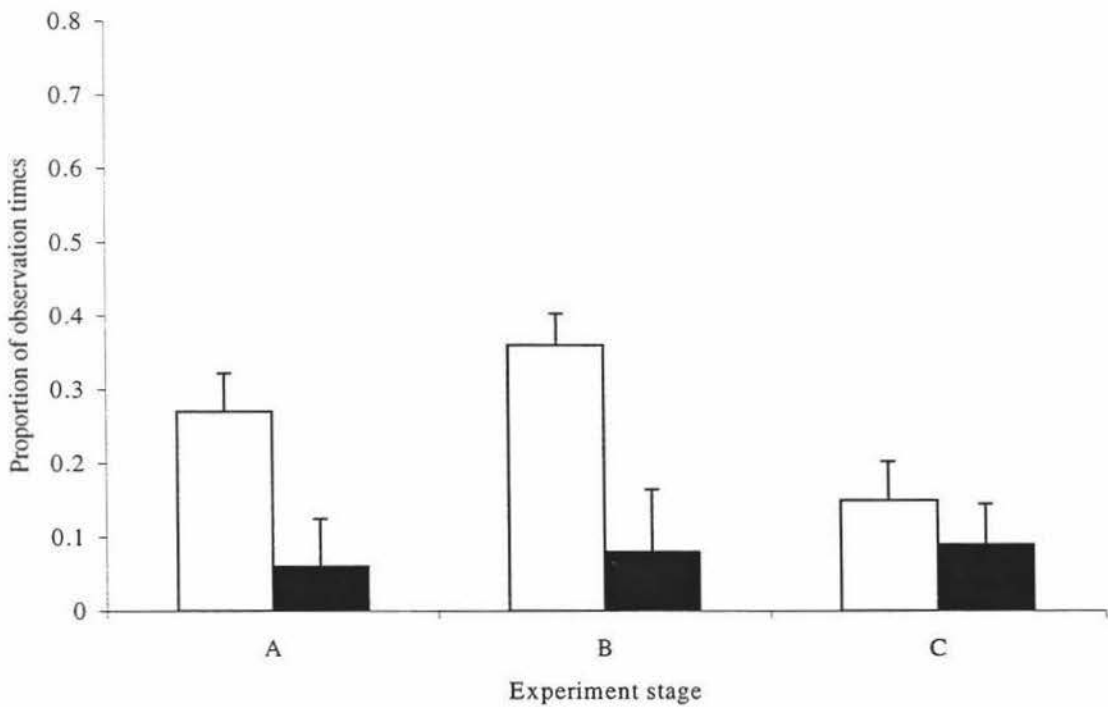
Fig 4.2 Proportion of observation times (mean ± SE) where *H. chrysosireticus* were seen active during day (▢) and night (■) in flax enclosures.
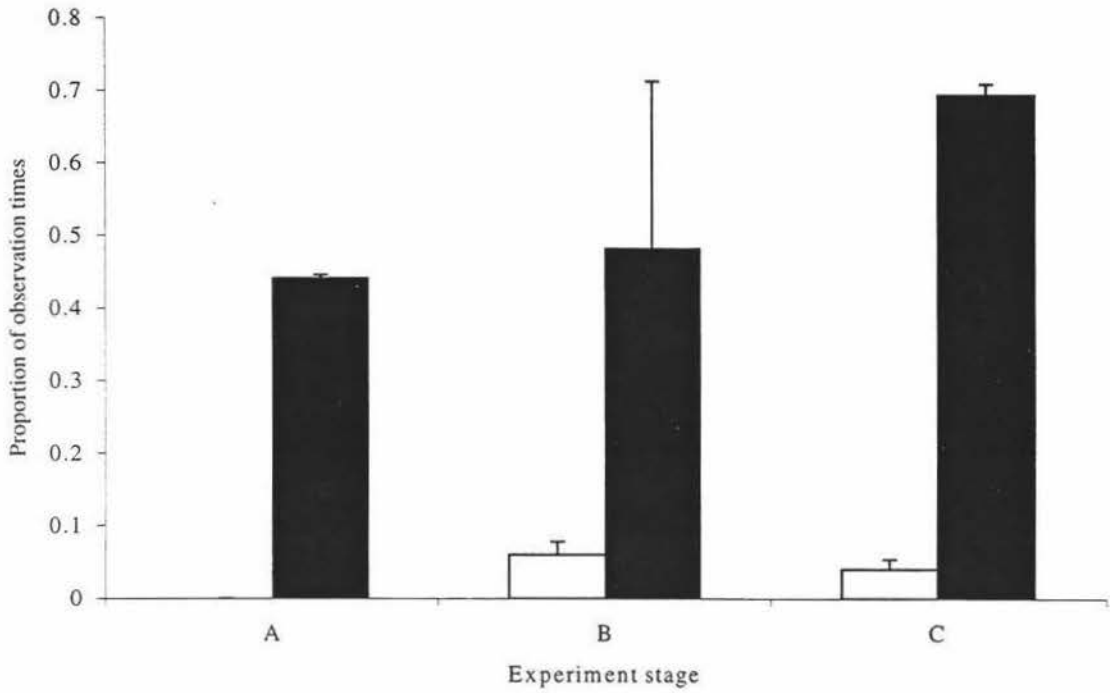
Fig 4.3 Proportion of observation times (mean ± SE) where *H. duvaucelii* were seen active during day (❑) and night (■) in manuka enclosures.
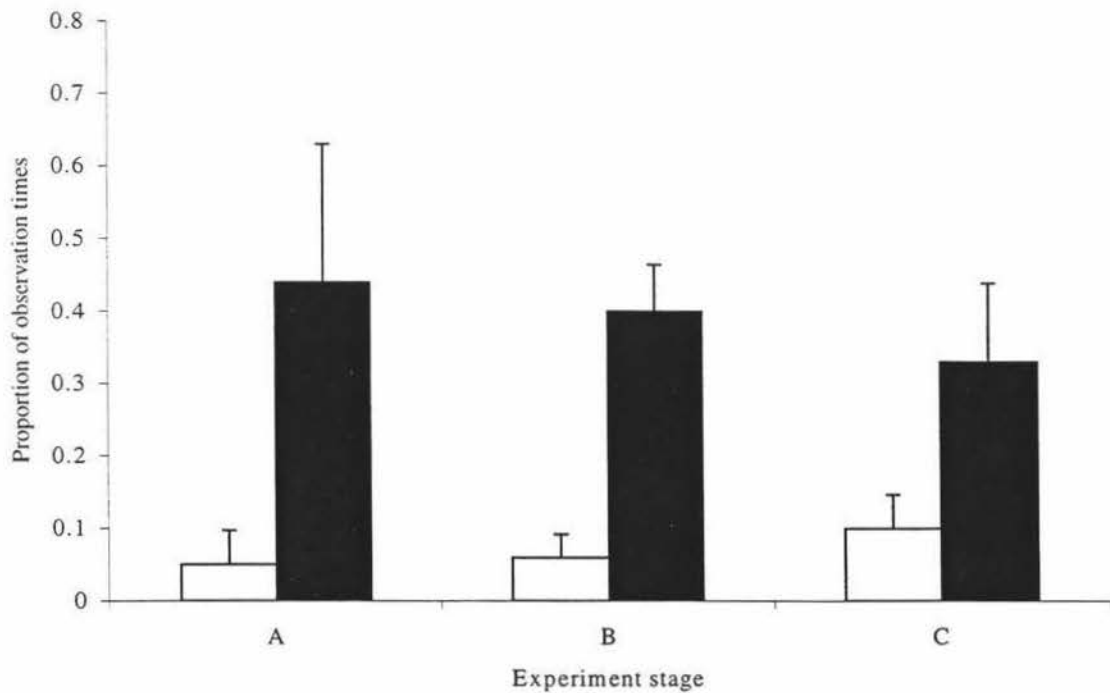
Fig 4.4 Proportion of observation times (mean ± SE) where *H. duvaucelii* were seen active during day (❑) and night (■) in flax enclosures.

4.3.2.2 Large enclosures - spatial distribution and climbing behaviour

Almost 80 percent of observations for *H. duvaucelii* in both manuka and flax enclosures were of ground foraging behaviour, compared to 15 percent for *H. chrysosireticus* ($F_{1,17}$ P=0.0035). Apart from differences in the vertical use of each enclosure, there was no difference in the use of the different sides of the enclosures between stages of the experiment for either *H. chrysosireticus* (F P= 0.6245) or *H. duvaucelii* (F P=0.4801). *H. chrysosireticus* tended to climb more in flax than in manuka ($F_{1.5}$ P=0.0004) with just under 97 percent of all encounters being above ground either in the vegetation or on the enclosure itself . This tendency to climb in flax was consistent for *H. chrysosireticus* throughout all parts of the experiment (Fig 4.5).
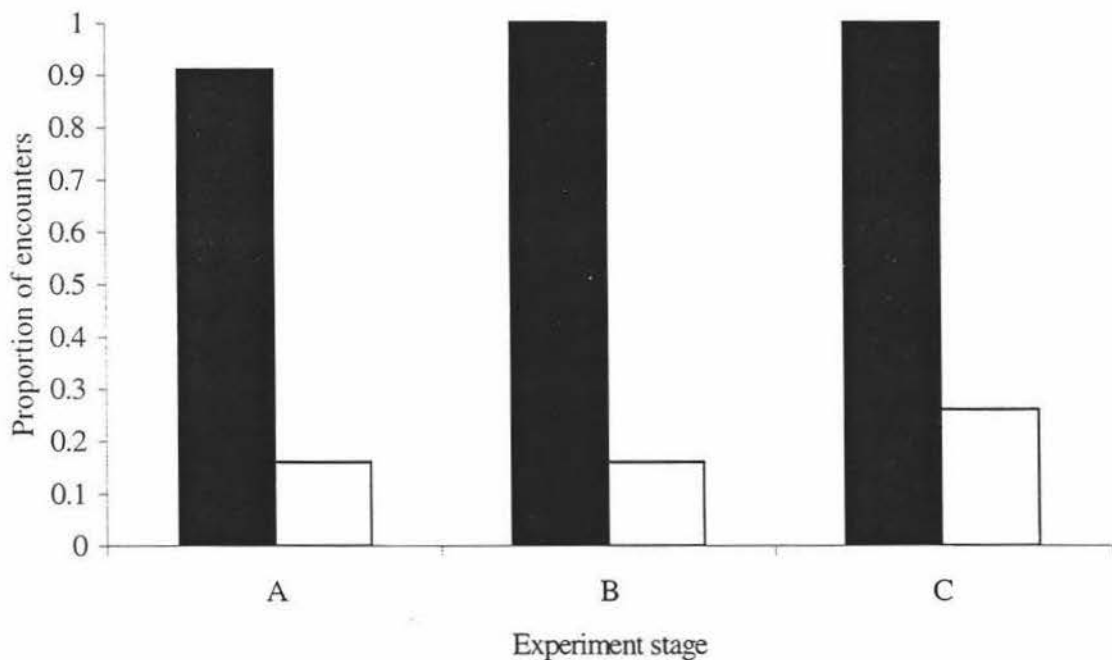
Fig 4.5 Proportion of encounters in which *H. chrysosireticus* (■) and *H. duvaucelii* (❑) were observed climbing on vegetation in flax enclosures.

However, in the manuka enclosures, *H. chrysosireticus* showed a noticeable increase in climbing behaviour during part B of the experiment ($F_{2,5}$ P=0.0450). This climbing behaviour declined when the partition was replaced (part C), but not significantly (Fig 4.6).
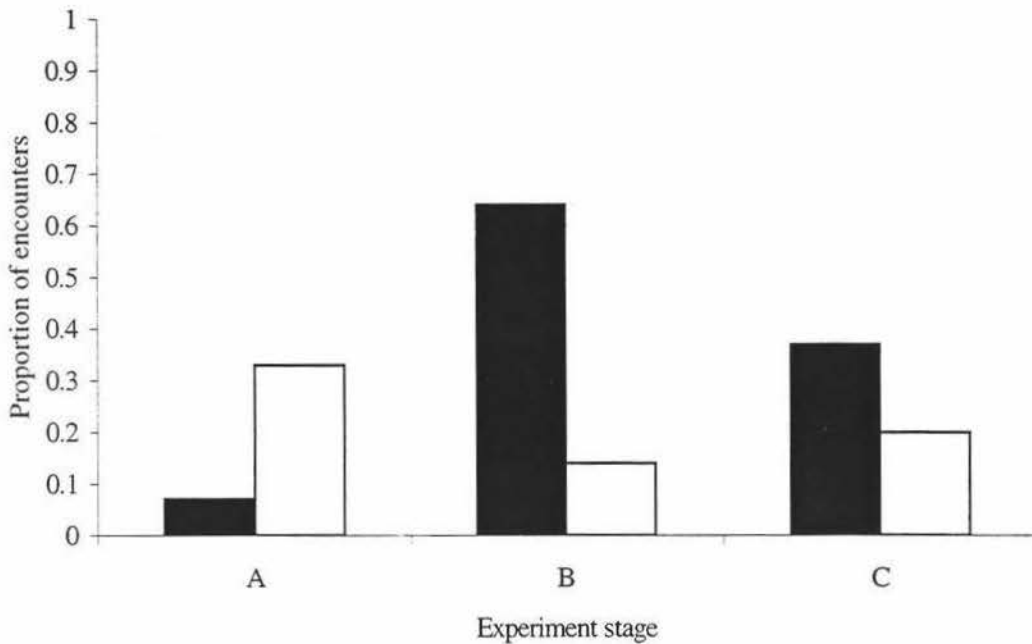
Fig 4.6 Proportion of encounters in which *H. chrysosireticus* (■) and *H. duvaucelii* (❑) were observed climbing on vegetation in manuka enclosures.

Although *H. duvaucelii* were predominantly ground dwelling, sub-adult *H. duvaucelii* tended to climb more frequently than the adults in both flax (mean = 0.45 cf. 0.20) and manuka (mean = 0.34 cf. 0.15). These differences however, were not significant ($F_{3.3}$ P=0.3964).

4.3.2.3 Use of flax inflorescences

No *H. duvaucelii* were observed taking nectar from the flax flowers. However, while only two records were made of *H. chrysosireticus* taking nectar from flower stalks in the enclosures, several others were seen high up on flax inflorescences elsewhere on the island. The 1997/98 summer was not a good flowering year for flax, which meant that only one inflorescence per flax plant, was available in each enclosure, limiting the potential for lizards to use the resource.

4.3.3 Small cages

All animals were noticeably active at night in both single species and mixed species

cages. No data are available for daytime activity in the single species cages therefore only comparisons of night activity levels are made. *H. duvaucelii* and *H. chrysosireticus* of all age classes were seen to be active up to 79 percent of the time in single species cages and up to 92 percent in mixed cages. However, when in mixed species cages, sub-adult and juvenile *H. chrysosireticus* significantly reduced their level of activity and were infrequently seen out of retreat sites (Fig 4.7). Young *H. chrysosireticus* (sub-adult and juvenile) were seldom seen at night during the experiment and were rarely seen foraging during the day. By day 10, all young *H. chrysosireticus* seen were under the cover of stones or bark, but were clearly alert. All sub-adult and juvenile *H. chrysosireticus* had disappeared by day 15. Remains of one of the sub-adult *H. chrysosireticus* were found in the faeces of the adult male *H. duvaucelii* housed in the same cage. Faecal samples were collected from two of the other *H. duvaucelii* but did not contain any recognisable lizard remains. The cages were purpose-built for the experiment and care was taken to ensure that they were escape proof. It seems likely, therefore, that the adult male *H. duvaucelii* also preyed upon the other three small *H. chrysosireticus*.

There were no significant differences in activity between *H. duvaucelii* and *H. chrysosireticus* in the four cages containing adult male *H. chrysosireticus*. In the cages containing sub-adult *H. duvaucelii* and adult male *H. chrysosireticus*, all animals appeared to forage freely at night. Occasionally *H. chrysosireticus* also emerged during the day. Both species were sometimes even recorded under the same retreats during the day (average four out of 11 occasions). In the two cages containing adult males of both species, aggressive interactions were observed on the second night when both *H. duvaucelii* were seen lunging towards the *H. chrysosireticus* in their cages. Both species remained well separated when active and in retreat, often at opposite ends of the cages. No tails were lost or actual fighting observed other than one *H. chrysosireticus* running into a retreat occupied by a *H. duvaucelii* during the day and biting the resident at the base of the tail. No aggressive interactions were observed between animals of the same species in the single species cages despite a higher density of geckos than in the mixed species cages.
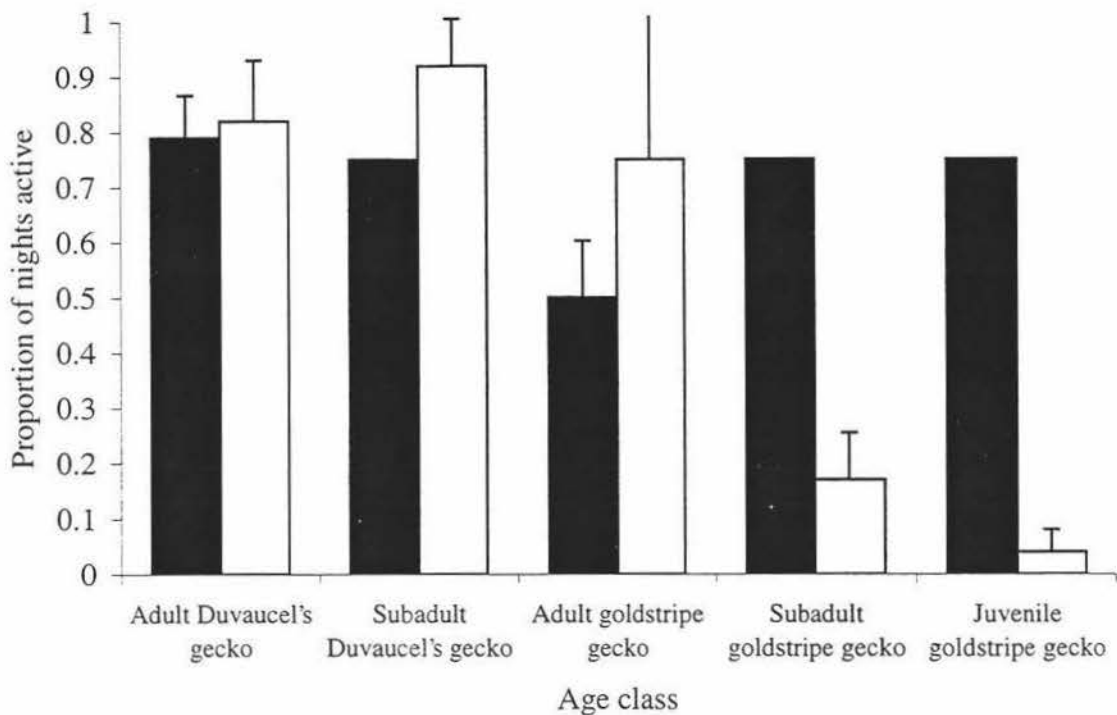
Fig 4.7 Proportion of nights (mean ± SE) where geckos emerged from cover in single species (■) and mixed species (❑) cages.

4.3.4 Condition of geckos after the experiments

With the exception of the four young *H. chrysosireticus* that disappeared, all geckos were re-caught and re-measured at the end of the experiments. No noticeable changes in body measurements were observed in geckos from either the small cages or the large enclosures and were not expected given the short duration of the experiments. One adult male *H. duvaucelii* (number 28) escaped just prior to the release in February 1998 but was caught nine months later approximately 60m. In this time his overall body length had increased by 5mm and he had put on 4.5g in body weight.

4.3.5 Release of H. duvaucelii on Mana Island

After the completion of the experiments all 21 *H. duvaucelii* were released on Mana Island on 24 February 1998. The release site was located at the mouth of Forest Valley

(Fig 1.2), the largest remaining area of mature trees on the island. This area was chosen for its diverse range of habitats such as coastal forest, scrub vegetation and rocky crevices along the shoreline. As *H. duvaucelii* were often found under bark and pieces of driftwood during the cage and enclosure experiments, large pieces of driftwood and bark were scattered around the release site as extra refuge sites for the geckos.

A further 19 *H. duvaucelii*, 15 females, two males and two sub-adults, were released at the same site from a second transfer in November 1998. Two of the females from this group were thought to be gravid at the time of the release. All animals were given a unique toe-clip combination before release in order to identify released geckos from any born on the island in subsequent years (Appendix three). The toes from this release were preserved in 70% ethanol and are being held by Dr Rod Hitchmough, VUW.

4.4 Discussion

Niche theory dictates that no two species can survive in the same environment without differing in their use of one or more niche dimensions (Schoener 1983). Of these, space (spatial niche), time (temporal niche) and food (trophic niche) are the three dimensions most often emphasised in studies of competitive interactions (Pianka 1977). In the cage and enclosure experiments described in this study, the use of time and space by *H. chrysosireticus* and *H. duvaucelii* in both single species and mixed species scenarios was investigated and despite the short duration of these experiments, some clear behavioural patterns emerged. Overall, *H. duvaucelii* were observed on more occasions than *H. chrysosireticus* in the large enclosures. This was due mainly to the ground-dwelling habits of *H. duvaucelii* and their tendency to forage in the open. *H. chrysosireticus*, on the other hand, tended to spend more of their time climbing amongst the vegetation. This may have made them more difficult to see especially in the flax enclosures at night, as I was unable to pull the flax leaves apart to accurately locate the geckos.

H. chrysosireticus were also observed to climb more frequently in manuka when *H. duvaucelii* were present. This is a similar pattern of avoidance behaviour observed in *H. duvaucelii* when in the presence of nocturnal, ground dwelling skinks on the Poor

Knights (Whitaker 1968) and in the presence of kiore (Whitaker 1973). The behaviour suggests that *H. chrysosireticus* perceive *H. duvaucelii* to be either a competitive or predatory threat, and hence change their behaviour accordingly. However, this pattern was not observed in the flax enclosures and may have been a result of the unfamiliar manuka habitat.

Although the proportion of time spent climbing by *H. chrysosireticus* decreased again in part C of the experiment, this was not a significant decrease. This may be explained in part by two invasions by one *H. duvaucelii* through the middle partition during the final part of the experiment. This is interesting in itself because no geckos were caught on the 'wrong' side during part A and suggests that the geckos may have been more persistent in getting through the barrier after they knew what was on the other side. On the other hand, this may have occurred naturally if the experiments had have been run for a longer time period.

Adult *H. duvaucelii* were commonly observed foraging on the ground in both the flax and manuka enclosures. However, published accounts of these geckos, from islands other than North Brother, often describe them as agile and frequent climbers especially in the presence of competitors or predators (Whitaker 1968, Christmas 1995). This ground-dwelling habit may, therefore, be an artefact of the treeless environment on North Brother Island and may change over time or successive generations of the species on Mana Island. However, sub-adult *H. duvaucelii*, did begin to climb more as the experiment progressed, which suggests either an ability to adjust to different conditions, or perhaps a tendency for juveniles to naturally climb more.

H. chrysosireticus increased their level of diurnal behaviour in flax in the presence of *H. duvaucelii*. This may have been coupled with a decrease in nocturnal behaviour that was undetected because of the difficulty of observing lizards amongst the flax at night. However, increased diurnal behaviour was also observed in the sub-adult and juvenile *H. chrysosireticus* in the small cages just prior to their disappearance. Behavioural changes in the presence of a competitor have been documented for the Anole, *Anolis wattsi* on St Eustatius in the Lesser Antilles, Netherlands. Rummel and Roughgarden (1985) discovered that in the presence of *A. bimaculatus*, *A. wattsi* tended to select

different perch positions and become active at different times of the day, although growth and reproduction of *A. wattsi* were not affected in the long term.

Despite being observed less, overall, *H. chrysosireticus* were observed more often at night in the manuka enclosures in comparison to the flax enclosures. This may be related to the more open nature of the manuka, offering less protection than a flax bush for *H. chrysosireticus* foraging during the day. It may also be due to the unfamiliar nature of the vegetation as all *H. chrysosireticus* used in these experiments originally came from flax. It also further indicates the importance of flax areas for *H. chrysosireticus* on Mana Island and that potential for displacement by other species is always considered in this habitat.

Apart from differences in activity periods and climbing behaviour, no other evidence of displacement was observed. The short nature of these experiments meant that changes to the overall body condition and reproductive success of each species over time could not be assessed. Despite the ABA design making each enclosure a 'standalone experiment', replicates of each enclosure run over longer periods of time would be useful. Constraints on the number of animals allowed for removal from North Brother Island at any one time and the time frame for the release of *H. duvaucelii* on Mana Island meant that this was not possible.

In the small cages, adult *H. chrysosireticus* generally appeared to be unaffected by the presence of *H. duvaucelii*, exhibiting similar levels of nocturnal activity to levels observed in the single species cages. Aggressive encounters initiated by *H. chrysosireticus* were also noted. However, sub-adult and juvenile *H. chrysosireticus*, were not so fortunate and appear to have been eaten by the adult *H. duvaucelii* males during the direct encounter experiment. Such predation represents the highest level of interference competition and has been noted in captive *H. duvaucelii* before (Thony 1994). In the wild, *H. duvaucelii* are known to prey on the young of smaller lizard species, such as *H. maculatus* on North Brother Island (Barwick 1982), but only when at high densities.

4.4.1 Comparison of small cages and large enclosures

The behaviour exhibited by *H. chrysosireticus* in the two sets of experiments differed markedly. In the small cages the *H. chrysosireticus* were reluctant to come out during the day, but were frequently seen to emerge after dark. However, in the large flax enclosures, the diurnal behaviour of the *H. chrysosireticus* in all stages of the experiment was comparable to levels observed in the wild (section 2.3.1). This raises an interesting point about the usefulness of captive studies to compliment detailed observational work in the field. The results of the Mana Island experiments suggest that the large enclosures were more accurate than the small cages in assessing behavioural changes, because they more closely resembled the wild situation. The increased nocturnal behaviour of *H. chrysosireticus* in the small cages was similar to documented cage behaviour of the species (Wilkinson 1977, 1981) and may be responsible for the widespread idea that *H. chrysosireticus* are essentially nocturnal.

4.4.2 Future encounters between H. duvaucelii and H. chrysosireticus on Mana Island

Despite influencing the behaviour of *H. chrysosireticus* and preying upon juveniles, 40 *H. duvaucelii* have been released on Mana Island. The release site in Forest Valley is over one kilometre away from the core population of *H. chrysosireticus*. Although *H. duvaucelii* are known to move distances of over 77 m (Whitaker 1968) they sometimes show strong home site fidelity (Christmas 1995). One *H. duvaucelii* that escaped on Waikoko flat (section 1.2 and Fig 1.2) just before the release to Forest Valley was captured again nine months later only 60 m from where it escaped. Despite being surrounded with flax, in prime *H. chrysosireticus* habitat, this animal had chosen to live in the generator shed, although its foraging range is unknown. This would suggest that these geckos might not disperse far from their release sites, however, this range is likely to vary according to habitat preferences by the individual geckos and cannot be considered typical in the absence of further dispersal data from Mana Island.

H. duvaucelii is a long-lived species and can take up to seven years to reach sexual maturity (Barwick 1982). They have also been reported to have a less than annual reproduction cycle (Cree 1994). These factors may result in slow population growth on

Mana Island, although the absence of natural and introduced predators will no doubt be an advantage. Seventy percent (50/71) of all adult *H. duvaucelii* caught on North Brother Island had re-grown tails. This is a high level of tail loss equivalent to that on rat infested islands but may be due to predation from tuatara (Christmas 1995). Mana Island is free of all introduced predators and has relatively few natural nocturnal ones at present with no tuatara or weka (*Gallirallus australis*) and only one or two moreporks. This, coupled with their ability to adjust to different habitats quickly, suggests that this species has the potential to do very well on Mana Island in the long term. However, this minimal predator state is due to change. At the time of writing, tuatara are planned for release sometime in 2000 (Miskelly 1997). As yet, seabirds are not properly established on the island and therefore the likely food source for tuatara will be smaller reptiles and invertebrates. The continual expansion of replanted and regenerating forest is also likely to encourage the establishment of more avian predators like moreporks and kingfishers. This added predation pressure, although unlikely to have a significant effect on the *H. chrysosireticus* population, may strongly influence the establishment of *H. duvaucelii*.

There are several cases in the literature where the introduction of a new lizard species has caused displacement and habitat shifts to resident or native species. Most of these involve the spread of the house gecko (*Hemidactylus frenatus*) to islands in the Pacific (Case and Bolger 1991). *H. frenatus* have been shown to displace mourning geckos (*Lepidodactylus lugubris*) from retreat sites (Frogner 1967) and around lights that attract insects (Case *et al* 1994). In Hawaii, *H. frenatus* successfully managed to displace three resident species since its introduction in the late 1940s to become the most common gecko species in built up areas (Oliver and Shaw 1953). However *H. frenatus* is an aggressive invader and in each case is an exotic introduction. Despite this, there are few documented cases where an introduced reptile has been considered responsible for the extinction of another.

H. duvaucelii, despite being known to eat the young of smaller species, is often the first to change its behaviour when in the presence of a competitor (eg Whitaker 1968, 1973; Christmas 1995). From these experiments, it appears that *H. duvaucelii* has the potential to influence the behaviour of *H. chrysosireticus* although the extent to which actual displacement could occur has not yet been measured. *H. duvaucelii* have been

shown to displace smaller gecko species from nectar sources (Eifler 1995). This was not shown here as the 1997/98 summer was not a good flowering year for flax, preventing measurement of such an interaction. With so much available and expanding habitat it seems unlikely that the density of *H. duvaucelii* will reach a level at which displacement of the *H. chrysosireticus* in flax will occur in the foreseeable future. Mana Island also has an abundance of *H. maculatus*, which are more likely to be encountered. Despite this, it may be beneficial to do further displacement trials over longer periods and habitat preference tests with *H. duvaucelii* to see if there is any preference for flax when other habitat types are available.

4.4.3 Conclusion

Although there is potential for *H. duvaucelii* to have a negative impact *on H. chrysosireticus* on Mana Island, this is only likely if densities of either species become extremely high or if *H. duvaucelii* actively choose to live in flax. The success and spread of *H duvaucelii* from the release site should be monitored at regular intervals starting from the release date and then every five years providing they become successfully established. In the event of more *H. duvaucelii* being transferred to Mana Island, these geckos should be used to further test for longer-term interactions with resident species and any habitat preferences using similar large enclosure experiments. This would also stand as a form of soft release for the geckos, increasing their chance of establishing successfully.

Future introductions of species as part of the restoration should proceed with caution and efforts should be made to experimentally assess the potential for conflict between introduced and resident species. Unfortunately this is not always financially or logistically practical. However, experiments of this nature will not only provide invaluable information on the success of translocations, but also help to form a better understanding of community and ecosystem organisation, which in turn may mitigate potentially disastrous conflicts.

Chapter Five

Conservation of *H. chrysosireticus*:
summary and recommendations

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Conservation of *H. chrysosireticus*: summary and recommendations

5.1 Ecology and population status of *H. chrysosireticus*

The research described here is the first documented study where *H. chrysosireticus* have been permanently marked and followed over time. The results from this work should serve as a baseline for monitoring the expansion and growth of the population on Mana Island, and for assessing any impacts present and future management practices may have on the species. Without a firm understanding of the basic ecology of a species the results of monitoring programmes are difficult to interpret accurately and can lead to inappropriate management decisions (Read 1999). In this study, *H. chrysosireticus* were found to show a high level of diurnal behaviour, atypical of the genus *Hoplodactylus*. This has implications for future surveys, and highlights the previously dismissed impacts diurnal predators and competitors may have on the *H. chrysosireticus* population.

Despite no detailed information on the location and status of *H. chrysosireticus* populations in Taranaki, the species has a low conservation priority ranking. Aside from the predation issue on the mainland, the Taranaki populations are far from secure. Wetland areas are continually being drained for agricultural development and other forms of habitat destruction may be preventing dispersal between small isolated populations. The volcanic nature of the Taranaki region also posses a potential treat to low lying areas in the event of a lahar. Too often in New Zealand we wait until a species is endangered or almost extinct before we act. New Zealand lizards are an important and unique part of our natural heritage and *H. chrysosireticus* is no exception.

The *H. chrysosireticus* population on Mana Island is nationally significant, not only because it represents the southern limit for the species, but also because it is the only population protected from introduced mammalian predators (Whitaker 1993) and habitat destruction. After seven years with no mammalian predators, growth of the *H. chrysosireticus* population on Mana Island is slow, and expansion into new areas is limited by the geckos' loyalty to a small area. From growth curve age estimates, *H. chrysosireticus* appear to be long lived, slow growing and unlikely to become reproductively active until at least four years of age. Then, like all New Zealand geckos, they can produce a maximum of only two young per year (Robb 1980b), again limiting the speed of recovery, even in optimal habitat.

The population estimate for the densest population of *H. chrysosireticus* on Mana Island was lower than an estimate for the same area four years earlier using different search and estimation calculations. Density estimates based on calculations of population size in this study are similar to the actual densities of *H. chrysosireticus* found in individual flax bushes. The high proportion of marked animals recovered in the final sample suggests that most of the catchable population was marked. Although Mana Island no longer has any introduced mammals, and other lizard populations on the island are generally increasing (Whitaker 1993), the *H. chrysosireticus* population may not yet be robust enough to deal with disruption. Introductions of competitors and predators, natural or otherwise, may impede or jeopardise expansion of the *H. chrysosireticus* population. Along with restoration goals, Mana Island has a valuable role in the continued conservation of existing species that are nationally threatened or rare (Atkinson 1990).

5.2 Future conservation of *H. chrysosireticus*

Whitaker (1993) made recommendations for the management of *H. chrysosireticus* on Mana Island, and suggested that searches be made at five-year intervals to ensure the well being of the population. The status of *H. chrysosireticus* on the mainland was also addressed and Whitaker (1993) suggested that experienced people make night searches of areas of suitable habitat, such as flax swamps, between Patea and Paremata. However, as *H. chrysosireticus* are frequently encountered more often during the day than the night, it is recommended here that both day and night searches are made in

these areas. A standard set of search protocols and interpretation statistics are also essential if monitoring results are to be at all useful.

Flax appears to be important for *H. chrysosireticus* as a preferred habitat in which they can gain some level of protection. The planting of flax corridors remains a practicable way of maintaining this species on Mana Island, and the newly established wetland area at Waikoko flat is an excellent start (Miskelly 1997). However, given that *H. chrysosireticus* appear to show strong site fidelity, the spread of these geckos into new areas may be slow.

More information on the status and meta-population dynamics of the Taranaki populations should be obtained and at least one area with effective predator control established in Taranaki for the future conservation of this species on the mainland.

5.3 Interactions with *H. duvaucelii*

Experiments to test interactions between *H. chrysosireticus* and *H. duvaucelii* on Mana Island highlighted differences in the behaviour of both species. Within these differences, however, there is substantial overlap. *H. chrysosireticus* are active in vegetation at night and during the day, whereas *H. duvaucelii* are nocturnal, but forage both on the ground and in vegetation (Table 5.1). *H. duvaucelii* were shown to influence the behaviour of *H. chrysosireticus* in flax and manuka plants, and prey on their young when in close contact. Clearly, more work is needed to establish how these factors will affect the *H. chrysosireticus* population in the long term. At present, however, it appears that although there is potential for *H. duvaucelii* to have a negative impact on *H. chrysosireticus* on Mana Island, this is likely only if densities of either species become extremely high, or if *H. duvaucelii* actively choose to live in flax.

At this stage it seems unlikely that the density of *H. duvaucelii* will reach a level at which displacement of the *H. chrysosireticus* in flax may occur in the short term, but a close watch should be kept on any expansion of *H. duvaucelii* into new habitats. Despite all released animals being toe-clipped, it would have been beneficial to fit several animals of different ages and sexes with radio transmitters to monitor their movements and spread after release. Radio transmitters have proven very useful in tracking large

lizards, including *H. duvaucelii,* in the past (Christmas 1995), and should be used if any further releases take place on Mana Island.

Table 5.1 Comparison of behavioural traits of *H. chrysosireticus* and *H. duvaucelii* from Mana Island experiments

	H. chrysosireticus	*H. duvaucelii*
Activity	Diurnal/nocturnal	Nocturnal
Foraging habit	Arboreal	Arboreal/ground dwelling
Habitat	Flax	Habitat generalists

With an increase in the available 'safe' habitat for reptiles following rodent eradication programmes, and the increasing popularity of restorations, careful thought should go into which species should be introduced and the sequence of those introductions (Gilpin 1987). New Zealand has a long history of translocations for species conservation (Clout and Saunders 1995), however, too many transfers are conducted without adequate investigation into the impact the introduced organism will have on the resident community (IUCN 1998). Restoration of a whole community is a difficult and complex process, and some may argue, technically impossible (Simberloff 1990). No species exists in isolation and it is unrealistic to expect newly establishing restoration communities to behave in the same way as those that have developed slowly over thousands of years.

5.4 Recommendations

1. Further surveys on Mana Island should be conducted according to a standard and repeatable procedure and measurements and records taken for all geckos caught during these surveys. Permanent marking of the geckos should continue to effectively monitor the growth of the population and their spread into new environments.

2. Maintain flax corridors between forest habitats on Mana Island to assist the spread of *H. chrysosireticus.*

3. Identify and survey key *H. chrysosireticus* populations on the mainland, including establishing their northern, eastern and southern limits.

4. Determine the genetic importance of the Mana Island *H. chrysosireticus* population in comparison to Taranaki populations, given their geographic distance and isolation.

5. Establish a protected area with effective predator control for *H. chrysosireticus* in Taranaki.

6. Further behavioural experiments on habitat choice and displacement with *H. duvaucelii* in enclosures on Mana Island, and regular monitoring of the spread and establishment of *H. duvaucelii* on Mana Island should be carried out. Similar experiments with other planned reptile releases would also be useful.

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Appendices

Appendix one:

Original measurements for toeclipped *H. chrysosireticus* on Mana Island.

Date	Toeclip	Number	Area	Time	Vege	Sex /age	Weight(g)	SVL(mm)	TL(mm)	TR(mm)
7/21/96	1100	1	A	21:55	Flax	M	8	70	63	n/a
7/21/96	1200	2	A	22:05	Flax	F	6.5	63	63	22
7/22/96	1300	3	A	18:20	Flax	M	6.5	67	21	11
7/22/96	1400	4	A	18:35	Flax	J	1	41	57	44
7/22/96	1500	5	G	19:05	Flax	J	1.4	47	57	n/a
7/22/96	1010	6	G	19:27	Flax	J	0.6	32	39	n/a
7/22/96	1020	7	A	20:01	Flax	F	7.5	65	66	24
7/22/96	1030	8	A	20:02	Flax	S	3	51	57	n/a
7/23/96	1540	9	A	18:10	Flax	M	0	62	59	35
7/23/96	1050	10	A	18:35	Flax	M	0	65	80	n/a
7/23/96	1,5-0-0-1	11	A	18:45	Flax	J	0	34	39	n/a
8/26/96	1002	12	A	19:15	Flax	J	2.2	44	52	n/a
8/26/96	1203	13	A	19:50	Flax	F	6	57	67	n/a
8/26/96	1004	14	A	20:30	Flax	J	1	33	37	n/a
8/28/96	1005	15	G	20:25	Flax	F	8	68	62	30
8/28/96	2100	16	G	21:50	Flax	S	3.6	50	68	n/a
8/28/96	2200	17	G	22:00	Flax	M	9.5	71	80	n/a
8/28/96	2300	18	G	22:20	Flax	F	8	69	83	n/a
8/28/96	2400	19	G	22:20	Flax	M	10	72	93	n/a
8/28/96	2500	20	G	22:35	Flax	F	9	69	79	n/a
8/28/96	2020	21	G	22:45	Grass	M	9.5	72	17	0
8/28/96	2010	22	G	23:45	Flax	F	7.2	62	74	n/a
11/14/96	4030	23	A	10:55	Flax	F	6.4	61	75	n/a
11/14/96	4040	24	A	11:45	Flax	F	7.4	66	31	0
11/14/96	2030	25	A	12:15	Flax	J	1	35	44	n/a
11/14/96	2040	26	A	12:35	Flax	J	1	32	32	n/a
11/14/96	2050	27	A	12:40	Flax	F	7.2	63	73	n/a
11/14/96	2001	28	A	13:05	Flax	J	2.6	43	72	n/a
11/14/96	2002	29	W	15:15	Flax	S	3.4	51	61	n/a
11/16/96	2003	30	G	13:55	Flax	F	8.5	69	81	n/a
11/16/96	2004	31	A	15:25	Flax	S	4	50.5	66	n/a
11/16/96	2005	32	A	15:55	Flax	F	6.4	61	74	n/a
11/16/96	3100	33	G	17:05	Flax	J	1.8	40	45	n/a
11/17/96	3200	34	A	23:10	Flax	F	8	64	79	n/a
11/17/96	3300	35	G	23:45	Flax	M	8	67.5	80	n/a
12/21/96	3400	36	A	8:50	Flax	M	9.7	70	70	34
12/21/96	3500	37	A	10:10	Flax	F	7.7	65	62	tip
12/21/96	3010	38	A	10:40	Flax	S	2.5	57	45	15
12/21/96	3020	39	A	11:25	Flax	F	4.4	59	56	n/a
12/21/96	3030	40	A	11:50	Flax	F	8.2	63	72	18
12/21/96	3040	41	A	12:00	Flax	J	1	37	42	n/a
12/21/96	3050	42	G	14:00	Flax	F	7.2	67	75	n/a
12/21/96	3001	43	G	14:30	Flax	F	6	61	75	n/a

Date	Toeclip	Number	Area	Time	Vege	Sex /age	Weight(g)	SVL(mm)	TL(mm)	TR(mm)
12/21/96	3002	44	G	22:20	Flax	F	7.2	69	80	n/a
12/21/96	3003	45	G	22:35	Flax	M	6.2	61	75	n/a
12/21/96	3004	46	G	22:45	Flax	F	8.7	67	82	n/a
12/21/96	3005	47	G	23:00	Flax	J	1.3	37	45	n/a
12/21/96	4100	48	G	23:25	Flax	J	1.6	39	50	n/a
3/15/97	4400	49	A	12:20	Flax	F	8	68	50	31
12/22/96	4200	50	A	10:20	Flax	F	8.7	66	80	n/a
12/22/96	4300	51	A	11:45	Flax	J	1.2	37	46	n/a
3/15/97	4500	52	A	12:40	Flax	F	9	70	66	55
3/15/97	5100	53	A	23:20	Flax	J	0.5	31	8	0
3/15/97	5200	54	A	23:20	Flax	J	0.6	31	35	n/a
3/15/97	1001	55	A	23:30	Grass	F	5.6	59	59	64
3/16/97	5300	56	G	11:20	Flax	J	2.6	46	55	n/a
3/16/97	5400	57	G	11:45	Flax	M	12	72	95	n/a
3/16/97	5500	58	G	13:50	Flax	F	6	59	74	n/a
3/16/97	5010	59	G	14:15	Flax	M	11.2	68	74	55
3/16/97	5020	60	A	17:45	Flax	J	0.4	29	27	n/a
3/16/97	5030	61	A	21:05	Flax	S	3.2	47	40	33
3/16/97	5040	62	A	22:20	Flax	M	9.7	70	74	55
3/17/97	5050	63	G	12:35	Flax	J	2	43	53	n/a
3/17/97	0210	64	G	20:20	Flax	F	10	69	61	40
3/17/97	5001	65	G	20:50	Flax	M	6	57	70	n/a
4/9/97	5002	66	G	21:25	Flax	F	9.5	69	80	n/a
4/9/97	5003	67	G	22:45	Flax	S	3	49	64	n/a
4/10/97	5004	68	A	12:50	Flax	J	0.4	29	37	n/a
4/10/97	5005	69	A	13:20	Flax	S	3.6	51	60	4
4/10/97	3330	70	A	13:45	Flax	M	9	69	68	42
4/10/97	0110	71	G	14:15	Flax	J	2	45	23	none
4/10/97	0120	72	A	16:50	Flax	M	7	61	81	n/a
4/11/97	0130	73	W	7:30	Flax	S	3.6	52	60	7
4/11/97	0140	74	A	10:35	Flax	F	6	63	43	39
4/11/97	0150	75	A	13:05	Flax	J	1.4	38	41	23
4/11/97	0101	76	A	13:45	Flax	J	2	42	52	n/a
5/16/97	0103	77	G	20:25	Flax	M	12	73	96	n/a
5/16/97	0102	78	G	20:40	Flax	M	8.8	66	83	n/a
5/16/97	0104	79	G	21:30	Flax	F	7.6	70	82	n/a
5/17/97	0105	80	A	12:45	Flax	F	7.2	62	55	31
5/17/97	0240	81	A	12:45	Flax	S	2.4	47	52	n/a
5/17/97	0220	82	A	13:05	Flax	S	2	43	45	n/a
5/17/97	0230	83	A	13:40	Flax	J	1.8	31	36	n/a
5/17/97	0250	84	G	15:45	Flax	F	9.5	73	86	n/a
5/17/97	0201	85	G	15:50	Flax	F	9.5	69	76	n/a
5/18/97	0202	86	A	11:20	Flax	M	10	72	75	45
5/18/97	0203	87	A	11:40	Flax	F	7.4	68	63	14
5/18/97	0204	88	G	12:15	Flax	S	2.8	49	44	44
5/18/97	0-2-0-4,1	89	G	21:15	Flax	F	7.5	65	71	n/a
5/18/97	0205	90	G	21:30	Flax	F	8	65	60	20

Date	Toeclip	Number	Area	Time	Vege	Sex /age	Weight(g)	SVL(mm)	TL(mm)	TR(mm)
5/18/97	0310	91	G	21:45	Flax	F	10	73	65	n/a
5/18/97	0320	92	G	22:00	Flax	F	8	70	80	n/a
6/15/97	0330	93	A	14:50	Flax	S	5	58	64	n/a
6/15/97	0340	94	A	15:15	Flax	F	8.5	71	69	31
6/15/97	0350	95	G	18:55	Flax	S	2.6	44	56	n/a
6/15/97	0301	96	A	23:20	Flax	F	8.4	68	67	n/a
6/15/97	0302	97	A	23:35	Flax	F	8.2	66	76	n/a
6/16/97	3021	98	A	13:55	Flax	J	0.6	29	21	0
6/18/97	0303	99	A	20:00	Flax	J	1.2	33	37	n/a
6/18/97	0304	100	A	20:10	Flax	J	1	31	5	0
6/25/97	0305	101	G	13:15	Flax	M	8.5	72	0	0
6/25/97	0-4,2-3-1	102	G	13:15	Flax	F	7.8	70	20	0
6/25/97	0401	103	G	13:35	Flax	F	8.5	78	76	n/a
6/25/97	0402	104	G	14:25	Flax	F	10	74	84	n/a
6/25/97	0403	105	G	14:50	Flax	M	8.2	66	76	n/a
6/25/97	0404	106	G	20:20	Flax	J	1	32	0	0
6/26/97	0405	107	A	13:35	Flax	F	5.4	60	59	36
6/27/97	0455	108	G	14:00	Flax	M	11	71	82	n/a
7/23/97	0011	109	A	21:00	Flax	S-F	4.6	57	62	n/a
7/23/97	5-4,2-0-0	110	A	21:00	Flax	M	7.5	68	74	n/a
7/23/97	0012	111	A	21:00	Flax	M?	3.8	53	60	n/a
7/23/97	0013	112	A	21:25	flax	F	5.6	61	66	n/a
7/23/97	0014	113	G	22:30	flax	F	9.2	71	81	n/a
7/23/97	0051	114	G	22:45	Flax	F	8	62	74	n/a
7/24/97	0015	115	G	10:25	Flax	M	10.5	76	76	23
7/24/97	0021	116	G	10:25	Flax	M	9.2	69	70	47
7/24/97	0022	117	A	13:30	Flax	J	1.2	33	39	n/a
7/24/97	0023	118	A	13:35	Flax	F	7	61	59	42
7/24/97	0024	119	A	13:35	Flax	F	8.5	69	56	40
7/24/97	0025	120	A	13:45	Flax	M	10	74	78	28
7/24/97	0031	121	A	14:00	Flax	F	0	0	0	0
7/24/97	0032	122	A	14:05	Flax	M	8	65	56	51
7/24/97	0133	123	W	21:35	Flax	M	11.8	72	79	39
7/24/97	0034	124	G	22:10	Flax	S	2.4	50	0	0
7/24/97	0035	125	G	22:10	Flax	M	6.4	62	64	26
7/24/97	0041	126	G	22:25	Flax	S	2.8	49	58	n/a
7/24/97	0042	127	G	23:00	flax	M	6.4	62	76	n/a
7/25/97	0043	128	A	11:10	flax	F	9	69	50	30
7/25/97	0044	129	A	11:10	flax	F	8.2	65	0	0
7/25/97	0045	130	G	11:50	Flax	J	1.2	34	43	n/a
7/25/97	51	131	W	22:05	Flax	F	10	68	61	38
7/25/97	0052	132	W	22:10	Flax	F	8	68	80	n/a
7/25/97	0053	133	W	22:20	Flax	J	0.6	32	36	n/a
8/15/97	0054	135	A	0:00	Flax	M	7.2	63	68	n/a
8/16/97	0055	136	G	10:00	Flax	M	9.5	71	71	34
8/16/97	4010	137	A	11:40	Flax	F	7	66	66	26
8/16/97	4020	138	A	12:00	Poroporo	M	6.2	60	54	38

Date	Toeclip	Number	Area	Time	Vege	Sex /age	Weight(g)	SVL(mm)	TL(mm)	TR(mm)
8/16/97	3440	139	A	12:20	Flax	M	10.2	72	59	58 & 28
8/16/97	4050	140	A	13:05	Flax	M	8	67	72	tip
8/16/97	4001	141	A	13:25	Flax	S	5	54	57	28
8/16/97	4002	142	G	22:30	Flax	F	8	65	71	n/a
8/17/97	1003	143	A	9:20	Flax	F	7.5	63	72	n/a
8/17/97	4004	144	A	9:20	Flax	F	8	65	45	22 & 11
8/17/97	4005	145	A	9:20	Flax	M	5	57	60	27
8/17/97	4003	146	A	9:20	Flax	M	7.5	66	55	39
8/17/97	0040	147	A	9:35	Flax	F	7.3	62	60	34
8/17/97	1040	148	A	9:50	Sedge	M	11.7	71	59	37
7/27/97	0020	149	G	13:00	Flax	F	9.5	71	77	n/a
10/20/97	3,4,5-0-3-3,5	150	G	16:45	flax	F	10	70	82	n/a

Notes:

Areas A and G are marked on Fig 1.2. Area W is in Weta Valley and area J is located at Waikoko flat at the junction of the Southern track and the track to Weta Valley.

Time = time of capture

Toeclip = number of toe clipped from inside to out, left front foot, right front, left rear, right rear. Natural toe loss was incorporated into the combinations and are recorded with the feet separated by a dash (-) and toe numbers separated by comma (,).

SVL = snout to vent length

TL = tail length

TR = tail regeneration measured from break to tip

Appendix two:

Measurements and habitat data for *H. duvaucelii* caught on North Brother Island
November 1997 and November 1998.

Date	Time	Substrate	Toeclip	Sex/age	Weight	SVL	Tail L	Tail R	Transferred
21/11/97	23:30	rock	-	F	28.5	100	33	23	No
21/11/97	17:30	aluminum	-	F	35	108	107	39	No
22/11/97	21:25	rock	-	F	33	108	83	74	No
22/11/97	21:35	rock/ground	-	F		110	58	45/26	No
22/11/97	21:25	rock	-	J	3.6	54	50	n/a	No
22/11/97	21:40	rock	0-0-3-2	M	28	118	79	69	Yes
22/11/97	21:40	rock	0-0-2-5	M	31	106	81	72	Yes
22/11/97	21:45	rock	0-0-4-2	S	12.6	76	76	n/a	Yes
22/11/97	21:45	rock	-	F	>30	118	89	67	No
22/11/97	21:55	rock	-	F	22.7	99	15	7	No
22/11/97	22:00	rock	0-0-1-3	F	47	115	109	12.5	Yes
22/11/97	22:15	rock	-	S	19	94	69	24	No
22/11/97	22:15	rock	-	F	29	101	74	63	No
22/11/97	22:15	rock	-	F		106	83	67	No
22/11/97	22:25	rock	0-0-4-1	J-S		59	42	30	Yes
22/11/97	22:10	rock	0-0-3-1	M	26.5	102	11	0	Yes
22/11/97	22:45	rock	0-0-1-2	M	34	112	90	60	Yes
22/11/97	23:00	rock	-	F		109	110	n/a	No
22/11/97	23:00	rock	-	J		54	55	n/a	No
22/11/97	23:30	rock	*5-4-4-4	F	31	107	96	54	No
22/11/97	23:30	rock	0-0-3-5	S	14	79	78	n/a	Yes
22/11/97	23:30	rock	0-0-3-3	M	36	111	112	n/a	Yes
22/11/97	23:45	rock	0-0-2-3	M	33	107	109	n/a	Yes
22/11/97	23:45	rock	-	F		109	94	32.5	No
2311/97	0:00	hebe trunk	-	F		113	77	48/07	No
22/11/97	23:00	rock	0-0-3-4	M	38	115	121	n/a	Yes
22/11/97	23:10	rock	-	F	38	111	119	n/a	no
23/11/97	0:25	concrete	0-0-5-1	M	26	101	75	6	Yes
23/11/97	22:20	rock	0-0-2-1	S	16	84	64	38	Yes
23/11/97	23:35	rock	0-0-4-3	S	12	80	80	n/a	Yes
22/11/97	23:15	rock	*5-4-4-2	F	38	110	90	58	No
21/11/97	21:30	taupata/rock	-	S	28	99	74	59	No
21/11/97	21:45	wall	*4-4,1-2,5-0	F	38	111	52	43	No
21/11/97	22:10	ground	-	S	20.5	89	78	30	No
21/11/97	22:15	rock	-	F	27.5	111	95	30	No
21/11/97	22:15	rock	0-0-1-1	F	36	113	87	76	Yes
21/11/97	22:35	rock	0-0-4-5	S	8	67	63	n/a	Yes
21/11/97	22:35	rock	0-0-4-4	S	-	80	79	n/a	Yes
21/11/97	22:50	rock	0-0-1-4	F	44	114	74	16	Yes
21/11/97	23:05	rock	*5-4-3-5	M	41	114	97	42	Yes
21/11/97	23:11	rock	0-0-2-4	F	25	100	108	n/a	Yes
21/11/97	23:20	rock	0-0-1-5	S	15	85	84	n/a	Yes
26/11/98	16:15	under tin	-	S	10	70	73	n/a	No
26/11/98	16:15	under tin	-	M	42.5	118	74	60	No
26/11/98	17:00	under rock	-	J-S	4.8	56	60	n/a	No

Date	Time	Substrate	Toeclip	Sex/age	Weight	SVL	Tail L	Tail R	Transferred
26/11/98	17:00	under rock	0-0-5-3,1	M	38	109	97	71	Yes
26/11/98	20:00	under tin	2-0-3-0	F	37	116	90	53	Yes
26/11/98	21:30	rock	0-0-5-4	S	16	88	89	n/a	Yes
26/11/98	21:50	rock	-	J	-	55	57	n/a	No
26/11/98	22:10	tussock	0-0-5-5	S	14	82	84	n/a	Yes
26/11/98	22:15	rock	2-0-0-3	F	34.5	114	80	71	Yes
26/11/98	22:15	rock	-	S	19.5	96	81	53	No
26/11/98	22:35	rock	-	F	29.5	110	69	55	Yes
26/11/98	22:45	rock	-	M	35	109	88	47	Yes
26/11/98	23:00	rock	-	S	10	74	29	21,13	No
26/11/98	23:10	taupata	2-0-1-0	F	35.5	111	110	33	Yes
26/11/98	23:15	concrete	3-0-4-0	M	41	113	100	57	No
26/11/98	23:50	dirt/rock	2-1-2-0	F	37.5	109	92	55,30	Yes
26/11/98	23:55	rock	*5-5-2-4	F	44	112	94	60	No
26/11/98	23:55	rock	2-0-4-0	F	38	113	106	27	Yes
27/11/98	0:30	ice plant	2-0-5-0	F	33	108	86	58	Yes
27/11/98	0:30	rock	2-0-0-2	F	41	115	80	69	Yes
27/11/98	0:40	rock face	-	J	4.8	55	68	n/a	No
27/11/98	0:50	rock	2-0-0-4	F	31	107	86	57	Yes
27/11/98	0:50	rock	2-0-0-5	F	32.5	113	79	62	Yes
27/11/98	0:50	rock	3-0-1-0	F	25.5	102	78	60	Yes
27/11/98	0:50	rock	0-0-5-2	F	30.5	114	111	49	Yes
27/11/98	1:45	concrete	5-5-5-0	F	41	111	101	54	No
27/11/98	1:50	under hebe	2,4-0-2-0	F	26.5	107	39	29	Yes
27/11/98	1:50	rock	-	M	33	110	48	30,09	No
27/11/98	2:00	rock	4-0-4-0	F	28.5	101	106	n/a	Yes
27/11/98	1:50	rock	-	J-S	-	-	-	-	Seen

Notes

Substrate: vegetation or substrate gecko found on

Toeclip: *existing toeclip (Thompson et al. 1992) or new 'Mana' toeclip (transferred animals only), 0 = no toeclip

Sex/age: F = female, M = male, S = subadult, J = juvenile

Weight: (to nearest 0.5g)

SVL: Snout-to-vent (to nearest mm)

Tail L: tail length, vent to tail (to nearest mm)

Tail R: tail regeneration from break to tail tip (to nearest mm)

Transferred: yes = taken to Mana; no = returned to point of capture

Emendations

Page 56, section 4.3.2.1 should include:

One female *H. duvaucelii* was caught twice on the *H. chrysosireticus* side of the swamp flax enclosure during part C of the experiment. Both times she was captured and replaced on the *H. duvaucelii* side.

Page 75, reference should read:

Chester P.I.; Raine J.I. 1990: Mana Island revegetation: data from late holocene pollen analysis. In: *Ecological restoration of New Zealand islands*. eds. D.R. Towns; C.H. Daugherty; I.A.E. Atkinson. Conservation Sciences Publication No. 2. Department of Conservation, Wellington, 113-122.