Breeding success of adult female kakapo (*Strigops habroptilus*) on Codfish Island (Whenua Hou): correlations with foraging home ranges and habitat selection

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"An oversized budgie with an antique perfume that walks by night, lives not in the tropics but in the cold blast of the roaring forties, and breeds by holding a singing contest." (Warne, 2002)

Breeding success of adult female kakapo (*Strigops habroptilus*) on Codfish Island (Whenua Hou): correlations with foraging home ranges and habitat selection

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Kakapo (*Strigops habroptilus*) are a flightless, nocturnal parrot endemic to New Zealand. Thought to be extinct within their natural range, kakapo are currently listed as *nationally critical*. The current population of 86 individuals is managed by the Department of Conservation's National Kakapo Team on two offshore islands in southern New Zealand, with all females of breeding age on Codfish Island (Whenua Hou). Kakapo only breed once every two to five years, coinciding with the mast fruiting of specific plant species. On Codfish Island, the proportion of adult female kakapo that breed in rimu (*Dacrydium cupressinum*) fruiting years is dependent on the quantity of fruit produced, with fewer females attempting to breed during low mast years. The purpose of this research is to investigate why only some adult female kakapo breed in low rimu fruiting years on Codfish Island, specifically assessing if foraging home range size and/or habitat selection influence breeding.

A total of 506 location points were collected at night for 18 adult female kakapo between March and May 2006. These were used to estimate foraging home ranges and to assess if kakapo select for particular types of vegetation. Ecological Niche Factor Analysis was used to determine the relative importance of habitat variables in the distribution of female kakapo and to predict areas of suitable breeding habitat when rimu fruit is limited. The breeding success of individuals in 2005, a low rimu mast year, was used to identify if differences in home ranges or habitat selection occurred between breeding and non-breeding females.

The large variation in foraging home range sizes recorded in this research was consistent with previous studies. Foraging home range sizes were on average twice the size for breeders than for non-breeders, suggesting that adult female kakapo may be limited in their ability to breed by the size of the area they occupy. Adult female kakapo did not randomly use vegetation on Codfish Island as some vegetation types were not used, while others were common inside foraging home ranges. Adult female kakapo utilise a broad niche and are capable of surviving

in a wide range of habitats. However, breeding females were more specialised in their niche requirements than non-breeders, with breeders utilising areas with higher abundances of mature rimu trees. Females occurred in high elevation, flat areas of the island but this may have been because this is where appropriate vegetation types occurred.

During low rimu mast years, breeding adult females were predicted to occupy habitat in high elevation, plateau areas with a high abundance of rimu. Areas identified as sub-optimal habitat for breeding included the coastal areas, the lower elevation area of the main valley and some ridgelines. The home ranges of all 10 breeding females contained some optimal habitat, while females who did not breed were more likely to be located in sub-optimal habitat. Although there were significant areas of optimal breeding habitat not occupied by adult female kakapo, other kakapo may have been present in these areas. To increase the proportion of females that breed in low rimu mast years, it may be necessary to remove sub-adult females or surplus adult males living in optimal breeding habitat from the island. Alternatively, females in sub-optimal breeding habitat could be fed supplementary foods or transferred to other islands where there is unoccupied suitable breeding habitat available.

Key words: kakapo; *Strigops habroptilus*; Codfish Island; radio-tracking; home range; habitat selection; Ecological Niche Factor Analysis

Acknowledgements

Arrangement of thesis

This thesis is written as a series of five chapters, two of which are written as stand-alone papers with a separate introduction, methods, results and discussion. To avoid significant repetition between chapters, a general methods chapter is included. The general introduction and general discussion chapters help to integrate the papers into a thesis format. References and appendices for all chapters are included at the end of the thesis.

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Chapter 1   General Introduction

1.1   Statement of research problem

Kakapo (*Strigops habroptilus;* Gray, 1845) are a flightless, nocturnal parrot endemic to New Zealand. The largest parrot in the world, kakapo were once common throughout the main islands of New Zealand in a variety of habitats. After human settlement kakapo populations declined due to habitat destruction, predation by introduced predators and hunting by humans (Worthy & Holdaway, 2002). Today the conservation status of kakapo is *nationally critical* with 86 individuals remaining in two populations. The populations are managed by the Department of Conservation's National Kakapo Team on two offshore islands: Anchor Island in Fiordland and Codfish Island (Whenua Hou) near Stewart Island. The last remaining breeding population of kakapo includes 21 adult females of breeding age that currently reside on Codfish Island.

Kakapo can only breed in years when there is an abundant supply of fruits or seeds available to feed their chicks. On Codfish Island the podocarp species rimu (*Dacrydium cupressinum*) is the only species that produces sufficient fruit for kakapo to breed (Harper *et al.*, 2006). As rimu fruit is only produced in mast years that occur once every two to five years, breeding is infrequent on Codfish Island. In mast years when rimu fruit is produced, the proportion of adult females that attempt to breed is dependent on the quantity of rimu fruit available, with more females nesting in years when fruit is more abundant (Elliott, 2006). In the 2002 breeding season there was a large rimu mast and all but one of the adult females on Codfish Island nested. The most recent breeding season occurred on Codfish Island over the 2004/2005 summer when only a small quantity of rimu fruit was produced. During this low rimu mast year only 10 of the 21 adult female kakapo on the island nested.

The purpose of this research was to investigate why only some adult female kakapo attempt to breed in low rimu mast years on Codfish Island. If it is known why some females breed and others don't when fruit supply is limited, then it may be possible to manage the kakapo population in a way that ensures more females breed in low rimu mast years. As the overall aim of the National Kakapo Team is to increase the kakapo population to a self-sustaining level (Powlesland, 1989), any increase in the number of kakapo that attempt to breed in breeding seasons would be a valuable contribution to their conservation.

1.2   Current knowledge

1.2.1   Appearance, distribution and status

Kakapo are also known as ground, night or owl parrots (Higgins, 1999) and are the last remaining members of the endemic New Zealand sub-family Strigopinae (Powlesland *et al.*, 2006). Kakapo are well camouflaged with their mottled yellowish-green plumage blending with foliage even at close range (Powlesland *et al.*, 2006). Adults have an owl-like facial disc surrounding forward pointing eyes, a broad, pale grey beak, robust short legs, large feet and a rounded, relatively short tail (Higgins, 1999; Powlesland *et al.*, 2006). Kakapo are the heaviest parrots in the world (Bryant, 2006) with weights varying seasonally from 1.6 – 4 kg for males and 1.3 – 2 kg for females (Eason *et al.*, 2006). Kakapo are herbivorous (Higgins, 1999; Butler, 2006; Wilson *et al.*, 2006) and have a long life-span with the oldest known kakapo now thought to be between 40 and 100 years of age (Clout, 2006; Powlesland *et al.*, 2006).

Before human settlement kakapo were common from sea level to alpine areas throughout the main islands of New Zealand in a variety of habitats (Worthy & Holdaway, 2002; Powlesland *et al.*, 2006). By the early 1880s their known range had been reduced to the central North Island and forested areas of the South Island (Lloyd & Powlesland, 1994). Kakapo remained locally common in Fiordland until the 1950s (Williams, 1956) and a small male-dominated population persisted in remote areas of Fiordland until the 1980s (Butler, 1989; Atkinson & Merton, 2006). A breeding population of kakapo was discovered on Stewart Island in 1977 (Lloyd & Powlesland, 1994) but declined due to cat predation in the following years (Best & Powlesland, 1985; Butler, 1989). Between 1980 and 1997 kakapo in Fiordland and on Stewart Island were transferred to mustelid and cat-free offshore islands (Powlesland *et al.*, 2006).

Intensive management by the Department of Conservation's National Kakapo Team has helped to increase the kakapo population from a low of 51 birds in 1995 (Powlesland *et al.*, 2006) to 86 individuals in 2007. Their current conservation status is ranked as *nationally critical* by the Department of Conservation, the highest conservation ranking available in New Zealand (Hitchmough, 2002; Powlesland *et al.*, 2006).

The last remaining breeding population of kakapo currently resides on Codfish Island, near Stewart Island (Figure 1.1). In 2006 there were 54 kakapo present on Codfish Island, including the only surviving 21 females that were of breeding age, 9 years or older (Eason *et al.*, 2006). These breeding females play a vital role in increasing the kakapo population and hereafter are referred to as *adult* females. The remaining 33 kakapo on Codfish Island in 2006 were adult males and juveniles of both sex. In 2006 a second population of 31 kakapo were managed by the National Kakapo Team on Anchor Island in Dusky Sound, Fiordland. One adult male was also on Maud Island in the Marlborough Sounds.
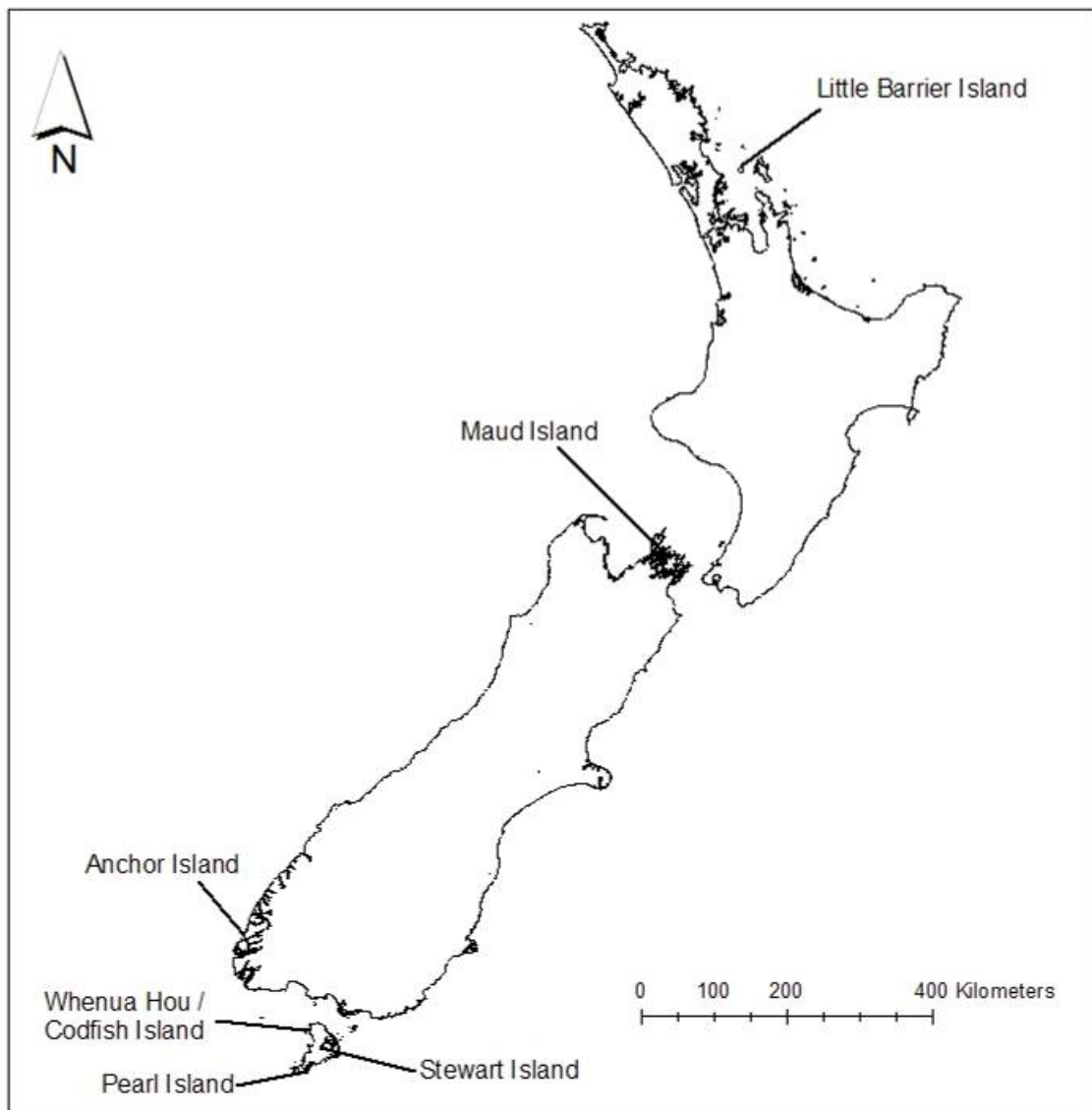
Figure 1.1. Islands around New Zealand where kakapo have been located.

1.2.2   Diet and foraging behaviour

Kakapo are exclusively herbivorous (Higgins, 1999; Butler, 2006; Wilson *et al.*, 2006) eating a wide variety of plant species (Best, 1984; Butler, 2006). Around 80 plant species were recorded in kakapo droppings collected in Fiordland during the 1970s (Butler, 2006). Kakapo eat a range of different parts of plants including the bark, twigs, leaves, fern pinnae, tussock-grass tillers, nectar, fruit, seeds, rhizomes, ripe sporangia, roots of herbaceous plants and fungi (Best, 1984; Higgins, 1999; Atkinson & Merton, 2006; Butler, 2006; Wilson *et al.*, 2006). As many of these foods are only available for short periods seasonally (or in masting species only once every two to five years) kakapo have evolved as opportunistic feeders able to adapt their diet as new food sources become available (Higgins, 1999).

Kakapo have the lowest metabolic rate recorded for any bird in the world (Bryant, 2006) as most of the plant material they eat is of low nutrient quality (James *et al.*, 1991). Any food that enters the stomach must be finely ground as their gizzard is not well developed (Higgins, 1999). Their short powerful bill and broad thick tongue are used to crush and grind any coarse plant material to a suitable size for digestion (Kirk *et al.*, 1993). Any nutritious juices are extracted but fibrous material is not ingested so is rejected from the bill with the aid of the tongue as a pellet or 'chew' (Best, 1984; Higgins, 1999; Butler, 2006).

The main feeding pattern of kakapo has been described as a 'discontinuous light browse' as would result from a bird foraging on the move (Best, 1984). Foraging activity is thought to be interspersed with long periods (up to 60 min) of inactivity (Higgins, 1999). Kakapo generally forage during the hours of darkness but there are some reports that females with dependent young may feed in daylight around dawn or dusk (Best, 1984; Higgins, 1999). Kakapo have a well developed sense of smell (Hagelin, 2004) that is likely to be more useful in foraging than their limited binocular vision (Powlesland *et al.*, 2006). Kakapo sight is generally considered poor but may be useful when traversing unfamiliar ground at night (Higgins, 1999).

Kakapo are thought to obtain a large proportion of their diet from within one metre of the ground where plant species diversity is generally the greatest (Butler, 2006). They are skilled climbers (Higgins, 1999; Butler, 2006) regularly climbing trees up to 10 m in height. During

breeding seasons females are often observed up to 30 m above the ground in the canopy of rimu trees where they collect fruit for their chicks (Higgins, 1999).

It appears that kakapo may have individual preferences for different food types depending on their previous experience and preference for particular tasting plants (Butler, 2006). These foraging behaviours were evident on Stewart Island where feeding patterns were often inconsistent between individuals, despite living in areas of similar habitat at the same time (Higgins, 1999). Nutrient analysis suggests that kakapo may select the most nutritious parts of plants and the most nutritious species when foraging (Butler, 2006).

Kakapo diet differs significantly between breeding and non-breeding years (Wilson, 2004; Wilson *et al.*, 2006) with a breeding season diet containing twice as much protein as in non-breeding years (Powlesland & Lloyd, 1994). As breeding only occurs during years of mast fruiting (Elliott *et al.*, 2001) it is not surprising that in December to March of breeding years, adult female kakapo eat more podocarp and other fruits than in non-breeding years (Wilson *et al.*, 2006). Understorey vegetation may also be important in kakapo diet during breeding years, with females recorded to eat more *Blechnum* spp. fronds than in non-breeding years. Females are less likely to eat *Dracophyllum* spp. and leatherwood (*Olearia colensoi*) leaves during breeding years compared to non-breeding years. In non-breeding years the incidence of Hall's totara (*Podocarpus hallii*) leaves in the diet of females is higher than in breeding years, possibly because females spend more time in totara trees looking for fruit in years when other fruits are scarce, eating the leaves of the trees at the same time (Wilson *et al.*, 2006).

1.2.3   Breeding biology and behaviour

Kakapo are the only species of parrot and the only New Zealand bird species to be lek breeders (Merton *et al.*, 1984). In lek mating systems males display to attract females with successful males mating with more than one female. Male kakapo display in arenas known as 'track and bowls' consisting of a series of shallow depressions (bowls) in the ground linked with areas of cleared vegetation (tracks) (Merton *et al.*, 1984; Higgins, 1999). To attract females the male sits in his bowl and produces a low-pitched 'booming' sound (Higgins, 1999; Powlesland *et al.*, 2006) that can carry up to 5 km on a still night (Merton *et al.*, 1984). Booming continues for six to eight hours a night for three to five months of the year

beginning in December and finishing in March (Powlesland *et al.*, 1992). Between January and March (Higgins, 1999; Eason *et al.*, 2006; Powlesland *et al.*, 2006) female kakapo will travel up to several kilometres from their home range to mate (Butler, 1989).

As male kakapo play no role in reproduction after copulation, females return to their home range where they nest on the ground in natural cavities such as rotten logs or under dense vegetation (Powlesland *et al.*, 1992). Egg laying occurs between late January and mid-March (Higgins, 1999) with two to four eggs laid per clutch (Heather & Robertson, 2000; Eason *et al.*, 2006). Eggs take around 30 days to incubate, hatching between late February and early April (Eason *et al.*, 2006). Chicks are brooded in the nest for the first three to four weeks (Powlesland *et al.*, 2006). After eight to ten weeks the female will roost away from the nest by day and visit only briefly each night to feed her chicks (Powlesland *et al.*, 1992). From around nine weeks chicks will spend increasing time away from the nest until they finally fledge at around ten to twelve weeks, usually between late May and mid-June (Powlesland *et al.*, 2006). Fledglings associate with and receive some food from their mother for at least three months following fledging (Higgins, 1999).

Breeding triggers

Kakapo breed infrequently at intervals of two to five years (Powlesland *et al.*, 1992; Eason *et al.*, 2006) coinciding with the masting of certain plant species that produce large crops of protein-rich fruits and seeds (Powlesland *et al.*, 1992; Higgins, 1999; Elliott *et al.*, 2001). Nesting has only been recorded on Pearl, Stewart and Codfish Islands in southern New Zealand when the podocarp species (Family Podocarpaceae) rimu or pink pine (*Halocarpus biformis*) have masted (Harper *et al.*, 2006). On Little Barrier Island nesting may have been triggered by abundant seeds produced by kauri (*Agathis australis*) and beech (*Nothofagus* spp.), while on Maud Island kakapo have bred in the absence of podocarps (Cockrem, 2006). In Fiordland and other areas of the South Island kakapo probably bred in response to the masting of beech (Atkinson & Merton, 2006). As rimu is the only masting species on Codfish Island (Courtney, 1992) where the last 21 adult female kakapo of breeding age are managed, the current kakapo population is dependent on the infrequent masting of this species to breed.

Breeding frequency on Codfish Island

The proportion of adult female kakapo that nest in a rimu mast year is dependent on the quantity of rimu fruit produced (Elliott, 2006). Since 1996 the level of rimu masting has been

recorded on Codfish Island by counting the proportion of fruiting tips on four marked branches of the same ten rimu trees each year (Harper *et al.*, 2006). In 2002 an average rimu mast of 36% was recorded (G. Elliott, pers. comm.) and 20 of the 21 adult female kakapo on Codfish Island nested (Figure 1.2). In 1997 a rimu mast of 14% resulted in 6 of the 10 adult females on the island attempting to breed. The lowest rimu mast so far recorded in a breeding season was over the 2004/ 2005 summer when an average rimu mast of 10.5% resulted in 10 of the 21 adult female kakapo on Codfish Island nesting (R. Moorhouse, pers. comm.).
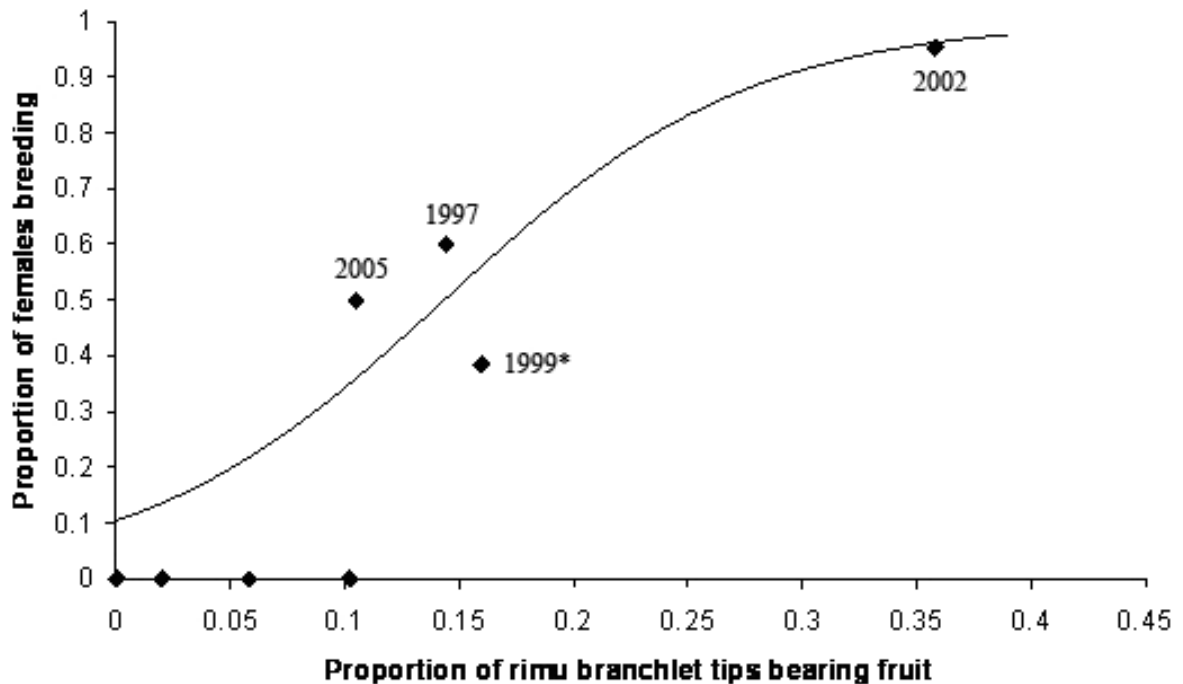
Figure 1.2. A higher proportion of females will attempt to breed in years of high rimu fruit abundance, as measured by the proportion of rimu branch tips bearing fruit. Each dot on the graph represents a rimu mast year and the proportion of females that nested in that year on Codfish Island (*indicates on Pearl Island). The solid line is a fitted logistic curve. Source: (Elliott, 2006).

Chick survival

In high mast years kakapo chicks are more likely to survive as females spend less time away from the nest searching for food and more food is available for chicks. In low mast years, or years when the rimu crop fails to ripen, a limited food supply means that females spend longer periods away from the nest increasing the risk of egg death caused by chilling of the embryo (Elliott *et al.*, 2001). As chicks are fed an almost exclusive diet of rimu fruit (Cottam *et al.*, 2006) in low mast years when little fruit is available many chicks become malnourished, show stunted growth and may die of starvation unless they can be removed from the nest for hand-rearing (Elliott *et al.*, 2001).

Supplementary feeding

Successful breeding for kakapo can only occur in the presence of unusually abundant quantities of high-quality protein rich foods (Powlesland *et al.*, 1992). These food resources must be within *c.*1 km of the nest (Powlesland *et al.*, 1992; Clout & Merton, 1998) and be readily available throughout the incubation, nestling and fledgling stages, a period of around six months (Powlesland *et al.*, 2006). Supplementary feeding was first introduced in 1989 with the hope that providing a source of protein-rich foods when the natural food supply was limited would allow females to breed more often (Powlesland & Lloyd, 1994).

Initial evidence suggested that supplementary feeding induced breeding on Little Barrier Island (Powlesland & Lloyd, 1994) but this was not sustained in subsequent years and supplementary feeding has had no effect on nesting frequency on Codfish Island (Elliott *et al.*, 2001). Although it has not yet triggered nesting, supplementary feeding may increase the number of females that can breed in a breeding year by allowing females to reach the minimum weight threshold required to breed (Elliott *et al.*, 2001).

The number of chicks that fledge may be improved by supplementary feeding when natural food supplies fail (Elliott *et al.*, 2001). In the breeding years of 1992 and 1997 when the rimu crops failed to ripen only those females that had not yet learnt to take supplementary food failed to fledge their chicks (Powlesland *et al.*, 2006). Under the current management regime all females are supplementary fed protein-rich pellets prior to and during the breeding season to ensure kakapo reach optimal breeding condition and to prevent egg and chick deaths.

A range of different plant species have been trialled as supplementary foods. Kakapo were fed freeze dried fruits of rimu and another podocarp species, kahikatea (*Dacrycarpus dacrydiodes*), in spring 2003 but no females subsequently nested (Harper *et al.*, 2006). As these foods were difficult to collect, more readily available foods that contained similar chemicals were fed to kakapo in a subsequent trial. In spring 2004 green pinecones and walnuts were fed to adult female kakapo on Codfish Island and subsequently 10 females nested during the 2005 breeding season. However the results of the trial were unclear as there was also a moderate rimu mast that year, so breeding could have been triggered by either green pinecones and walnuts or rimu fruit (Harper *et al.*, 2006). There have been two subsequent trials feeding green pinecones to females in spring 2005 and spring 2006 when

there was no rimu masting but females did not nest in either year, indicating that this type of supplementary food is not sufficient to trigger breeding.

1.2.4   Roost sites, movements and home ranges

Roost sites

Kakapo forage at night and roost during the day, usually entering their roost about one hour before sunrise and becoming active around one hour after sunset (Higgins, 1999). They roost in shallow caves, tree roots, rock overhangs, overhanging ferns or occasionally on low hanging branches (Higgins, 1999; Atkinson & Merton, 2006; Butler, 2006). Roost sites may be used repeatedly for days or weeks, with some used regularly or irregularly for many years (Higgins, 1999). In Fiordland kakapo are thought to have wandered large distances using many different roost sites for only short periods (Butler, 2006). As few droppings were recorded in each roost site, Gray (1977) speculated that kakapo roost in the nearest suitable site once they have finished foraging (Butler, 2006). Moorhouse (1985) also noted that on Little Barrier Island kakapo rarely seemed to use the same roost and utilised a variety of roost sites, suggesting that roost sites were a direct reflection of an individuals movements.

Movements

Adult female kakapo may travel several kilometres a night to reach patchily distributed food resources (Powlesland *et al.*, 2006). When feeding chicks, female kakapo are known to travel at least 1 km from their nest to feed on heavily fruiting trees (Higgins, 1999). On Codfish Island during the 2005 breeding season female kakapo travelled up to 230 m from their nest to feed in rimu trees (R. Moorhouse, pers. comm.).

Although flightless, kakapo are capable of travelling considerable distances over a relatively short time. Radio-tagged individuals have been recorded ascending more than 300 m in altitude or walking at least 5 km in a direct line in a single night (Best & Powlesland, 1985). Rates of travel of around 50 m/ hour were recorded on Maud Island during foraging trips (Walsh, 2002).

Home ranges

An animal's home range is not the whole area traversed in its life-time but the area used in its normal day to day activities that contains all the resources required for its survival (Krebs & Davies, 1996). Both male and female kakapo generally stay within similar home ranges much of the year, for a number of years, with some overlap occurring between feeding areas of individuals (Merton *et al.*, 1984; Moorhouse & Powlesland, 1991; Powlesland *et al.*, 1992). Kakapo are known to vocalise their whereabouts, perhaps to signal their presence to other kakapo, but they do not fight to defend their foraging areas so are not considered territorial (Powlesland *et al.*, 1992). Some fighting does occur however between male kakapo over track and bowl mating areas (Powlesland *et al.*, 2006). Kakapo are generally considered solitary (Higgins, 1999; Heather & Robertson, 2000) but recent evidence suggests that juveniles especially may forage in close proximity to each other with considerable overlap between home ranges (Farrimond, 2003). Adult males have also been observed roosting within short distances of each other (D. Eason, pers. comm.).

Kakapo home ranges have been studied on a number of islands around New Zealand, with each study showing a variation in home range size between individuals. Home range sizes varied from 15 – 50 ha on Stewart Island (Best & Powlesland, 1985); 0.8 – 11.4 ha on Pearl Island (Trinder, 1998); 21 – 38 ha on Little Barrier Island (Moorhouse, 1985); 0.8 – 29 ha (Trinder, 1998) and 2 – 145 ha (Walsh *et al.*, 2006) on Maud Island. Research on Little Barrier Island found that female home ranges were 10 - 20 ha larger than those of males, although this result was not statistically significant (Moorhouse, 1985). A study on Codfish Island found that adult female kakapo had significantly smaller core home ranges than juveniles, suggesting that juveniles range over wider areas than adults (Farrimond *et al.*, 2006). On Little Barrier Island some kakapo were known to shift their home ranges seasonally (Moorhouse & Powlesland, 1991) and on Maud Island kakapo home ranges varied greatly between seasons with the smallest ranges recorded in winter (Walsh *et al.*, 2006).

As most of these previous home range studies were conducted using day-time location data they provide an estimate of roosting home ranges. However as kakapo are thought to roost in locations near to where they finished foraging the previous evening (Gray, 1977; Moorhouse, 1985), some previous studies have interpreted day-time home ranges to be similar to night-time foraging home ranges (eg. Farrimond *et al.,* 2006). Research by Trinder (1998) on Maud

and Pearl Islands tested this interpretation and found that in some cases day-time roost sites underestimated an individual's home range, although the results were not statistically significant because of small sample sizes. For kakapo resident in an area for two years or longer, Trinder (1998) concluded that there was a reasonably good chance that daytime fixes would not reflect foraging home ranges. Instead Trinder (1998) recommended that any study of foraging home ranges should be conducted using night time location data.

Some prior research has been conducted on home ranges of adult female kakapo on Codfish Island (Farrimond *et al.*, 2006), but as this used mostly day-time location data it is probably not an accurate reflection of night-time foraging home ranges. Farrimond *et al.* (2006) studied the locations of 13 adult female kakapo before (September 2001 – January 2002) and after (September 2002 – January 2003) the 2002 breeding season. Home range sizes varied from 14 – 44 ha and were not significantly different in size between these two periods, suggesting that rearing young does not require expansion of a female's home range (Farrimond *et al.*, 2006).

1.2.5   Habitat Use

<u>Historical accounts</u>

Prior to their decline kakapo were most common in the wetter regions of New Zealand, in lowland podocarp-broadleaf and wet montane beech (*Nothofagus* spp.) forests (Worthy & Holdaway, 2002; Butler, 2006). They were not exclusively forest dwellers with historical reports frequently associating kakapo with grassland habitats (Butler, 2006) and other low-growing vegetation such as shrubland, subalpine scrub and herbfields (Higgins, 1999). Kakapo often occurred near the edge of forests (Williams, 1956), preferring ecotones between vegetation types and seral vegetation communities, as these areas supported a wide diversity of food species (Higgins, 1999; Atkinson & Merton, 2006). These favoured foraging areas known as "kakapo gardens" (Atkinson & Merton, 2006) were also found in disturbed sites such as regenerating landslides, avalanche debris fans and river flats (Best & Powlesland, 1985; Butler, 2006).

The vegetation types inhabited by the last known wild populations probably do not represent the preferred habitat of kakapo but instead show their remarkable ability to adapt to a range of

environments. In Fiordland the last known male kakapo were found near the tree line in alpine areas of steep-sided valleys (Butler, 2006) where the vegetation was mostly scrub, fern, tussockland and herbfields less than 1m high (Atkinson & Merton, 2006; Butler, 2006). On Stewart Island kakapo inhabited mostly podocarp-hardwood forest, manuka (*Leptospermum scoparium*) scrub, yellow-silver pine (*Lepidothamnus intermedius*) scrub and alpine areas (Best & Powlesland, 1985).

Vegetation use studies

Since intervention by conservationists, the last remaining kakapo and their offspring have been transferred to a range of offshore islands with different vegetation communities. Habitat selection has been studied on Little Barrier Island (Moorhouse, 1985) and on Maud Island (Walsh, 2002) but the vegetation on these islands is significantly different to Codfish Island. The vegetation on Maud Island in the Marlborough Sounds has been severely modified by farming and forestry (Walsh, 2002), quite different to the mostly unmodified habitat of Codfish Island. Little Barrier Island in the Hauraki Gulf has a much warmer climate and vegetation that consists of a mixture of manuka, northern rata (*Metrosideros robusta*)/ tawa (*Beilschmiedia tawa*) forest and patches of kauri (*Agathis australis*) forest (Moorhouse, 1985).

The vegetation on Codfish Island represents a relatively untouched southern lowland forest ecosystem (McClelland & Roberts, 1998). The island is mostly podocarp-broadleaf forest including patches of kamahi (*Weinmannia racemosa*) forest, coastal daisy and pakahi scrub. A vegetation map of Codfish Island (Figure 4.2) created in 2005 by Waikato University describes the composition and location of sixteen vegetation types across the island. There have been no previous studies of vegetation use by kakapo on Codfish Island or any other islands in southern New Zealand with similar vegetation types. The vegetation on Codfish Island is described in more detail in Chapters 2 and 4.

Topography utilised by kakapo

In Fiordland kakapo occupied a range of terrains including ridges, benches and avalanche fans that were high on the sides of valleys while some occupied lower lying areas (Butler, 2006). Kakapo can occupy a range of elevations with historical reports of them being found from near sea-level to the subalpine zone (> 1200 m a.s.l.) (Butler, 2006; Powlesland *et al.*, 2006). The last known male kakapo found in Fiordland mostly inhabited high elevation areas near

the tree line at around 1000 – 1200 m above sea level (Butler, 2006). These may have been the last refuges where they were able to survive rather than their preferred elevation. Male kakapo transferred to islands have established home ranges mainly on the upper slopes, high plateaus and summit regions, whereas females have generally settled at slightly lower elevations on the mid slopes (Powlesland *et al.*, 2006).

In southern regions of New Zealand kakapo may favour north facing slopes, as 13 male kakapo found in Fiordland in the 1970s all inhabited the more sunny parts of steep sided valleys (Atkinson & Merton, 2006). On two islands in northern New Zealand (Little Barrier and Maud) kakapo preferred south or south-western facing slopes as these provided a relatively cool, moist and shaded environment (Moorhouse & Powlesland, 1991; Powlesland *et al.*, 2006). Kakapo habitat does not appear to be limited by slope as the home ranges of two male kakapo in the Esperance Valley, Fiordland had slopes of 7° and $42 - 45^{o}$ respectively, showing that either fairly flat or steep areas are suitable (Atkinson & Merton, 2006).

1.3   Knowledge gaps

Maximising the proportion of females that breed each breeding year is a key management goal for kakapo conservation (Cresswell, 1996). Supplementary feeding has helped some females to reach a minimum weight threshold required for breeding (Elliott *et al.*, 2001), but providing high-protein food does not guarantee that all females will breed especially in low rimu mast years when natural food supplies are limited. There is currently no information available that could explain why some females are able to breed in low rimu mast years on Codfish Island and others are not. The size of foraging home ranges and/ or the types of habitat they use may help to explain this variation in breeding attempts.

Prior to this study there had been no research into the foraging home ranges used by adult female kakapo on Codfish Island. As daytime roosting home ranges have been found to underestimate foraging ranges (Trinder, 1998), day-time home ranges estimated by Farrimond (2006) on Codfish Island probably underestimate foraging home ranges. There have been two previous studies of vegetation selection by kakapo but their findings are no longer relevant to the current kakapo population as both studies involved vegetation communities that were distinctly different from the habitat on Codfish Island.

1.4   Aim and objectives

This research will address section 9.4 of the Kakapo Recovery Plan (1996 – 2005) that calls for research to *"obtain and analyse information on home range and habitat quality, and relate this to breeding histories"* (Cresswell, 1996, pg 17). Specifically, this research aims to investigate if the ability of adult female kakapo to breed on Codfish Island in low rimu mast years is dependent on the size of their foraging home ranges and/ or their access to habitat with particular vegetation and topographical characteristics.

Objectives of this study are to:

1   Estimate the location and size of foraging home ranges for adult female kakapo on Codfish Island, and determine if they differ significantly between females that bred and those that did not breed during the 2005 breeding season.

2   Compare the vegetation types used by adult female kakapo to what is available on the island, to determine if females use habitat randomly or select for particular vegetation . Compare vegetation types used by females that bred and those that did not during the low rimu mast year of 2005.

3   Investigate the relative importance of a range of habitat variables in determining the distribution of adult female kakapo on Codfish Island, and determine if the importance of these variables differs between females that bred and those that did not during the 2005 breeding season.

4   Produce a habitat suitability map of Codfish Island showing areas that may be suitable for kakapo to breed in low rimu mast years. Determine if any adult female kakapo occupy sub-optimal habitat for breeding, and if any areas of the island that would be suitable for breeding are not currently occupied by adult females.

Chapter 2   General Methodology

This chapter describes the study site, provides some history on the kakapo selected for this study and explains how the data collected was analysed. It also contains some preliminary results involving the data collection and explains how the raw data was organised for further analysis.

2.1   Study site

Codfish Island (Whenua Hou) is located 3 km off the northwest coast of Stewart Island (46° 46' South, 67° 38' East). The island is 1475 hectares and 5 km across at its widest point, rising to a maximum height of 292 m on the south-west side of the island (Meurk & Wilson, 1989). There are two large bays on the northern side of the island and two ridges running north enclose sheltered valleys that feed into these bays (Figure 2.1).
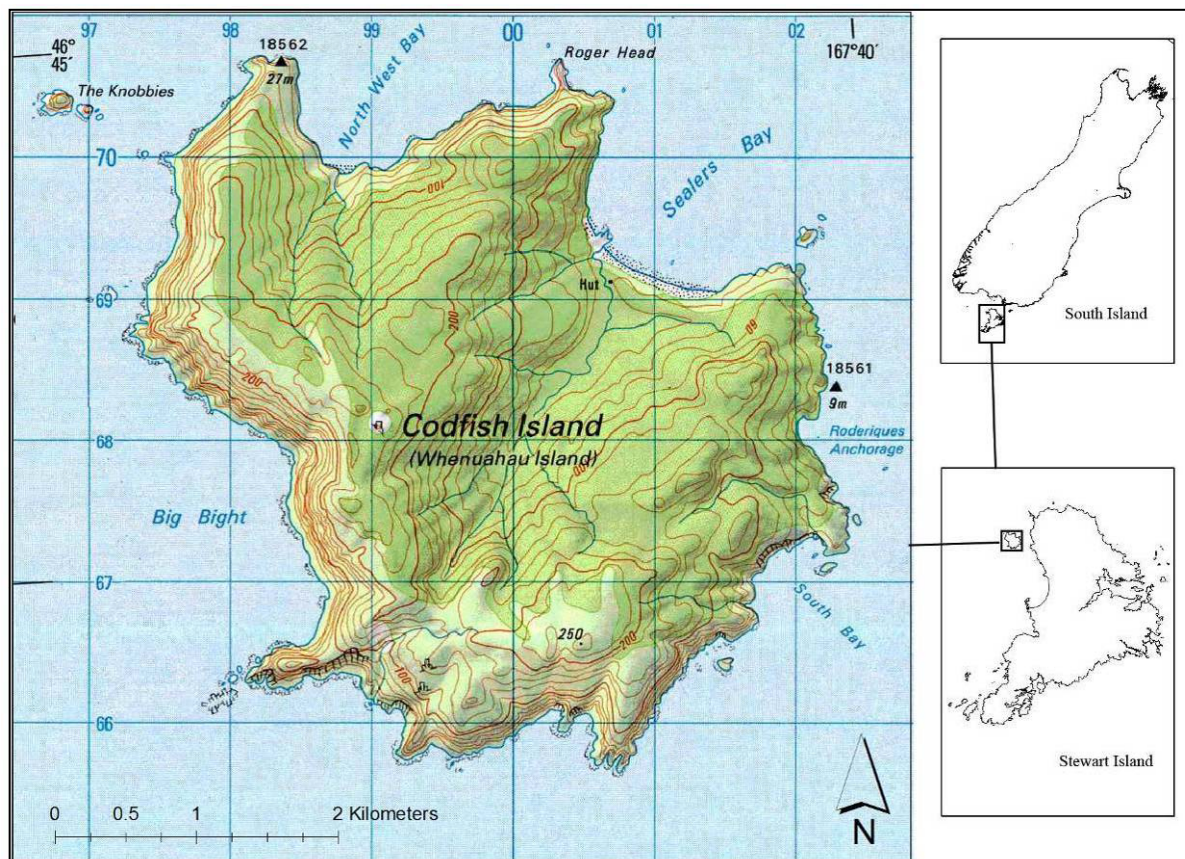
Figure 2.1. Map of Codfish Island (Whenua Hou) showing its location off the northwest coast of Stewart Island, New Zealand.

The main valley floor running into Sealers Bay is the flattest part of the island (Figure 3.3). The sides of the ridges and valleys are generally steep with some slopes over 60 degrees. The south-western side of the island is characterised by steep slopes and cliffs along the exposed coastline. There are two areas of higher elevation with peaty soils on either side of the main

valley leading into Sealers Bay. These areas are of undulating terrain and support the home ranges of most adult female kakapo in this study.

The geology of Codfish Island is mostly granite, overlain by peaty soils with a number of rock outcrops on the high western ground (Meurk & Wilson, 1989). The mean annual rainfall is 1500 - 2000 mm and the mean temperature is 13.9^{o} in January and 7.3^{o} in June. Much of the island is exposed, especially the south-western side where wind plays a major role in determining the pattern of vegetation and intensifies the effects of altitude (Meurk & Wilson, 1989).

The first European settlement south of Foveaux Strait was at Sealers Bay on Codfish Island where ex-sealers, their maori wives and children lived from 1823 – 1850 (Meurk & Wilson, 1989; Hall-Jones, 1994). In the late 1800s cattle were grazed on the island under lease, possums (*Trichosurus vulpecula*) were established on the island for the fur trade and there was occasional muttonbirding (Meurk & Wilson, 1989). Despite these activities, human impacts have been minor leaving the island relatively unmodified. Fire occurred in pakahi scrub on top of the island and in an area of forest north-east of the summit, but it does not appear to have altered the vegetation significantly (Meurk & Wilson, 1989). Forest around Sealers Bay was felled for timber and this area has regenerated into second growth kamahi forest.

Probably the greatest impacts from human occupation have been caused by the introduction of kiore (*Rattus exulans*), possums and weka (*Gallirallus australis scotti*) to the island. Prior to their eradication in the 1980s, possums caused browsing damage to a number of plant species including broadleaf (*Griselinia littoralis*), rata (*Metrosideros umbellata*), wineberry (*Aristotella serrata*) and caused the virtual elimination of punui (*Stilbocarpa lyalli*) from the island (Meurk & Wilson, 1989). The weka, native to nearby Stewart Island, was introduced to Codfish Island and before its eradication in the 1980s severely affected the breeding of Cook's (*Pterodroma cookii*) and mottled (*Pterodroma inexpectata*) petrels (Meurk & Wilson, 1989). Kiore were probably introduced by early explorers. Known to predate on kakapo eggs and newly hatched chicks (Lloyd & Powlesland, 1994), kiore were eradicated from Codfish Island in 1998 (McClelland & Roberts, 1998). Codfish Island was designated a Nature Reserve in 1968 to protect its outstanding wilderness values and relatively unmodified flora and fauna. Access to the island is by permit only.

Codfish Island supports a range of vegetation types similar to nearby Stewart Island (McClelland & Roberts, 1998). The low lying valleys are dominated by rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*), kamahi (*Weinmannia racemosa*) and rata (*Metrosideros umbellata*) forest with a canopy height of 10 - 18 metres (Meurk & Wilson, 1989). Elevated and exposed areas of the island are characterised by stunted vegetation one to two metres tall, consisting mainly of manuka and *Dracophyllum longifolium.* Coastal areas are covered by a dense scrub consisting of *Senecio* spp.*, Olearia* spp., *Hebe elliptica* and *D. longifolium* (Meurk & Wilson, 1989). A checklist of vascular plants compiled in 1992 found 225 indigenous plant species present on Codfish Island and 32 introduced species (Courtney, 1992).

The vegetation types on Codfish Island are described in more detail in Chapter 4, where the vegetation types occupied by adult female kakapo are investigated. A vegetation map of Codfish Island created by Lars Brabyn (Waikato University) in 2005 (Figure 4.2), shows the location of 16 vegetation types. Each vegetation type is described by its canopy and sub-canopy species with some references made to understorey vegetation and maximum canopy height (Appendix 8). The map was created using aerial photos, infra-red images and ground surveys of the island (L. Brabyn, pers. comm.).

2.2   Kakapo on Codfish Island

Kakapo were first transferred to Codfish Island in 1987 from Stewart Island (Blackburn, 1968; Butler, 1989). There is no evidence that kakapo previously inhabited Codfish Island (D. Eason, pers. comm.). Since their initial release, kakapo have been transferred between Codfish Island and other islands around New Zealand for management purposes (Appendix 1). In 2006 at the time of this study 54 kakapo were present on Codfish Island including 21 adult females of breeding age. The 33 other kakapo on the island included 9 juvenile females, 22 adult males and 1 juvenile male.

2.2.1   *Kakapo in this study*

The kakapo in this study were all adult females of breeding age, 9 years or older (Eason *et al.*, 2006). Although all 21 of the last remaining adult female kakapo were on Codfish Island during the time of this study it was not possible to include them all in this research. After several weeks of radio-tracking it was found that it was not possible to obtain accurate

location estimates for two females Maggie and Wendy that lived in coastal areas. Nor was it possible to obtain accurate locations for a third bird Hoki, who had been hand-raised, as she often followed us at night. The remaining 18 adult females were studied (Appendix 1).

As kakapo are often transferred between island sanctuaries, the individuals in this study have spent variable lengths of time on Codfish Island. Prior to the start of this research in March 2006, six of the adult females in this study had been continuously resident on Codfish Island for the previous seven years. Seven of the adult females had been resident for five years on Codfish Island, four had only been present for two years and one female had only returned to the island the previous year (Appendix 1). As most of these females were first captured on Stewart Island as adults (Lloyd & Powlesland, 1994), their actual age is unknown with the exception of two birds that were captured as chicks (Appendix 1).

2.2.2   Breeding history of kakapo in this study

Since kakapo were first transferred to Codfish Island in 1987, nesting has occurred in four of the 19 years they have been present on the island: 1992, 1997, 2002 and 2005. Five females also nested in 1999 when all kakapo on Codfish Island were transferred to Pearl Island to allow the eradication of kiore from Codfish Island. During the 1992 breeding season 10 of the 18 adult female kakapo in this study were present on Codfish Island and five (50%) of them nested. Since 1996 the level of rimu masting has been recorded on Codfish Island by counting the proportion of fruiting tips on four marked branches, of the same ten rimu trees, each year (Harper et al., 2006). In the 1997 breeding season the mean rimu mast on Codfish Island was recorded as 14% (G. Elliott, pers. comm.). In this low rimu mast year 12 of the 18 females in this study were present on Codfish Island and six (50%) nested (Appendix 1).

The most productive breeding season on Codfish Island occurred in 2002 when there was a large rimu mast of 36% and all but one of the adult female kakapo on the island nested. All 18 adult female kakapo in this study were present on Codfish Island during the 2002 breeding season and all females nested, except Jane who has not yet been recorded to breed. The last breeding season on Codfish Island occurred in 2005 when there was a low rimu mast of 10.5% (R. Moorhouse, pers. comm.). All 18 adult female kakapo in this study were present on Codfish Island during the 2005 breeding season but only ten females (56%) nested (Appendix 1).

The 18 adult female kakapo in this study could be ranked on their breeding ability based on the number of times they have nested, irrespective of island, since and including 1992. Five females (Alice, Cyndy, Sarah, Suzanne and Zephyr) have bred four times during this period. Five females (Flossie, Lisa, Margaret-Maree, Sandra and Sue) have bred three times since 1992. It is interesting to note that eight of these ten females (Alice, Cyndy, Flossie, Lisa, Margaret-Maree, Sarah, Sue and Suzanne) also nested in the low rimu mast year of 2005. The remaining two females (Bella and Fuchsia) that nested in 2005 had only nested twice since 1992 (Appendix 1).

Six of the 18 adult females in this study (Bella, Fuchsia, Heather, Nora, Ruth and Solstice) have only bred one or two times since 1992 (Appendix 1). Only one female (Jane) has never been recorded to breed. Impaired mobility in one leg may restrict her ability to mate although she is still able to climb trees and walk significant distances (D. Eason, pers. comm.).

2.3   Collection of field data

Location points were estimated for 18 adult female kakapo on Codfish Island in two periods of autumn and early winter of 2006: 15 March – 19 April and 3 – 30 May. As kakapo begin to forage around 1 hour after sunset and roost around 1 hour before sunrise (Higgins, 1999), information on foraging locations could only be collected during the hours of darkness. To ensure that kakapo were active when being studied, location points were collected no earlier than two hours after sunset and no later than two hours before sunrise.

All known kakapo are fitted with radio-transmitters (Clout, 2006) so they can be individually identified and located. Transmitters weigh 20 - 35 grams, are enclosed in a protective epoxy resin casing and are mounted onto the bird's back using a back-pack style harness. The normal pulse rate is 35 pulses per minute (ppm). Transmitters have an internal loop aerial and a battery life of 12 to 18 months. They are replaced annually by National Kakapo Team staff.

The main method used to estimate foraging locations was triangulation (Figure 2.2). Triangulation allows the location of a transmitter to be estimated using two or more bearings obtained from known location points (White & Garrot, 1990). On Codfish Island there are permanently marked points spaced between 25 to 150 m apart along tracks on the island. Their exact position has been calculated from the mean of three readings taken by a hand-held

Global Positioning System (GPS) unit by the National Kakapo Team staff. There are around 770 fixed location points on Codfish Island from which bearings could be taken for triangulation.

Portable *TR4* radio receivers (Teleonics, Arizona) and three element *Yagi* hand-held aerials (Sirtrack, New Zealand) were used for radio-tracking. Aerials were fitted with a sighting compass and bearings were estimated to the nearest degree. Although it was not possible to measure, it is likely that the true accuracy of the bearing estimates may have been to the nearest 10 degrees because of difficulties in triangulation caused by human judgement, terrain, signal strength and interference from surrounding trees.

To estimate the location of a transmitter using triangulation, up to ten bearings were recorded in the field and the five that provided the closest intersection were entered into the National Kakapo Database (a Microsoft Access database designed by Graeme Elliott to estimate triangulations and record kakapo information). From the five bearings, the three that provided the closest intersection were used to estimate the location of the transmitter. In an accurate triangulation (Figure 2.2a) the estimated location of the transmitter is the intersection of the three bearings. In a less accurate triangulation (Figure 2.2b) the transmitter could be anywhere within the triangle created by the three bearings but is estimated to be at the centre of the triangle. If the triangle was wider than 40 m at its widest point it was considered to be too inaccurate for this study and was not included in home range estimates or later analysis.

Kakapo were occasionally seen or heard on or near the tracks on the island, and these sightings were recorded as additional locations. Sighted birds were identified from their transmitter frequency and their location described as either being at a fixed location point along a track, or a certain distance and bearing from a fixed location point.

As the 18 kakapo in the study were spaced widely across the 1475 hectare island, a team of three or four people was needed to collect the required number of location points. On most nights it was possible to collect one location for each kakapo in the study. Locations were assumed to be biologically independent if a maximum of one point was collected per night for each bird.
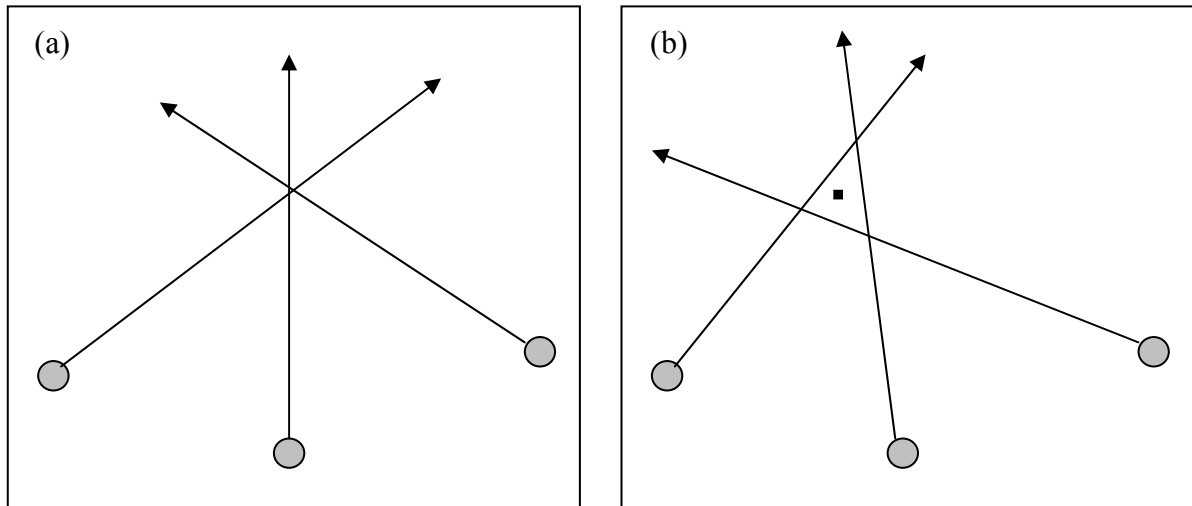
Figure 2.2.   In triangulation the location of a transmitter is calculated as the intersection of three bearings (arrows) that are taken from fixed location points (grey circles).   In an accurate triangulation (a) bearings intersect at one point.   In a less accurate triangulation (b) the intersection of the bearings creates a triangle where the transmitter's location is estimated to be in the centre (black square).

The order in which birds were located each night was varied to try to ensure locations for each kakapo were collected at varying times after sunset.   However due to difficult terrain and the distances we were required to traverse each evening, often the only feasible option was to alternate the direction in which a route was travelled, resulting in some birds being located either early or late in the evening, or always in the middle of the night, rather than obtaining an even spread throughout the evening.

2.4   Triangulation accuracy and errors

Locations calculated from triangulations are only estimates and not exact points (Springer, 1979).   A number of factors can affect the accuracy of triangulations.   Those that cannot be controlled include terrain, vegetation cover and atmospheric conditions (White & Garrot, 1990; Whithey *et al.*, 2001).   Other factors affecting triangulation accuracy that are controllable to some extent include operator error, distance between the transmitter and the receiver and the time taken between bearings (Springer, 1979; Harris *et al.*, 1990).

2.4.1   Minimising controllable errors

A number of approaches were used in this study to minimise controllable errors. Differences in operator error were minimised by training all volunteers in the preferred telemetry methods. Distances between the transmitter and the receiver were kept to a minimum by taking bearings from as close to the birds as was feasibly possible while remaining on the tracks. Bearings were taken from a number of angles around the birds wherever possible to increase triangulation accuracy. Triangulations were not recorded when bad weather made it difficult to accurately read bearings or to hear the receiver, although the use of headphones could often overcome this problem.

To avoid introducing movement error into the data, triangulations were not recorded when the signal strength from a transmitter was variable, indicating that a bird was probably moving (Mech, 1983). To minimise the risk that a bird could move while a triangulation was being estimated, the operator moved as fast as possible between fixed location points recording the time that each bearing was obtained. The time taken between the first and the last bearings used in a triangulation varied depending on the location of the kakapo, the terrain, track conditions and the distance between fixed location points. In some instances the time taken between the first and last bearings used for a triangulation was reduced if two people recorded bearings for the same bird simultaneously.

The mean time taken between bearings for the locations used in later analysis (see section 2.5) was 14.6 ± 7.6 min (Appendix 2). The triangulations with the five longest times between the first and last bearings were 58, 47, 44, 43 and 38 minutes. In only 18 of 482 triangulations was the time over 30 minutes (Appendix 2). There are two reasons why triangulations with longer times between the first and last bearings were unlikely to be significantly inaccurate and did not need to be excluded from further analysis.

Firstly, if a bird did move during the time the triangulation was recorded it was unlikely that the bearings recorded for the triangulation attempt would have intersected accurately, if they intersected at all, so the chance of such a triangulation making it into the dataset for analysis was low.

Secondly, if a kakapo did move during a triangulation and this triangulation was included in further analysis, then it is likely that the scale of any movement error would have been insignificant. As kakapo are known to move at rates of up to 50 m/ hour while foraging (Walsh, 2002) and the mean time taken between bearings for triangulations in this study was 14.6 ± 7.6 min, the movement error associated with an average triangulation could be expected to be around 12 metres. As the triangulation method itself creates estimates of locations rather than exact points (Springer, 1979), and an error of around 20 m is already associated with each triangulation (see section 2.4.2), any additional movement error would not significantly change the estimated location.

2.4.2   Calculating triangulation error

When interpreting triangulation data it is important to know the amount of error that is likely to be associated with each estimated location. A common method used to measure location error is to triangulate a test transmitter in a known location and then compare the distance between the transmitter's actual and estimated locations (Millspaugh & Marszluff, 2001). I calculated the location error for 25 triangulations in areas of Codfish Island inhabited by adult female kakapo. Test transmitters (identical to those used on kakapo) were hidden at known location points along the tracks by volunteers. The location of the test transmitters was then estimated using the same triangulation methods outlined above.

The distance between the estimated and actual location of test transmitters ranged from 3.2 m to 43.6 m, with a mean distance of 19.3 ± 12.2 m (Appendix 3). Two separate triangulations recorded on a transmitter located in the same known location resulted in two quite different error values of 6.3 m and 37.1 m, indicating that perhaps human error rather than physical factors of the environment are a large cause of triangulation errors. The mean error value of 19.3 m was rounded up to 20 m for convenience and applied as a buffer around each location point estimated using triangulation.

Some error will also be associated with kakapo sightings as although the birds were seen or heard, their location still had to be estimated using a bearing and distance estimate from the nearest fixed location point. It was not possible to estimate the error associated with sightings, but it could be expected to be less than that associated with triangulations. However to ensure that errors associated with sightings were not underestimated the same 20

m error value calculated for triangulations was applied as a buffer around sightings. When these error values are taken into account for triangulations and sightings, the actual location of the kakapo could have been anywhere within the 20 m radius circle surrounding the estimated location point.

2.5   Data organisation

2.5.1   Removal of locations possibly influenced by supplementary feeding

Kakapo on Codfish Island are fed supplementary foods to enhance their breeding potential, as explained in section 1.2.2 of the general introduction chapter. During the first nine days of this study, supplementary food was provided for kakapo (at hoppers placed within their normal home ranges) once every three days, with the last rations for the season being distributed on 24 March 2006.

To ensure that locations analysed in this study reflected the natural foraging behaviour of kakapo, and were not influenced by the placement of artificial foods, location records collected while kakapo were being supplementary fed were excluded from the analysis. Location points collected during the three days after feeding stopped were also excluded from the analysis to act as a buffer period. From 28 March onwards it was assumed that kakapo would have resumed their natural foraging behaviour. In total 78 location points were excluded from the analysis as they were collected during supplementary feeding.

2.5.2   Location points used for further analysis

After the 78 location points collected during supplementary feeding were removed from the dataset there were 506 points remaining to be used in further analysis: 482 triangulations and 24 sightings (Appendix 2). The number of location points collected for each individual kakapo ranged from 17 to 34, with a mean of 28.1 ± 4.5 points. The location points for the 18 kakapo in this study were mostly clumped in two areas on either side of the main valley although some females occurred in more outlying areas (Figure 2.3).
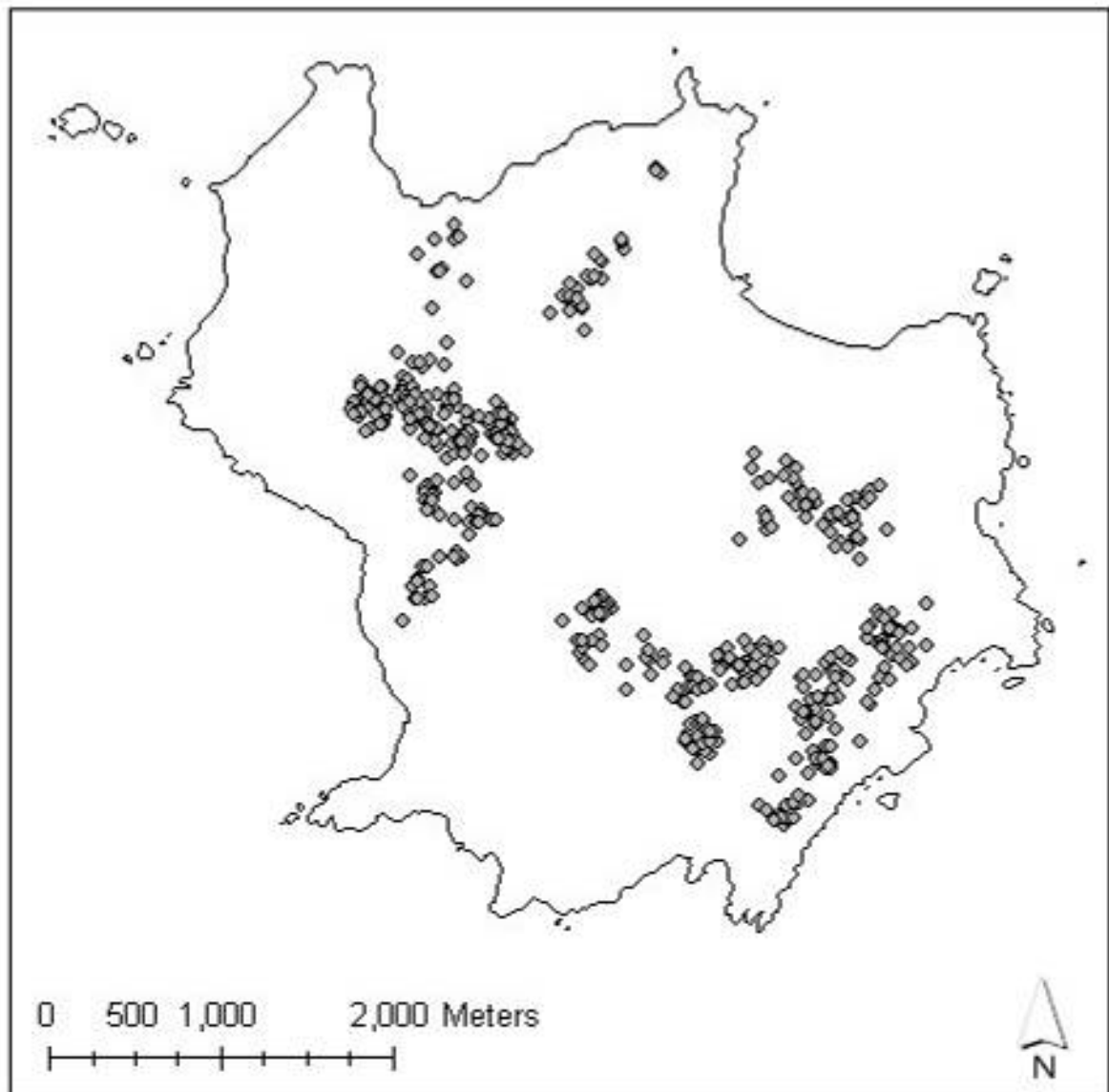
Figure 2.3. The distribution of locations on Codfish Island for the 18 adult female kakapo in this study.

2.6   Comparing 2006 foraging data using 2005 breeding success

One of the objectives of this research was to assess why only a small proportion of female kakapo attempt to breed in low rimu mast years on Codfish Island, by determining if home range size or habitat types used by females may influence their ability to breed. Unfortunately during 2006 when I conducted field work there was a low rimu mast and no females attempted to breed, so I was unable to make any direct comparisons between foraging behaviour and breeding attempts during 2006. As a next best alternative I compared foraging home ranges for individuals in 2006 based on their breeding success in 2005.

2.6.1   Breeding success defined

The breeding success of an animal could be determined by a range of measures including clutch size, number of fertile eggs laid and hatching or fledging success. However in kakapo the outcome of breeding attempts is often influenced by a number of variables not directly related to the fitness of individual females. For example a large proportion of eggs are infertile, eggs have a low hatch rate (Elliott *et al.*, 2006) and nests are often manipulated with eggs and chicks being moved between nests (Elliott *et al.*, 2001). For these reasons the breeding success of a female in the 2005 breeding season was defined in this research by if she attempted to breed, rather than the outcome of any nesting attempt.

If a female nested, regardless of the outcome of that nest, then it was considered that she had successfully bred so was called a 2005 "breeder". If a female did not produce a nest during the 2005 breeding season then it was considered that she did not successfully breed and was referred to as a "non-breeder" during 2005. It is important to note that the status of breeder or non-breeder, only applies to breeding success in 2005. As explained in section 2.2.2, the females that did not breed in 2005 had all previously nested on Codfish or other islands, with the exception of Jane, indicating that they had the ability to breed but did not in the low rimu mast year of 2005.

2.6.2   Comparison of locations from breeding and non-breeding years

To be able to compare foraging home ranges for individuals in 2006 based on their breeding status in 2005, I needed to be fairly certain that females used similar home ranges in both of these years. Research by Farrimond *et al.* (2006) suggests that breeding does not alter home range size, as rearing young did not require expansion of a female's home range. Radio-tracking studies by Farrimond *et al.* (2006) on Codfish Island during September - January of 2001/ 2002 and 2002/ 2003 found that home ranges of adult female kakapo were similar in these breeding and non-breeding years.

2.6.3   Statistical methods

To determine if variation occurs in an individual's home range between breeding and non-breeding years, location data from the autumn period of 28 March to 30 May was collated from two previous breeding years (2002 and 2005) and two previous non-breeding years (2003 and 2004). Location data for these four years was mostly day-time roosting data collected during routine monitoring by NKT staff using a mixture of triangulations, sightings

and snark records. (A snark is a portable electronic device placed in the field that records any visits of transmitted kakapo to within several metres of the receiver). Six of the 18 adult female kakapo in this study could not be included in this analysis as they were not present on Codfish Island for all years between 2002 and 2006 (Appendix 1 and Appendix 4). For the remaining 12 females that were included, there were considerably fewer locations available for each individual in each of these four years compared to the number of locations collected during the 2006 field season. The number of locations collected during these four years was variable between individuals and years (Appendix 4).

Due to the limited and variable quantity of location points available for adult female kakapo from the two breeding and two non-breeding years, it was not possible to estimate home range sizes for these years that would have been comparable with home range estimates for 2006. Instead the proportion of location points collected between 28 March and 30 May from previous years that overlapped with the 2006 minimum convex polygon (MCP) foraging home range (estimated in Chapter 3) was calculated for the 12 females for each year (Appendix 4).

A mixed-model ANOVA was used to determine if the proportion of points from each year overlapping with the 2006 foraging home range was affected by a number of fixed and random variables. This analysis method accounts for the non-independence of the data arising from multiple years of locations on the same adult female kakapo. The fixed variables included in the mixed-model ANOVA were the year (2002 to 2005), if the year was a breeding or non-breeding year, the breeding status of the individual (breeder or non-breeder during 2005) and the size of the MCP home range for autumn 2006. The individual female, nested within 2005 breeding status, was included as a random factor in the model. The ANOVA was performed in the statistical package R (R Development Core Team, 2005).

2.6.4   Results and implications

There was no significant difference in the proportion of location points that overlapped with the 2006 foraging home range between breeding and non-breeding years ($p = 0.759$, $t = 0.309$, $df = 37$). The breeding status of an individual in 2005 did not influence the proportion of points that overlapped with the 2006 foraging home range ($p = 0.164$, $t = 1.51$, $df = 9$) and nor did the size of the foraging home range ($p = 0.568$, $t = 0.593$, $df = 9$).

These results suggest that adult female kakapo on Codfish Island occur in similar areas during breeding and non-breeding years, and supports research by Farrimond *et al.* (2006) that adult female kakapo on Codfish Island use similar home ranges in breeding and non-breeding years. As home ranges do not appear to differ significantly in their location between breeding and non-breeding years, home ranges used by individuals in the breeding year of 2005 and the non-breeding year of 2006 are most likely similar, thus allowing a comparison of 2006 foraging home ranges based on the breeding success of individuals in 2005.

Chapter 3   Foraging Home Ranges

3.1   Introduction

Home range studies are useful for determining key ecological and behavioural traits of a species. Defined as the "area traversed by an individual in its normal activities of food gathering, mating and caring for young" (Burt, 1943) a home range is not the whole area traversed by an animal in its life time but the area in which it normally lives (White & Garrot, 1990). Described by their location, size and structure, a home range will contain all the resources an animal requires for its survival (Millspaugh & Marszluff, 2001). Home ranges may vary between individuals depending on their age, sex, breeding condition or the environmental variables of the area (McFarland, 2006).

Home range studies are particularly useful for conservation of rare and endangered species as knowledge of home range size and structure can help to understand the ecology of a species and its interaction with the environment. Results from home range studies can be used to answer a number of research questions, such as the resource and habitat requirements of populations, interactions between individuals or management boundaries required for populations (White & Garrot, 1990; Kernohan *et al.*, 2001; Marszluff *et al.*, 2001). In New Zealand, home range studies have been used to understand the area and habitat requirements of a number of endemic bird species and their predators. Results from these studies are often used to guide conservation management, such as making recommendations for predator control (Elliott *et al.*, 1996), estimating if island populations are at carrying-capacity (Ryan & Jamieson, 1998) or determining which individuals of a population should be transferred to new areas (Walsh *et al.*, 2006).

Home range use has been investigated for adult female kakapo on a number of islands around New Zealand, including Codfish Island (Whenua Hou). Most of these studies used daytime roosting locations to estimate home ranges, based on the assumption by Moorhouse (1985) that roost sites are a direct reflection of an individual's movements. But more recent research by Trinder (1998) comparing day and night time home ranges on Maud and Pearl Islands found that day time roost sites can underestimate foraging home range size. Although this difference was not significant because of small sample sizes, Trinder (1998) was able to conclude that daytime locations may not provide an accurate reflection of foraging home ranges.

On Codfish Island kakapo will only breed in response to the mast fruiting of mature rimu (*Dacrydium cupressinum*) trees (Harper *et al.*, 2006). In lower mast years when less rimu fruit is available not all females will attempt to breed (Elliott *et al.*, 2006) presumably because of the patchiness of the fruit crops that trigger breeding (Eason *et al.*, 2006). If rimu trees were spread evenly across the island then it could be expected that in low mast years only females with large home ranges would have access to sufficient rimu trees to be able to breed. However if rimu trees occur in patches then females in small home ranges may be able to breed if they occupy an area with a high density of rimu trees. The relationship between rimu abundance and breeding will be examined in Chapter 4. In this chapter variation in foraging home ranges among adult female kakapo will be investigated to determine if it may help to explain variation in breeding attempts in years of limited rimu fruit production.

This chapter addresses two main objectives: 1) to estimate the location, size and number of core areas of foraging home ranges used by adult female kakapo on Codfish Island, and 2) to determine if home range sizes differ significantly between females that bred and those that did not during the 2005 breeding season. Home range estimates will also be used in Chapter 4 to describe habitat selection by adult female kakapo.

3.2   An overview of home range methods

There are numerous estimation techniques available to calculate home ranges, each with their own merits and limitations (Harris *et al.*, 1990; Kernohan *et al.*, 2001; Kenward *et al.*, 2003; Borger *et al.*, 2006). As each technique is based on different assumptions, it is recommended that any study of ranging behaviour include at least two analysis techniques (Kenward, 1987; Kernohan *et al.*, 2001; Horne & Garton, 2006). This study uses both minimum convex polygon (MCP) and kernel density methods to estimate kakapo foraging home ranges.

Minimum convex polygons

The MCP method is one of the oldest and simplest home range estimation techniques (Harris *et al.*, 1990; Seaman *et al.*, 1999). An MCP home range (Figure 3.1) is constructed by connecting the outermost foraging location points to form a polygon enclosing all other points (Kernohan *et al.*, 2001). The MCP method is commonly used in home range studies (Harris *et al.*, 1990; White & Garrot, 1990; Seaman *et al.*, 1999) especially when comparing home range estimates from different studies (Borger *et al.*, 2006).

The MCP method makes the assumption that the boundary of a home range is determined by the outermost locations (Borger *et al.*, 2006). But as outlying points are included, the MCP can often include large areas that are never visited by the animal (Harris *et al.*, 1990). MCP home ranges are extremely sensitive to sample size (Seaman *et al.*, 1999) with unpredictable changes in the variance of home ranges with increased sampling effort (Borger *et al.*, 2006). Results from MCP home range estimates should therefore be interpreted with caution (White & Garrot, 1990; Borger *et al.*, 2006). If a similar number of location points are used for each estimation, MCP home ranges can be reliably compared (Seaman *et al.*, 1999).

Kernel density estimation

The kernel density method of home range estimation overcomes some of the inherent problems with MCP. Developed by Worton (1989), kernel home ranges are useful as they not only predict the total area used by an animal but they also estimate the time an animal spends in any given area of its home range (Seaman *et al.*, 1999). The internal structure of a home range is predicted by placing a kernel over each point in the sample to calculate the probability of an animal occurring at each point within its range (Harris *et al.*, 1990). In effect a 'contour' map is produced for each home range indicating the likelihood of encountering the individual within specified locations (Seaman & Powell, 1996).

A user-defined band width parameter controls the width of the individual kernels and therefore determines the amount of smoothing applied to the data (Harris *et al.*, 1990; Kernohan *et al.*, 2001). If a small smoothing parameter is used the fine detail of the data can be observed but with a larger band width all local peaks and valleys are smoothed over into a single surface so that only the most prominent features are visible (Worton, 1989; Kernohan *et al.*, 2001). Determining the band width is a critical component of kernel estimations (Kernohan *et al.*, 2001) as small changes can have a large effect on range size estimates (Harris *et al.*, 1990). The least squares cross-validation (LSCV) method is the current method recommended in ecological literature for statistically estimating the smoothing parameter (Worton, 1989; Seaman *et al.*, 1999). The LSCV process examines various smoothing parameters and selects the best one for the dataset. In a fixed-kernel estimation the same smoothing parameter is used for the whole home range area (Worton, 1989).

Kernel estimations are based on the assumption that all location points are independent (Kernohan *et al.*, 2001). The method is non-parametric so the data does not have to be normally distributed (Seaman *et al.*, 1999). Unlike the earlier probabilistic ellipse methods, which assumed an animals use of space followed a normal distribution around a single centre of activity, kernel home range estimates allow for multiple centres of activity (Harris *et al.*, 1990). As kakapo generally utilise patchily available food resources within a larger foraging area (Higgins, 1999), the kernel home ranges should effectively represent their foraging areas.

3.3   Methods used in this study

Location points were collected for kakapo on Codfish Island as described in Chapter 2, using triangulations and sightings. Locations were collected in two periods: 28 March - 19 April and 3 - 30 May 2006. A total of 506 locations were collected for the 18 kakapo in this study, comprising of 482 triangulations and 24 sightings. The number of locations used for home range analysis for individuals ranged from 17 to 34, with a mean of 28.1 ± 4.5 (Appendix 2).

Two home range estimation techniques (Figure 3.1) were used in this study as they provided estimates based on different assumptions. Minimum convex polygons (MCP) were used to provide basic information on home ranges and to allow comparisons with previous studies. The kernel method was also used to provide more detailed information on the intensity of use within home ranges. The smoothing parameter used to estimate kernel home ranges was calculated using the least squares cross-validation (LSCV) technique (Seaman & Powell, 1996). Kernel home ranges were estimated using 95%, 75% and 50% core areas. Home ranges were estimated using the software Ranges6 v.1.2 (Kenward *et al.*, 2003).

3.3.1   *Comparison of home range methods*

The size of home ranges estimated using the MCP and 95% kernel methods were compared to determine if they produced similar home ranges. Home range sizes were compared in the statistical package R (R Development Core Team, 2005) using a paired t-test, after normality of the data and equality of variances had been confirmed.
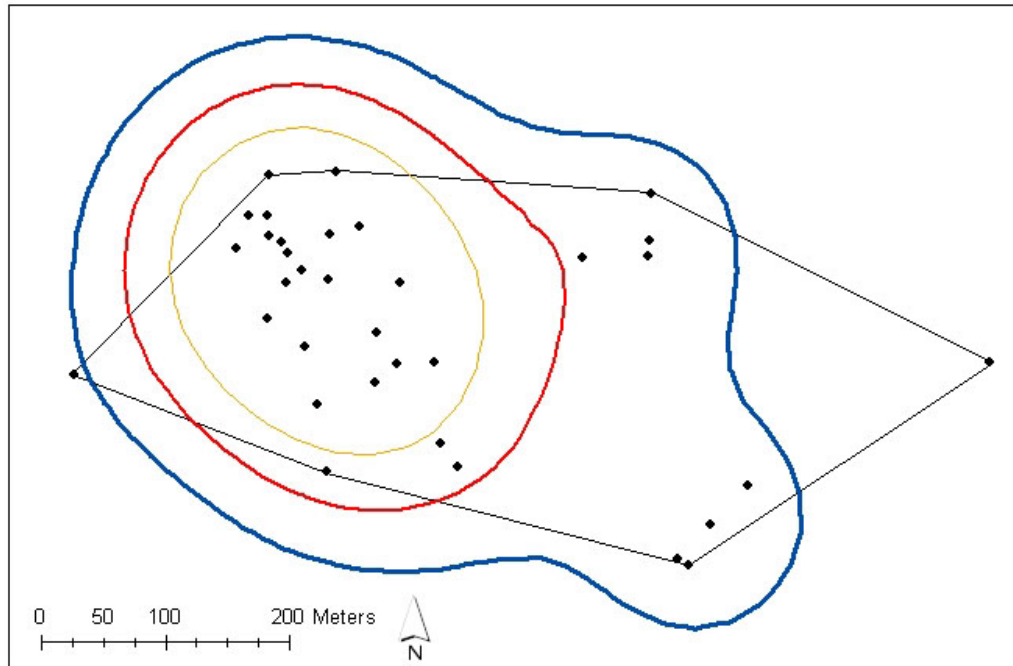
Figure 3.1. An example of the two home range estimation techniques used in this study: MCP (black polygon) and fixed kernels (95% as blue polygon; 75% as red and 50% as yellow polygon). The locations used to estimate home ranges are shown as black dots.

3.3.2   Home range asymptotes

The incremental area analysis function in Ranges6 (Kenward *et al.*, 2003) was used to produce size estimates for each MCP home range, starting with the first 3 locations collected and adding the remaining points consecutively. The number of locations required to reach a stable home range was determined by plotting the cumulative home range area against the number of location points used for each estimate until an asymptote was reached. A home range is determined to be stable at the point where it first starts to reach an asymptote (Harris *et al.*, 1990).

There are no suggestions in the literature on whether a home range is considered stable if it continues to increase in area after reaching an asymptote. For this study if a home range increased significantly in area (by more than 0.25 ha) after reaching the first asymptote, but did not reach a second asymptote, then it was assumed not to be a stable home range. If a second asymptote was reached then the home range was assumed to become stable at the start of the second asymptote.

3.3.3   Comparing home ranges between breeders and non-breeders

Mean home range sizes were compared using the statistical package R (R Development Core Team, 2005) for two groups: females that bred during the 2005 breeding season (n =10) and females that did not breed (n = 8). Two sample t-tests were used to compare mean home range sizes of MCP and 95% kernel ranges. Mean home range sizes for 75% and 50% kernels were compared using the non-parametric Wilcoxon rank sum test (unpaired), as these were not normally distributed.

Home ranges for all individuals were plotted on a map of Codfish Island to compare their location across the island, to assess any overlap between individuals and to determine the number of core areas in each female's home range. Home ranges were also plotted on a three-dimensional aerial photo of Codfish Island to describe their topography.

3.4   Results

3.4.1   Comparison of home range methods

The shape and structure of home ranges differed between the two estimation methods. MCP home ranges were more angular in shape than the smooth surfaced kernel home ranges. Kernel home ranges were often represented by two polygons rather than the single polygon of MCP ranges (Appendix 5). The size of home ranges also differed depending on the estimation method (Table 3.2). The 95% kernel home ranges were between 0.34 and 5.57 ha larger than the MCP home ranges for 14 of the 18 females studied. The mean size of 95% kernel home ranges for the 18 adult female kakapo in the study was 11.88 ± 7.07 ha, slightly larger than the mean size of MCP home ranges at 10.59 ± 7.22 ha, although this difference was not statistically significant (t = -2.033, df = 17, p-value = 0.058).

3.4.2   Home range asymptotes

Four of the 18 MCP home ranges did not reach a final stable asymptote (Table 3.1) according to the criteria adopted for this research. For example, Bella reached a first asymptote after 11 location points, but her home range then continued to increase in size and did not reach a second asymptote. Fuchsia's home range continually increased never reaching an asymptote. Jane and Solstice both reached second asymptotes at 26 and 21 points respectively, but then their home ranges continued to increase (Appendix 6).

Table 3.1. The number of locations required to reach an asymptote for MCP home ranges compared to the number of locations used in home range estimations for each adult female kakapo.

Female	No. of points required to reach an asymptote	No. of points used in MCP estimates
Alice	16	34
Bella	Not reached	25
Cyndy	21	27
Flossie	13	29
Fuchsia	Not reached	31
Heather	16	23
Jane	Not reached	33
Jean	21	27
Lisa	19	29
Margaret-Maree	25	28
Nora	16	31
Ruth	15	28
Sandra	23	34
Sarah	17	22
Solstice	Not reached	33
Sue	24	30
Suzanne	22	25
Zephyr	12	17
Mean ± Std. dev.	18.6 ± 4.2	28.1 ± 4.5
Range	12 - 25	17 - 34

The number of locations required to reach a stable home range in this study varied from 12 – 25 points. Excluding the ranges that did not become stable, the mean number of locations required to reach a final stable asymptote was 18.6 ± 4.2, around ten less locations than the average number used to estimate home ranges (Table 3.1).

3.4.3   Home range locations

Foraging home ranges for the 18 adult female kakapo in this study were located in two areas on either side of the main valley on Codfish Island (Figure 3.2). Females that bred in the 2005 breeding season were located on both sides of the island, as were females that did not breed (Figure 3.2).
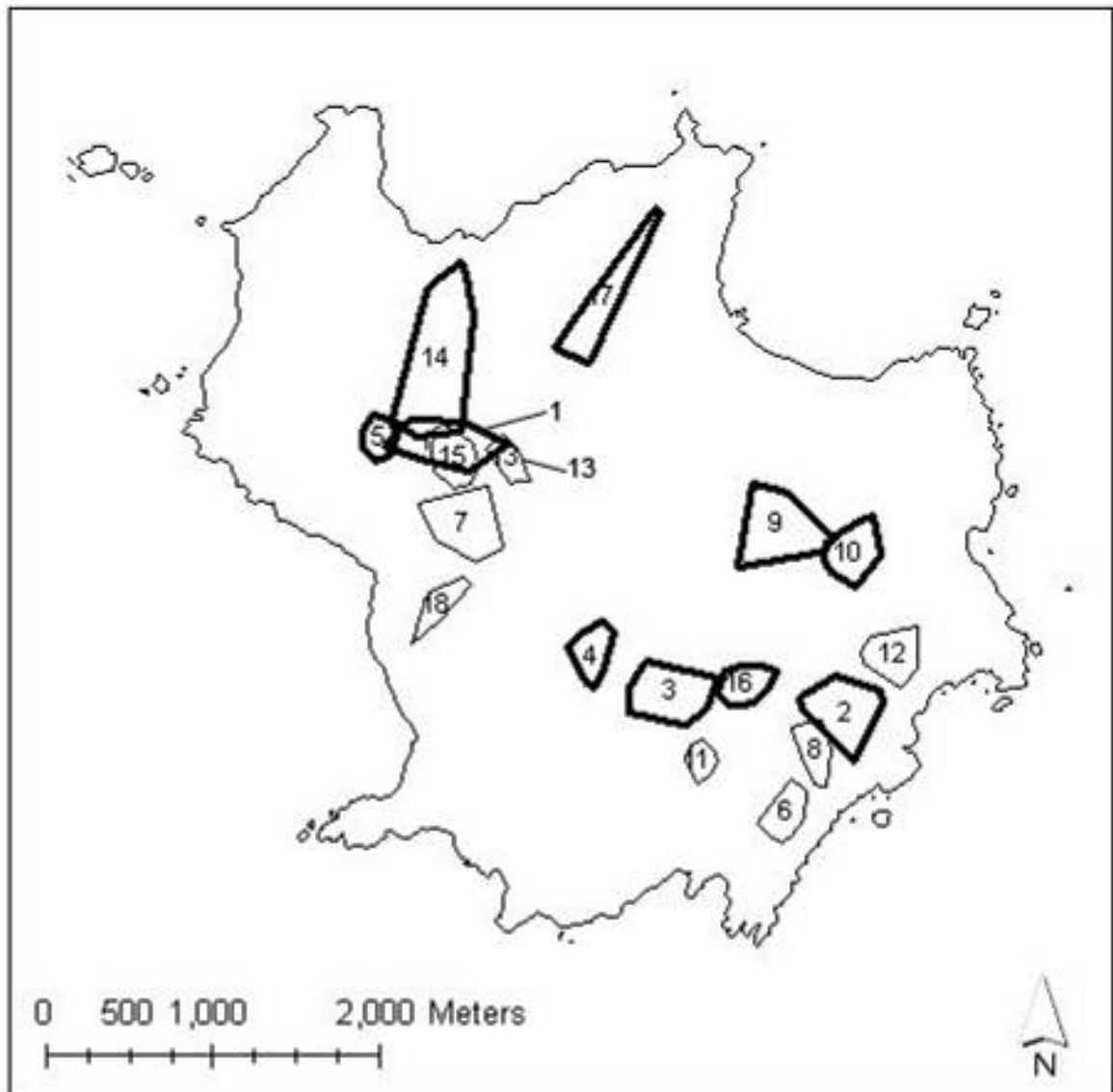
Figure 3.2. MCP foraging home ranges estimated for 18 adult female kakapo on Codfish Island. Dark polygons represent females that bred in the 2005 breeding season and light polygons represent females that did not breed. Home ranges are labelled as per Table 3.2 to represent individual females.

3.4.4   Topography of home ranges

The foraging home ranges of adult female kakapo on Codfish Island were mostly located in high elevation plateau areas of the island, although there were a few exceptions (Figure 3.3). One female Flossie (4, two core areas) was located in the upper area of the main valley, in a lower elevation area than most other females. Sarah (14, two core areas) was located in the other main valley on the island. Suzanne (17) was located mostly along a ridge, as was Zephyr (18) until she moved to a steeper coastal cliff region later in the study. Heather (6) was also located nearer the coast on flatter terrain. The topography utilised by adult female kakapo will be investigated in more detail in Chapter 4.
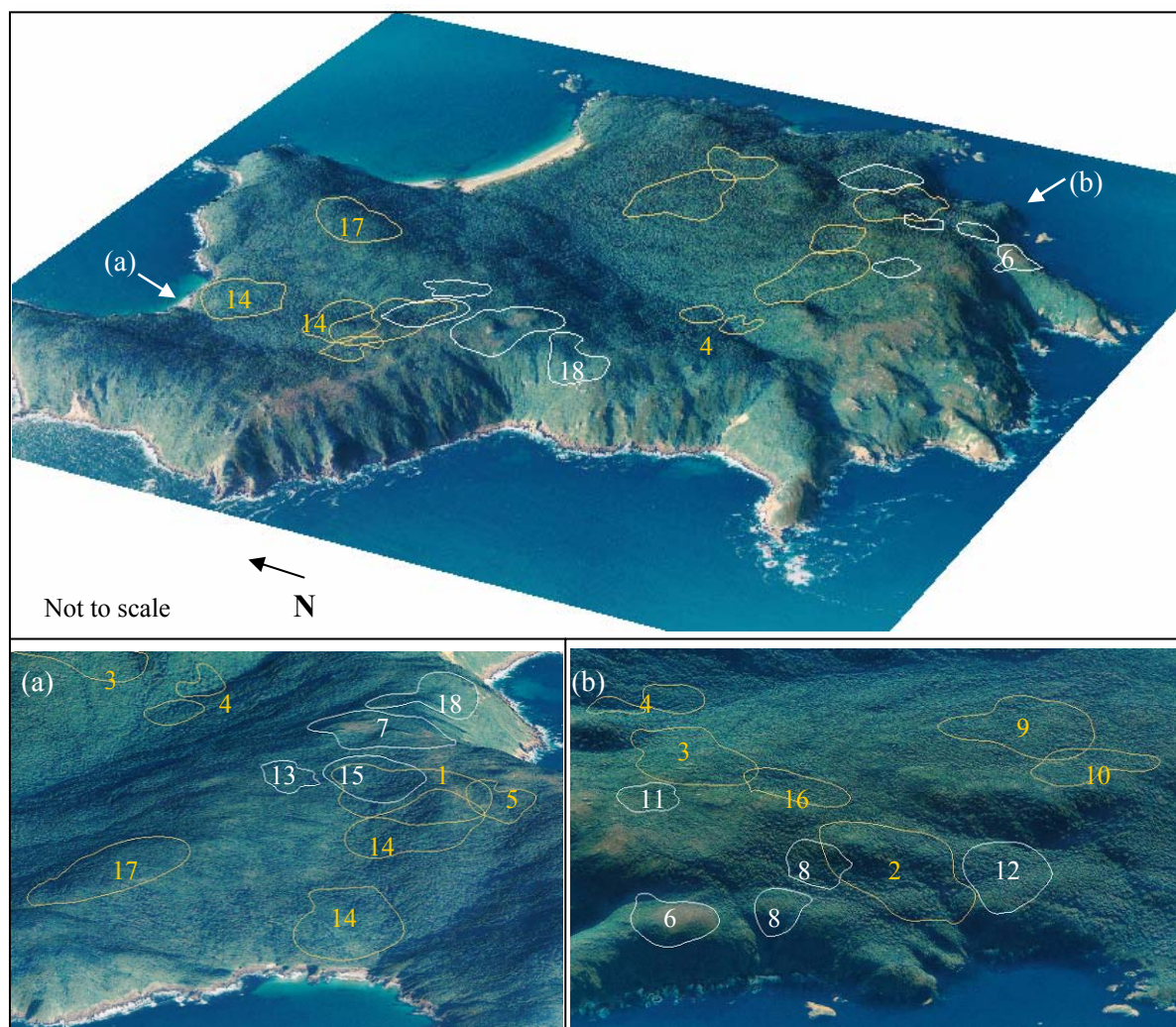
Figure 3.3. Topography of 95% kernel foraging home ranges for 18 adult female kakapo displayed on a 3D aerial photo of Codfish Island (top image). Insets (a) and (b) show enlargements of home range locations on the north-west side and south-east sides of the island respectively, as viewed from the locations shown on the main image. Females are labelled as per Table 3.2, with females that bred in the 2005 season shown in yellow and females that did not breed in 2005 shown in white.

3.4.5   Home range structure

In contrast to the MCP method, the kernel estimation method can result in home ranges
containing more than one polygon. Three adult females had their 95% kernel home range
estimated as two core areas: Flossie (4), Sarah (14) and Jean (18) (Figure 3.4).
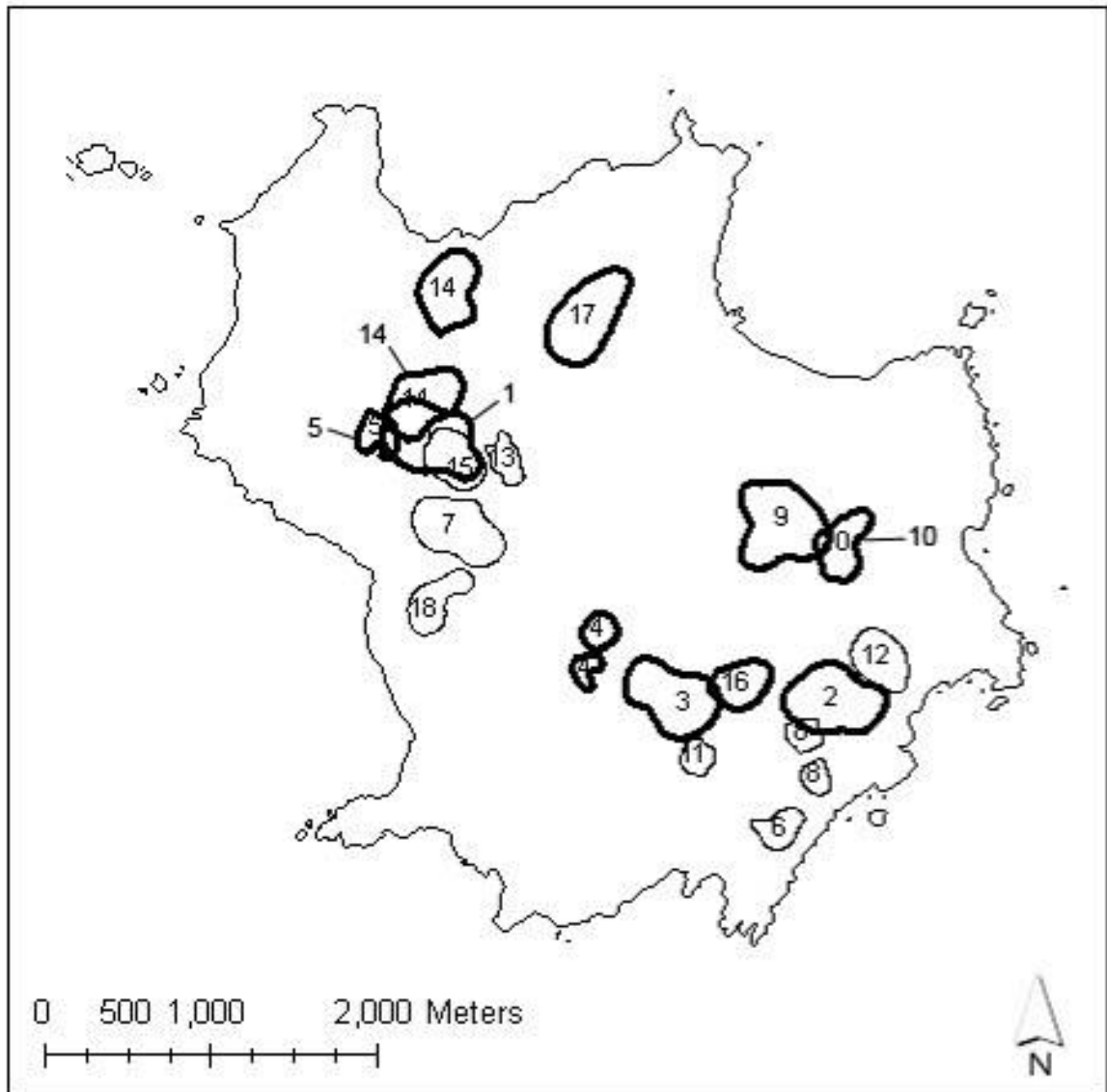
Figure 3.4. Foraging home ranges estimated using the 95% kernel method for 18 adult female kakapo
on Codfish Island.   Dark polygons represent females that bred in the 2005 breeding season and light
polygons represent females that did not breed. Home ranges are labelled as per Table 3.2 to represent
individual females. *Note*: three females had home ranges as two kernels (4, 8 and 14).

The internal structure of foraging home ranges was estimated using 75% and 50% kernel home ranges. The 75% kernels were interpreted as the outer core areas used by females. Five females had their outer core area represented by two polygons: Flossie (4), Jane (7), Jean (8), Sarah (14) and Zephyr (18) (Figure 3.6).
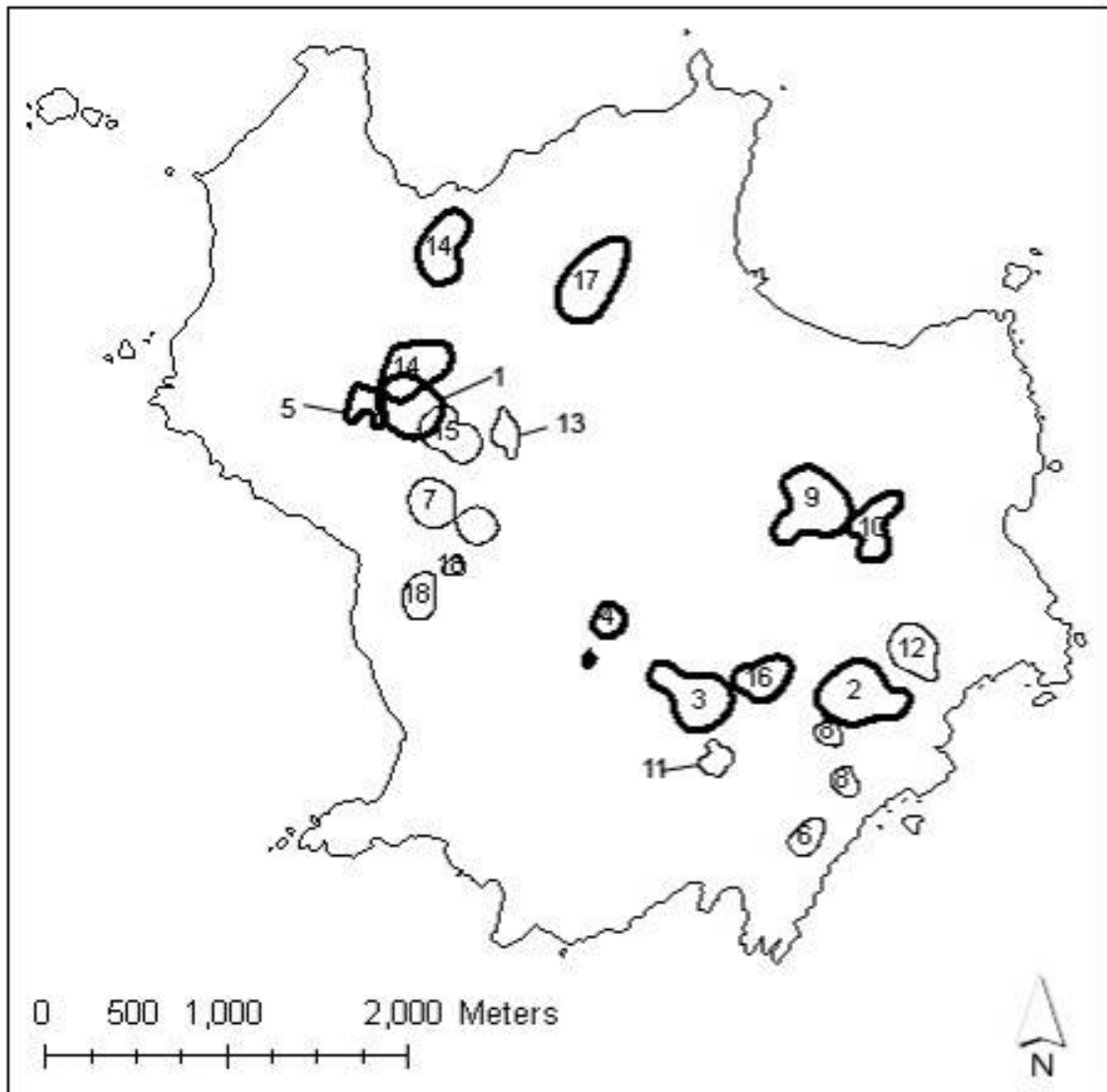
Figure 3.5. Foraging home ranges estimated using the 75% kernel method for 18 adult female kakapo on Codfish Island, labelled as per Table 3.2. Dark polygons represent females that bred in the 2005 breeding season and light polygons represent females that did not breed. *Note:* five females had their 75% kernel home range represented by two polygons (4, 7, 8, 14 and 18).

The 50% kernel home ranges were interpreted as the core foraging areas used by adult female kakapo. Six females had their 50% kernel home ranges represented as two polygons: Jane (7), Jean (8), Sarah (14), Solstice (15) and Zephyr (18) (Figure 3.6).
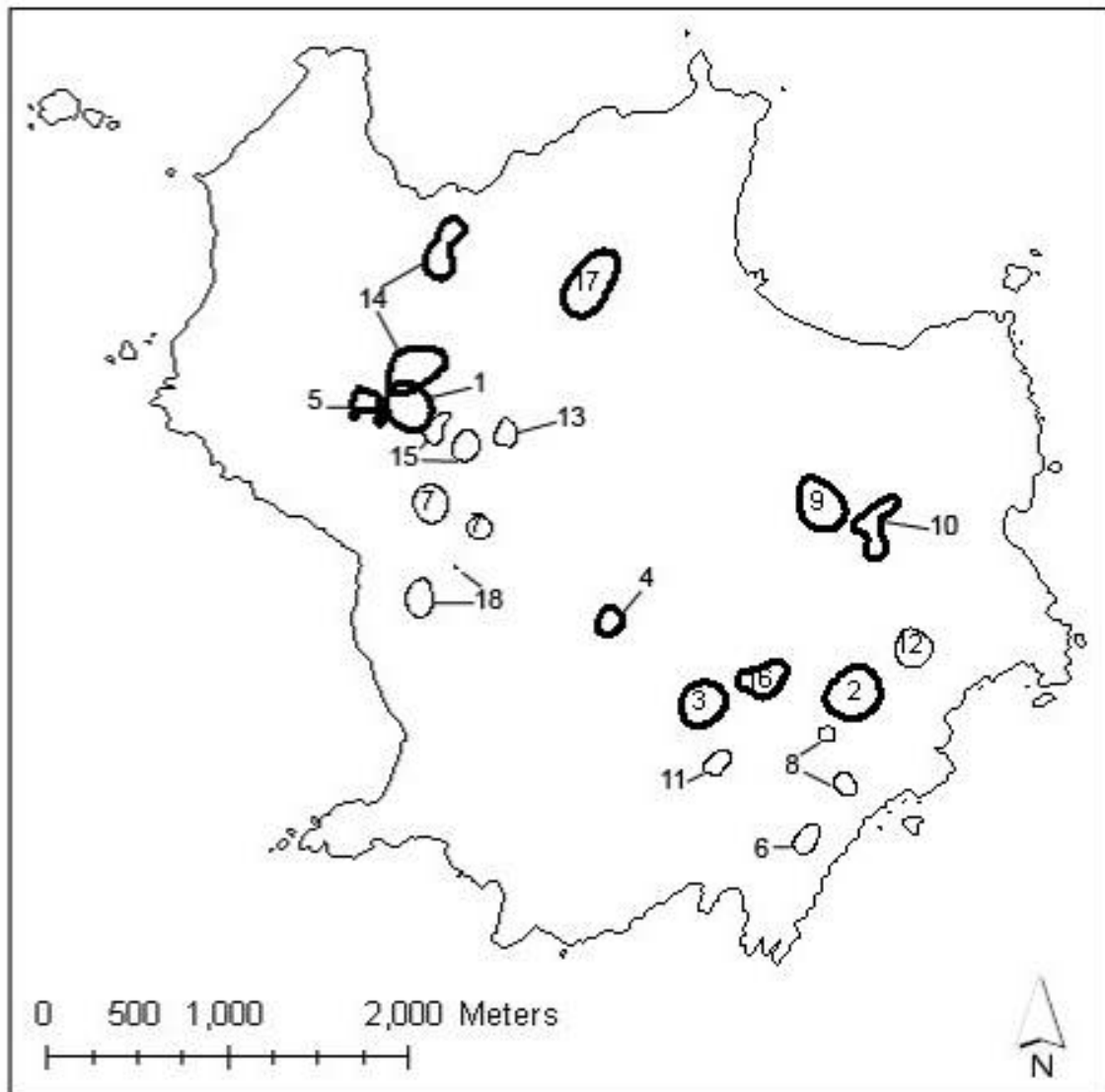
Figure 3.6. Foraging home ranges estimated using 50% kernels for 18 adult female kakapo on Codfish Island. Dark polygons represent females that bred in the 2005 breeding season and light polygons represent females that did not breed. Home ranges are labelled as per Table 3.2 to represent individual females. *Note:* five females had their home range represented by two kernels (7, 8, 14, 15 and 18).

3.4.6   Overlap between home ranges

There was some overlap in MCP home ranges for nine of eighteen (50%) females studied, although the majority of overlaps were minor. There was one exception, with the female Alice whose MCP home range overlapped considerably with Solstice and slightly with three other females (Figure 3.2). Home ranges estimated by 95% kernels overlapped for eleven of the eighteen (61%) females studied, although again most of these overlaps were small with the exception of Alice (Figure 3.4).

The only overlap of 75% kernel home ranges was with Alice's home range that overlapped with Solstice, Sarah and Fuchsia. There were no other overlaps in 75% kernel home ranges although several females had close boundaries with each other (Figure 3.5). Using 50% kernels, there was only one small overlap that occurred between Alice and Sarah's home ranges (Figure 3.6).

3.4.7   Size of foraging home ranges

Home range size was variable for both the MCP and kernel methods, as shown by the large range and standard deviation of means (Table 3.2). The size of MCP home ranges for all birds in the study varied from 3.13 - 32.95 ha, with a mean of 10.59 ha and a standard deviation of 7.22 ha. The size of 95% kernel home ranges varied from 3.47 - 26.51 ha, with a mean size of 11.88 ± 7.07 ha.

The largest home range estimated using the MCP method was Sarah's at 32.95 ha. This was almost twice the size of the next largest home range, Lisa's at 17.96 ha. Sarah's home range was ten times larger than the smallest home range, a 3.13 ha home range used by Nora. Three other small home ranges of four to five hectares were used by Fuchsia, Zephyr and Jean (Table 3.2). The size of home ranges does not appear to be correlated with their location on the island, with both small and large home ranges occurring on either side of the main valley (Figure 3.2).

Table 3.2. The size of MCP and kernel home ranges for females that bred and those that did not breed in the 2005 breeding season and the number (N) of locations used for home range estimates. The ID values are used to identify home range polygons in figures in this chapter.

ID	Females	N	MCP (ha)	95% kernel (ha)	75% kernel (ha)	50% kernel (ha)
Breeding females in 2005						
1	Alice	34	14.36	19.93	9.21	5.10
2	Bella	25	14.81	19.02	12.08	6.53
3	Cyndy	27	14.76	18.02	10.28	4.70
4	Flossie	29	6.37	6.06	2.71	1.65
5	Fuchsia	31	4.26	4.71	3.20	1.78
9	Lisa	29	17.96	21.17	12.12	5.59
10	Margaret-Maree	28	9.26	8.98	6.18	3.86
14	Sarah	22	32.95	26.51	16.66	9.71
16	Sue	30	6.16	7.84	5.42	3.59
17	Suzanne	25	13.83	17.97	11.36	6.94
Non-breeding females in 2005						
6	Heather	23	6.60	4.99	2.86	1.69
7	Jane	33	14.49	16.61	9.28	4.47
8	Jean	27	5.85	6.32	3.42	1.78
11	Nora	31	3.13	3.47	2.41	1.40
12	Ruth	28	8.91	9.61	6.23	3.38
13	Sandra	34	4.09	4.43	2.71	1.44
15	Solstice	33	7.54	9.95	7.05	3.52
18	Zephyr	17	5.21	8.30	4.82	2.44
Mean ± standard deviation:						
-All females		28.1 ± 4.5	10.59 ± 7.22	11.88 ± 7.07	7.11 ± 4.17	3.87 ± 2.29
-2005 breeders		28.0 ± 3.4	13.47 ± 8.24	15.02 ± 7.47	8.92 ± 4.46	4.95 ± 2.44
-2005 non-breeders		28.2 ± 5.9	6.98 ± 3.55	7.96 ± 4.24	4.85 ± 2.48	2.52 ± 1.15
Range for all females		17 – 34	3.13 – 32.95	3.47 – 26.51	2.41 - 16.66	1.40 – 9.71

The size of 75% kernel home ranges varied for all birds in the study from 2.71 - 16.66 ha, with a mean size of 7.11 ± 4.17 ha. The size of 50% kernel home ranges varied from 1.40 - 9.71 ha, with a mean size of 3.87 ± 2.29 ha (Table 3.2).

The size of 2006 foraging home ranges was compared between females that bred and those that did not breed in the 2005 breeding season (Table 3.2). For three of the four home range estimation techniques, foraging home ranges were significantly larger, almost twice the size, for females that bred compared to females that did not breed in 2005 (Figure 3.7). The mean size of MCP ranges for females that bred in 2005 was 13.47 ± 8.24 ha, significantly larger than the mean size for non-breeding females of 6.98 ± 3.55 ha (t = 2.2466, df = 12.778, p-value = 0.043). The mean size of 95% kernel home ranges for females that bred in 2005 was 15.02 ± 7.47 ha, significantly larger than the mean size for females that did not breed, 7.96 ± 4.24 ha (t = 2.376, df = 16, p-value = 0.030).
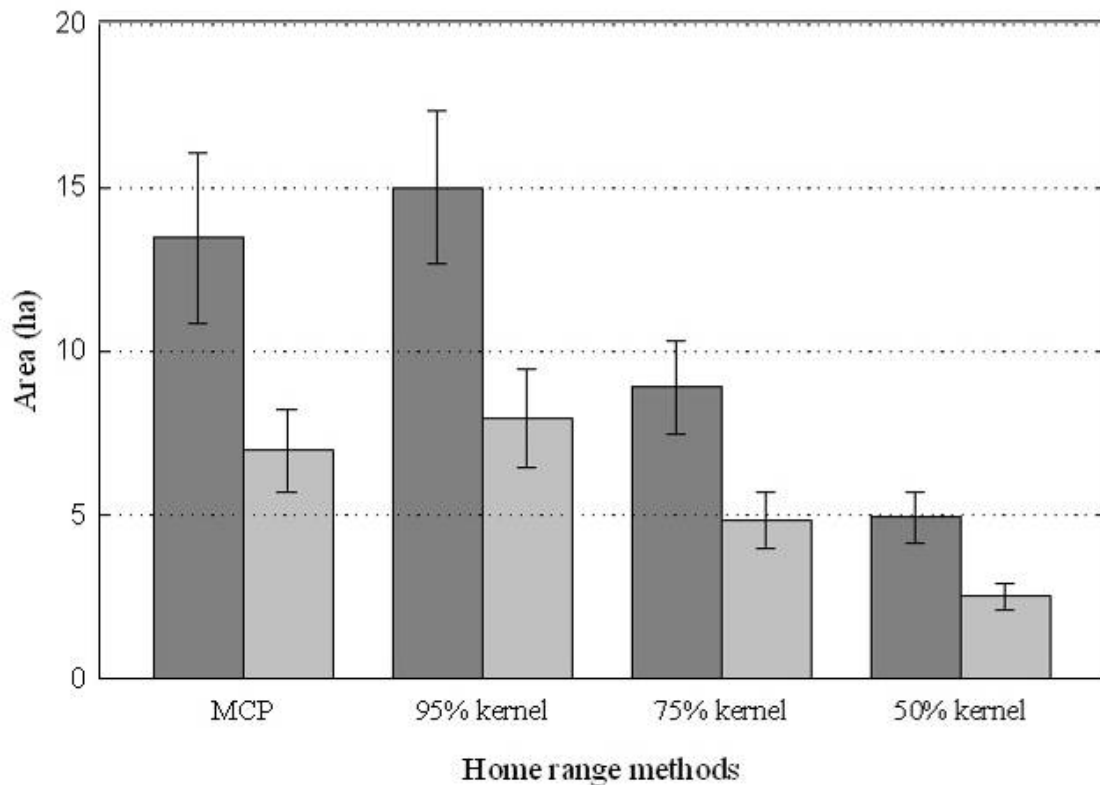
Figure 3.7. For each of the home range methods, the size of foraging home ranges is compared for breeders (dark bars) and non-breeders (light bars) during the 2005 breeding season. Variation in the sizes is shown using standard error bars.

The mean size of core home ranges estimated using 50% kernels was 4.95 ± 2.44 ha for females that bred in 2005, significantly larger than the core area of 2.2 ± 1.15 ha for females that did not breed in 2005 (W = 67.5, p-value = 0.01638, n = 18). The size of 75% kernels tended to be larger for 2005 breeders than for non-breeders, with mean home range sizes of 8.92 ± 4.46 ha and 4.85 ± 2.48 ha respectively, however this difference was not statistically significant (W = 61.5, p-value = 0.062).

3.5   Discussion

3.5.1   Comparison of home range methods

Foraging home ranges differed in appearance and size depending on which estimation technique was used. When overlaid on the location points used to estimate each home range (Appendix 5), 95% kernels and MCP home ranges both appeared to overestimate the size of home ranges. The MCP method has been widely criticised by a number of authors for its overestimation of home ranges as it uses all location points in the estimate, including outliers

(White & Garrot, 1990; Borger *et al.*, 2006). The 95% kernel method has also been known to overestimate home ranges, especially when small sample sizes are used (Seaman *et al.*, 1999).

The 75% kernel home range appears to be the most realistic representation of foraging home ranges for kakapo in this study. In most cases the 75% kernel home range border closely resembled the area covered by the location points but excluded any major outliers (Appendix 5). The 50% kernel home range was useful for estimating core area(s) as it includes only the central foraging locations. The 75% kernel home range estimate will be used for further analysis in Chapter 4 as it provides a realistic and probably conservative estimate of foraging home ranges.

3.5.2   Home range asymptotes

It was difficult to interpret the point at which home ranges became stable. Home range size may have reached an asymptote, but when additional points were added the area sometimes increased reaching a second asymptote. If no additional location data had been collected after the first asymptote was reached then one could have assumed that the home range had become stable. Due to confusion over interpretation of asymptotes, their usefulness in home range studies could be questioned. Home range sizes are likely to expand or retract as kakapo make use of seasonally available food sources or shift in response to annual climatic changes (Moorhouse, 1985; Walsh *et al.*, 2006). When comparing home range estimates between individuals it may be more important to ensure that a similar number of location points are used for each estimate than to determine if each home range reaches an asymptote (Seaman *et al.*, 1999).

3.5.3   Structure of home ranges

As the kernel method of home range estimation calculates the probability of an animal occurring at each point within its range, kernels are able to estimate the structure of a home range, defined as the number of discrete areas that an animal utilises (Harris *et al.*, 1990). During this study three females had their 95% kernel home range split into two polygons and a number of others had their 75% and 50% kernel home ranges represented as more than one polygon. The number of foraging areas was not related to breeding status, as a similar number of breeding and non-breeding females from 2005 utilised two foraging areas in at least one of their kernel home ranges.

3.5.4   Home range locations and topography

Females that bred in 2005 and those that did not had foraging home ranges located on either side of the main valley on Codfish Island, suggesting that there was no preference for either side of the valley for breeding. The topography of the island may have influenced the location of adult female kakapo, as no females were located on the steep coastal cliffs or lower elevation areas of the main valley. Both breeders and non-breeders mostly occurred in higher elevation areas, with most females being located on the plateau areas of the island (Figure 2.3). The topography used by adult female kakapo will be addressed in more detail in Chapter 4.

There was a general trend amongst females that location points collected in May were at lower elevations than those collected in March and April. This was most evident in females that had kernel home ranges with two polygons, where the lower elevation polygon was only utilised in the later periods of the study (eg. Flossie). Some females with two kernels mostly used the lower elevation kernel during May but still made some visits to higher elevation feeding areas in the later period of the study (eg. Sarah and Zephyr). In some cases females whose kernel home ranges were represented by one polygon (eg. Suzanne) had location points that were collected later in the study at lower elevations than the earlier points. The use of lower elevation areas in the later periods of the study may be related to a drop in air temperature, as the mean minimum and maximum air temperatures recorded at sea level on Codfish Island were significantly lower in May than they were in March/ April of 2006 (Appendix 7).

3.5.5   Overlap between home ranges

As there was some overlap of 95% kernel and MCP home ranges between females, but mostly no overlap of 75% and 50% kernels, females appear to use wider foraging areas that may occasionally overlap and core areas that are mutually exclusive. Previous research has also found some overlap between kakapo feeding areas (Merton *et al.*, 1984; Moorhouse & Powlesland, 1991). Kakapo are not thought to be territorial as they do not fight to defend their foraging areas, but they are known to vocalise their whereabouts (Powlesland *et al.*, 1992) perhaps to ensure that their core foraging areas do not overlap.

Although the home ranges of adult female kakapo in this study did not overlap considerably, it is quite possible that their home ranges overlapped with male or juvenile kakapo that were also present on Codfish Island, although this was not possible to assess in this study. A previous study on Codfish Island found considerable overlap of 50% kernel and MCP ranges between juvenile and adult kakapo (Farrimond *et al.*, 2006). It is perhaps less likely that the home ranges of adult females and adult males would overlap compared to juveniles, as both sexes may be less tolerant of other adults in their home range.

3.5.6   *Size of foraging home ranges*

There was a large variation in home range sizes estimated for adult female kakapo during this study, with the largest home range being almost ten times larger than the smallest. Similar large variations have been recorded in previous studies where home range sizes varied from 15 – 50 ha on Stewart Island (Best & Powlesland, 1985); 21 – 38 ha on Little Barrier Island (Moorhouse, 1985); 0.8 – 11.4 ha on Pearl Island (Trinder, 1998); and 0.8 – 29 ha (Trinder, 1998) and 2 – 145 ha (Walsh *et al.*, 2006) on Maud Island. The mean home range size estimated for adult female kakapo during this study was similar to the mean size of home ranges estimated for adult female kakapo in previous studies, both on Codfish Island and on other islands around New Zealand (Table 3.3), with the exception of Maud Island where larger home ranges were recorded (Walsh, 2002) probably because of the exotic vegetation on the island.

Table 3.3. Home ranges sizes estimated for adult female kakapo in previous studies

Author	Location	Time of year	No. of females	100% MCP ± SD (ha)	95% kernel ± SD (ha)
Moorhouse (1985) [D]	Little Barrier Is	March 1983 – Sept 1984	3	12.00 ± 3.79 *	
Walsh (2002) [N]	Maud Island	Dec 2000 – Jan 2001	9	27.85 ± 27.4	54.76 ± 39.68
Trinder (1998) [N]	Maud Island	June – July 1998	6	10.52 ± 7.93	−
Trinder (1998) [N]	Pearl Island	May 1998	4	11.47 ± 8.08	−
Farrimond (2003) [B]	Codfish Island	Sept 2001 – Jan 2002	13	14.01 ± 11.0	19.51 ± 25.25
Farrimond (2003) [B]	Codfish Island	Sept 2002 – Jan 2003	13	15.55 ± 7.34	13.80 ± 6.25
This study [N]	Codfish Island	March – May 2006	18	10.59 ± 7.22	11.88 ± 7.07

Notes: N – from night data only;   D – from day data only;   B –from both night and day data
            * – modified minimum area home range method (maximum sizes recorded)

Females that bred in the 2005 breeding season had foraging home ranges in 2006 that were on average two times larger than the foraging home ranges used by females that did not breed in 2005. There have been no previous studies comparing home range sizes between breeding and non-breeding females in the same year, so these significant results can not be compared with previous studies. However home range size has been investigated for females over two consecutive summers immediately prior to the 2002 breeding season (September 2001 – January 2002) and after the breeding season when females had chicks (September 2002 – January 2003). Home range size did not change significantly between these two years, suggesting that rearing young does not require expansion of a female's home range (Farrimond *et al.*, 2006).

There are a number of reasons that could potentially explain why both foraging and roosting home ranges vary in size between individual kakapo, not only in this study but also on a number of other islands around New Zealand. Firstly, an individual preference for different home range sizes should not be discounted, as kakapo are parrots that are well renowned for acting idiosyncratically. For example the adult female Sarah was observed to travel long distances. Several days after supplementary feeding stopped in late March 2006, Sarah disappeared from her usual home range and was located three km away on the other side of the island. Although this location was not included in home range estimates as it was probably influenced by supplementary feeding, this incident suggests that Sarah has a tendency to travel long distances and may help to explain why she had a very large home range compared to other females.

Home range size may also be influenced by the age of an animal. The actual age of most adult female kakapo is unknown as they were captured on Stewart Island as adults, but the date of capture may provide some indications of age. The minimum age of females in this study based on the date of their first capture, ranges from 9 to 26 years with a mean minimum age of 20 ± 5 years (Appendix 1). However no relationship was observed between mean minimum age and home range size, as both relatively old and young females had large and small home ranges. A correlation may occur between the actual age of females and home range size, but this will only be possible to assess as more adult females of known age are added to the kakapo population.

It is also possible that the size of a female's home range may depend on her general health. The National Kakapo Team regularly monitor the health of kakapo on Codfish Island. Two female kakapo (Jane and Sandra) have restricted mobility in one leg, but these injuries are not thought to be disabling as they still wander long distances and climb trees (D. Eason, pers. comm.). These injuries are also unlikely to have influenced their foraging home range sizes, as Jane had a reasonably large home range compared to other females and Sandra had a small home range that was within the range of other small home ranges used by non-injured females (Table 3.3). The general health of all females is thought to be good and not thought to restrict their ability to breed or influence their home range size (D. Eason, pers. comm.).

The physical condition of female kakapo is also monitored by recording the weight of individuals, especially prior to and during breeding seasons. Female kakapo gain weight each year prior to the breeding season, even if it is not a breeding year, presumably so they are in good condition to produce eggs and incubate effectively (Eason *et al.*, 2006). As it is thought that female kakapo are required to reach a critical weight threshold to breed (Elliott *et al.*, 2001) it is possible that the weight of females prior to the breeding season may influence their ability to breed, although this was outside the scope of this study.

The number of years that a female has been resident on Codfish Island may also influence the size of her home range. It could be expected that females that were first transferred to the island would occupy larger areas as they had the first opportunity to establish their home ranges. Up until March 2006 when this study commenced, adult female kakapo had been continually resident on Codfish Island for periods of between less than one year and up to seven years (Appendix 1). There appeared to be no correlation between time on the island and home range size, as females resident for relatively short and long periods had both large and small home ranges.

It is also possible that home range size may vary depending on habitat quality. It could be expected that an animal with good quality habitat may only need a small home range to breed, whereas an animal with poor quality habitat may need a larger home range to obtain all the resources required to be able to reproduce. As kakapo on Codfish Island require mature rimu trees to breed, it could be expected that the quality of habitat required for breeding may be dependent on the abundance of mature rimu trees in the vegetation. This hypothesis will be tested in Chapter 4 where habitat selection of kakapo on Codfish Island will be investigated.

Chapter 4   Habitat Selection

4.1   Introduction

The environment in which an animal lives is defined as its habitat and is characterised by the physical and living components of the ecosystem (Allaby, 1999). Habitat selection is the notion that, instead of occurring randomly across a landscape, a species selects habitat types in which to live that contain the resources required for its survival (Alcock, 1989). Whenever possible, animals are thought to select for optimal habitat with high quality resources. If animals occur in less than optimal habitats, they may be able to obtain sufficient resources to survive but their physical health and/ or reproductive success may be affected (Manly *et al.*, 1993).

Understanding habitat selection is an important research goal for many conservation projects. Knowledge of what resources constitute an optimal habitat is important when making management decisions about where a species should be protected, which populations are most likely to benefit from management or if some populations are living in marginal habitat (Engler *et al.*, 2004; Lindenmayer & Burgman, 2005). Habitat selection is particularly important to study with remnant populations that may not be living in optimal conditions or for populations that have been transferred to new sites from their original habitat. Identifying optimal habitats required for a species to survive and breed effectively should be a key management goal for rare and endangered species (Primack, 1993; Brotons *et al.*, 2004).

Breeding performance has been shown to vary across habitat gradients for a number of bird species (Martin, 1987). For example a study of blue tits (*Parus caeruleus*) found that individuals in rich habitats with an abundant food supply raised more chicks than those in poor quality, food limited habitats (Tremblay *et al.*, 2003). The quality of foraging habitat occupied by breeding pairs was found to be one of three habitat characteristics that were important in defining suitable habitat for breeding in a study of red-backed shrike (*Lanius collurio* L.) in Belgium (Titeux *et al.*, 2007).

In New Zealand habitat selection by kakapo (*Strigops habroptilus*) has previously been studied on two islands in the northern part of the country: Little Barrier Island (Moorhouse, 1985) and Maud Island (Walsh *et al.*, 2006). However these studies are no longer relevant for kakapo management as the only known kakapo populations now occur on two islands in southern New Zealand where the vegetation is distinctly different to their northern

counterparts. The only breeding population of kakapo currently resides on Codfish Island (Whenua Hou), near Stewart Island. Research has shown that adult female kakapo will only breed when there is an abundant supply of rimu (*Dacrydium cupressinum*) fruit available and in years when the rimu fruit is limited, only some adult females will attempt to breed (Elliott *et al.*, 2006). However what is not known about kakapo breeding is if variation in breeding attempts between females in low rimu mast years is correlated with spatial patterns in habitat quality.

A key goal of kakapo conservation is to increase the number of females that breed in each rimu fruiting year (Cresswell, 1996). Supplementary feeding has helped to bring some females up to the critical weight threshold required to breed, but it has not been sufficient to substantially increase the proportion of females that breed in low rimu mast years (Elliott *et al.*, 2001). The future management of kakapo will benefit from an understanding of habitat selection by kakapo in southern vegetation types and why only some females are able to breed in low rimu mast years on Codfish Island. The aim of this study was to investigate habitat selection by adult female kakapo on Codfish Island and to determine if habitat use varied between breeding and non-breeding females in a low rimu mast year.

4.2   Methods

4.2.1   Study site

The study area of Codfish Island (Whenua Hou) is located 3 km north-west of Stewart Island in southern New Zealand. Gazetted a nature reserve, Codfish Island is around 1475 hectares in area, 5 km across at its widest point and rises to a maximum elevation of 292 m. The island is characterised by two main valleys that run into bays on the north and east of the island, two high elevation areas on the north and south of the island and steep coastal cliffs along the south-western coastline. A more detailed description can be found in Chapter 2.

4.2.2   Data Collection

A total of 506 locations were collected for 18 adult female kakapo on Codfish Island between 28 March – 30 May 2006. Locations were estimated using triangulations and sightings as described in Chapter 2. The number of location points estimated for each individual ranged from 17 to 34, with a mean of 28.1 ± 4.5 (Appendix 2). Females were located on both sides of the island in a range of terrains (Figure 4.1).
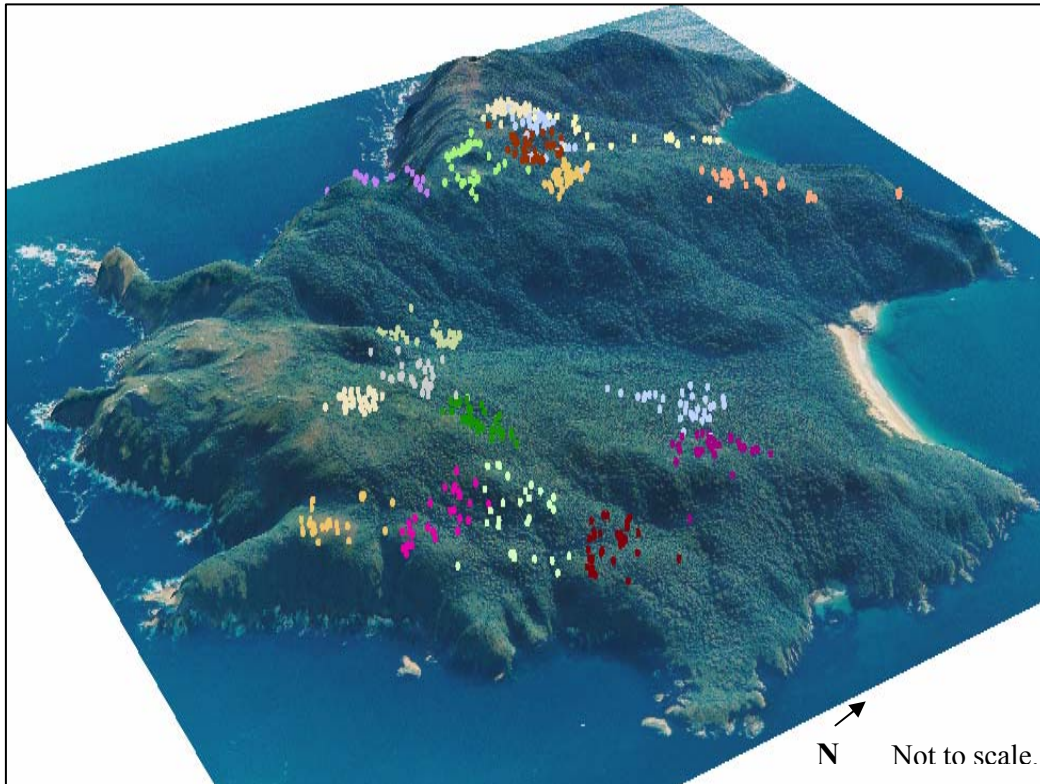
Figure 4.1. Locations for 18 adult female kakapo overlaid on a 3D aerial photo of Codfish Island. Locations for each individual female are represented by different colours.

4.2.3   Vegetation on Codfish Island

The vegetation on Codfish Island represents a relatively untouched southern lowland forest ecosystem similar to that of nearby Stewart Island (McClelland & Roberts, 1998).   The vegetation is dominated by podocarp-broadleaf forest but also contains coastal daisy scrub, kamahi forest and manuka-pakahi scrub as described in more detail in Chapter 2.

Raw vegetation map
The location of different vegetation types on Codfish Island was mapped during 2005 by Lars Brabyn (Waikato University) using aerial photos, infra-red images and ground surveys (Figure 4.2).   Sixteen vegetation types were recorded and described according to the main canopy and sub-canopy species present, with some reference made to the understorey vegetation (Appendix 8).   The area of each vegetation type on the island was calculated using the Geographic Information Systems (GIS) program ArcGIS version 9.1 (ESRI, 2005). Vegetation types occupied between less than 1% and up to 20% of the island's area (Appendix 9).   The five most dominant vegetation types (and the percentage of the island they occupied) were coastal daisy (20%), rimu-miro (17%), podocarp-mixed-stunted (12%),

rata-podocarp-short (11%) and kamahi-podocarp (10%).   The remaining eleven vegetation types occupied 5% or less of the islands area (Appendix 9).
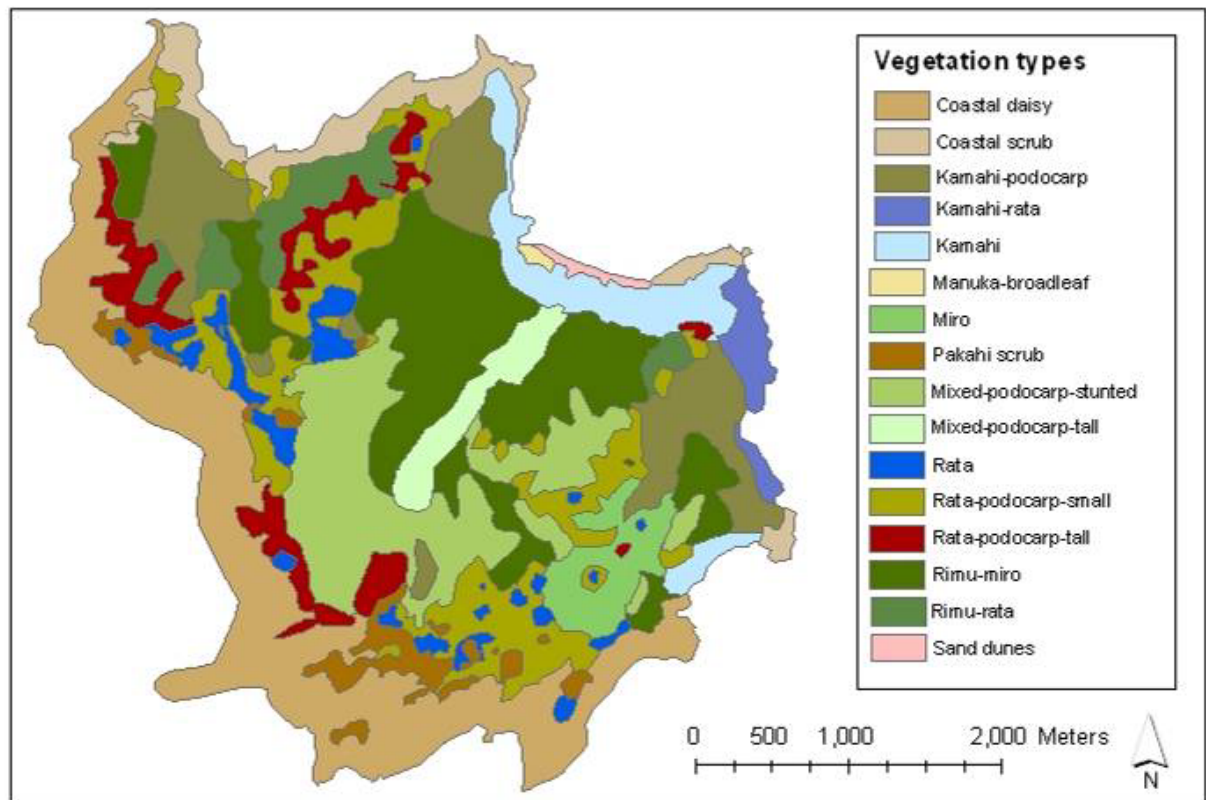
Figure 4.2. Map of Codfish Island showing the 16 vegetation types recorded during a survey by Lars Brabyn, Waikato University, in 2005. Vegetation types are described in Appendix 8.

Aggregated vegetation map

As there were too many vegetation classes in the raw vegetation map to include in subsequent analysis, an aggregated vegetation map (Figure 4.3) with five vegetation classes was created. Vegetation classes were aggregated based on the similarity of the species and the quantity of the vegetation type on the island, with all vegetation types occupying 10% or less of the islands area included as an *other* class (Table 4.1).   Each of the five vegetation classes represented between 12% and 32% of the islands area, with the *other* class representing the largest area (Table 4.4). Coastal daisy-pakahi scrub was the second most common vegetation type occupying 23% of the island's area, followed by rimu-miro (20%), rata-podocarp-short (13%) and mixed-podocarp-stunted (12%).

Table 4.1. Raw vegetation classes combined to create the aggregated vegetation map.

Aggregated Vegetation Classes	Raw Vegetation Classes
Rimu-miro	Miro-rimu
	Rimu-miro
Rata-podocarp	Rata
	Rata-podocarp-short
Mixed-podocarp-stunted	Podocarp-mixed-stunted
Coastal daisy-pakahi scrub	Coastal daisy
	Pakahi scrub
Other	Coastal scrub
	Kamahi
	Kamahi-rata
	Rimu-rata
	Kamahi-podocarp
	Rata-podocarp
	Podocarp-mixed-tall
	Manuka-broadleaf
	Sand dunes

Rimu-abundance map

As adult female kakapo rely on rimu fruit and seeds to feed their chicks (Cottam *et al.*, 2006), it could be expected that the number of mature rimu trees available to females may influence their ability to breed. To test this hypothesis a vegetation map was created that could be used for later analysis showing the likely abundance of mature rimu trees across the island (Figure 4.5). The rimu-abundance map was based on the descriptions of the sixteen vegetation types in the raw vegetation map (Appendix 8). The raw vegetation classes were grouped into three levels of rimu abundance: 1) high rimu abundance, 2) moderate rimu abundance and 3) no rimu expected to be present in the vegetation, as shown in Table 4.2 below.

Table 4.2. Abundance of mature rimu trees in the vegetation types from the raw vegetation map.

Rimu abundance classes	Raw Vegetation Classes
High rimu	Miro-rimu
	Rimu-miro
	Podocarp-mixed-stunted
	Podocarp-mixed-tall
	Rimu-rata
Moderate rimu	Rata-pod-short
	Kamahi
	Kamahi-rata
	Kamahi-podocarp
	Rata-podocarp
No rimu	Rata
	Coastal daisy
	Coastal scrub
	Pakahi scrub
	Manuka-broadleaf
	Sand dunes

4.2.4   Exploratory analysis of kakapo vegetation use

Firstly, exploratory analysis was conducted to describe the vegetation-type composition of adult female kakapo home ranges. The 75% kernel foraging home ranges estimated in Chapter 3 were overlaid onto the raw vegetation map in ArcGIS 9.1 (ESRI, 2005) and the *intersect* function was used to calculate the proportion of each vegetation type inside the home ranges.

Secondly, exploratory analysis was conducted to determine if vegetation-type composition of adult female kakapo home ranges differed from that of the island as a whole. The proportion of vegetation types inside the foraging home ranges of females was compared to the proportion available on the island using chi-squared tests for breeders and non-breeders. The aggregated vegetation map (Figure 4.3) was used in order to meet the assumptions of this analysis. The 75% kernel foraging home ranges were overlaid onto the map in ArcGIS 9.1 (ESRI, 2005) and the *intersect* function was used to calculate the proportion of each of the five vegetation types inside the home ranges. Chi-squared tests were performed in Microsoft Excel to determine if the proportion of each of the five vegetation types in the home ranges (observed values) differed significantly from the proportion of each vegetation type available on the island (expected values) for both breeders and non-breeders.

4.2.5   Multivariate analysis to assess habitat use

The results of the exploratory analysis would determine if kakapo appeared to be selecting for certain vegetation types or using them at random, but would not provide information on which vegetation types were most important in determining kakapo distribution. To further investigate habitat selection a multivariate analysis was used that included vegetation characteristics and other variables in a spatial model of kakapo distribution.

Habitat selection is often modelled by comparing the environmental variables of areas where a species is recorded, against areas where it is not located using techniques such as compositional analysis or generalised linear models (Aebischer *et al.*, 1993; Guisan & Zimmerman, 2000; Dickson & Beier, 2002). These techniques require spatial information on both the presence and absence of a species, known as presence-absence data (Pearce & Boyce, 2006). The radio-tracking data collected for this study only provided location data

that showed the presence of kakapo. As no information was collected on where kakapo were not located, the data collected for this study was presence-only data.

Habitat selection models have recently been developed that use presence-only data to model the distribution of a species by contrasting the environmental variables at presence-only locations with the environmental variables available across the study area (Pearce & Boyce, 2006). The presence-only model Ecological Niche Factor Analysis (ENFA) was used in this research. Developed and explained in detail by Hirzel *et al.* (2002), the ENFA method is implemented in the computer package *Biomapper 3.2* (Hirzel *et al.*, 2006a).

Ecological Niche Factor Analysis

The ENFA method is based on Hutchinson's (1957) concept of the ecological niche where every species has its own functional position within an ecosystem (Allaby, 1999). The ecological niche is modelled using eco-geographical variables (EGVs), physical and biotic parameters of the ecosystem that may be important in determining the distribution of the species. EGVs, such as elevation, are mapped quantitatively in grid cells across the reference area. Presence-only locations of the study species are converted to grid cells and then overlaid onto the study area. The ecological position that the species occupies is calculated for each EGV by contrasting the average value of the EGV across the study area with the average value in the cells occupied by the species. Any difference in these two values shows that the species is selecting for values of the EGV that are different to the average that is available in the study area. The ENFA results estimate the ecological niche of the species within the environmental parameters used to define the study area.

Creating eco-geographical variables

To model the distribution of adult female kakapo on Codfish Island, the whole island was chosen as the reference area and was modelled as a raster (grid-based) map based on the New Zealand Map Grid co-ordinate system. The island was divided into 5909 grid cells, each with a resolution of 50 m x 50 m. The resolution represented the minimum accuracy of the least accurate eco-geographical variable (EGV), the vegetation map of the island (L. Brabyn, pers. comm.). Nine EGVs were used to represent the habitat available on the island, two of which characterised the topography of the island and seven of which described the spatial distribution of relevant vegetation types across the island.

Topographical variables

A digital elevation model (DEM) produced by Landcare Research, with a resolution of 25 m, was used to describe the topography of the island. The elevation of the island was determined for each grid cell from the DEM after it had been reclassified to a 50 m resolution in ArcGIS 9.1 (ESRI, 2005). The slope and aspect (in degrees) of each grid cell was calculated from the DEM using the ArcTool Box spatial analyst functions in ArcGIS 9.1 (ESRI, 2005).

Vegetation variables

As kakapo on Codfish Island rely on rimu fruit to breed (Harper *et al.*, 2006) and results from the exploratory analysis showed that a large proportion of the home ranges occupied by breeding females contained vegetation with mature rimu trees (refer to section 4.3.1), the vegetation characteristics of the island were classified for the model according to the abundance of mature rimu trees within each vegetation type. The rimu-abundance map (Figure 4.5) was used in this analysis. Based on the descriptions of the sixteen vegetation types in the raw vegetation map (Appendix 8), the map shows three levels of rimu abundance: 1) high rimu abundance, 2) moderate rimu abundance and 3) no rimu expected to be present in the vegetation.

As the height of vegetation is variable across Codfish Island, and there is some indication that kakapo may prefer shorter vegetation (Atkinson & Merton, 2006; Butler, 2006), the remaining three EGV layers used in the habitat selection model showed the approximate canopy height of the vegetation across the island based on the descriptions in the raw vegetation map (Appendix 8). Vegetation types with the same estimated canopy heights were merged to create three layers with canopy heights of up to aproximately 20 m, 15 m and 5 m in height.

As *Biomapper 3.2* (Hirzel et al., 2006a) requires quantitative rather than categorical data, the rimu-abundance and canopy-height maps were converted into six separate raster grids each representing one of the six categories of the two maps. In ArcGIS 9.1 (ESRI, 2005) the cells in each of the raster grids were given the value of 0 or 1 to represent the absence or presence respectively of the vegetation layer. For example in the high-rimu abundance raster layer, grid cells where high-rimu abundance vegetation occurred were given a value of 1 and all other grid cells were given a value of 0.

To convert the six vegetation raster layers from binary to continuous data, the focal statistics function of ArcGIS 9.1 (ESRI, 2005) was used. This function calculates the proportion of a circular area, centred on the focal grid cell, which contains presence cells for the focal vegetation type. Values between 0 and 1 are assigned to each grid cell, with 1 representing 100% of the circular area containing the focal vegetation type. The circular area used for this analysis was the size of the mean 75% kernel home range (7.11 ha) with a radius of 85m.

Species data

Locations of adult female kakapo collected on Codfish Island using radio-tracking methods (described in Chapter 2) were used as species data inputs for the ENFA. To take into account errors in the radio-tracking method (as calculated in Chapter 2) a 20 m radius buffer was applied around each location. Two species grids were created for the ENFA, one representing locations of the ten females that bred in the 2005 season (breeders) and the other representing locations of the eight females that did not breed in 2005 (non-breeders). A female was considered to have bred if she produced a nest with egg(s) during the 2005 breeding season. The buffered location points for breeders and non-breeders were converted into two 50 m resolution grids, with a value of 1 or 0 assigned to each cell to show presence or absence of proof of presence (not a true absence) respectively of the focal females. A total of 280 locations were used to create the species grid for breeders and 226 locations were used to create the species grid for non-breeders.

Implementation of ENFA in *Biomapper 3.2*

To import the nine EGV and two species layers into *Biomapper 3.2,* all grids were converted from ESRI grid format to Idrisi32 format using conversion software in ArcGIS 9.1 (ESRI, 2005). Once imported into *Biomapper 3.2,* the EGVs were normalised using the Box-Cox algorithm (Box & Cox, 1964). The principles and procedures of how ENFA is implemented in a multivariate statistical framework have been described in detail in a previous paper (Hirzel *et al.,* 2002). In summary, as ecological variables are not independent a factor analysis is used in ENFA to transform correlated variables into the same number of uncorrelated factors, each explaining the same amount of variance as the original variables (Brotons *et al.*, 2004). The overall information explaining the ecological niche of the species is defined as two uncorrelated indices: marginality and specialisation.

Marginality is defined as the ecological distance between the species optimum and the mean habitat within the study area (Hirzel *et al.*, 2002). The larger the absolute value of marginality

(closer to 1) the more the species mean differs from the mean in the study area, with a value of 0 indicating no difference between the two means (Hirzel *et al.*, 2002). A negative marginality value indicates that the species mean is less than the mean in the study area and a positive value indicates the species mean is higher than the study area mean. The marginality value for each EGV defines optimum conditions for the species for each of the environmental parameters used to define the study area. The overall marginality value combined for all EGVs shows how the species niche differs from the overall habitat conditions available in the study area. The EGV with the highest marginality value has the most influence in determining the species' distribution (Hirzel *et al.*, 2002).

The second index describing the ecological niche of the species is specialisation. Specialisation shows the extent to which the use of EGVs by the species is narrow compared to the overall distribution of the EGVs in the study area. Specialisation is calculated in *Biomapper 3*.2 for each EGV as the ratio of the standard deviation of the study area distribution to that of the species distribution (Hirzel *et al.*, 2002). The inverse of specialisation is a measure of the species tolerance (Sattler *et al.*, 2007). Tolerance values range from 0 to 1, with the larger the tolerance value the more tolerant the species is to living in a wider range of environmental descriptors (Hirzel *et al.*, 2002). Any value below one indicates that the species show some specialisation. As specialisation/ tolerance coefficients measure variance, rather than a difference from the mean, only absolute values are relevant and the signs of coefficients have no meaning.

In ENFA the first axis accounts for all marginality of the species and some of the specialisation. The second and subsequent axes are then extracted orthogonally to explain the remaining specialisation of the species (Hirzel *et al.*, 2002). Most of the information explained by marginality and specialisation is contained in the first few axes (Hirzel *et al.*, 2002).

4.2.6   Evaluation of models

Ecological models have little merit if their predictions cannot, or are not, assessed for their accuracy using independent data (Fielding & Bell, 1997). Models can be validated by using species locations that were not included in the original model, but when species data is limited it is preferable that all available locations be used to develop the model. To overcome this

problem cross validation procedures have been developed that allow an assessment of the probability of occurrence by spatially partitioning the species data set into independent partitions (Manly *et al.*, 1993; Boyce *et al.*, 2002). In this study *k*-fold cross validation was used where the species data set was spatially partitioned into ten (*k*) equal sized partitions as recommended by Hirzel *et al.* (2006b). In turn, nine partitions were used to calibrate the model while the data points in the remaining partition were used to evaluate the model.

The method used to assess the accuracy of the models in this research was the continuous Boyce index (Hirzel *et al.*, 2006b), which is derived from the original Boyce index described by Boyce *et al.* (2002). The original Boyce index calculates the accuracy of the model by partitioning the habitat suitability values into a number of classes. For each habitat suitability class, two frequencies are calculated: (1) the *predicted frequency* of the evaluation points, which is the number of evaluation points from the evaluation partition that are predicted by the model to fall into the habitat suitability class; and (2) the *expected frequency* of evaluation points, which is the frequency of points expected to fall into the habitat suitability class from a random distribution of points across the study area (Boyce *et al.*, 2002).

From these two values the *predicted-to-expected* (P/E) ratio is calculated for each habitat suitability class by dividing the predicted frequency by the expected frequency. If the habitat model is accurate then a low suitability class would be expected to contain fewer evaluation presences than a random model, and a high suitability class should have more evaluation presences than expected by chance (Boyce *et al.*, 2002; Hirzel *et al.*, 2006b). As a 10-fold cross validation procedure was used, the P/E ratio was calculated ten times, once using each of the ten evaluation partitions. To evaluate the model the mean and standard deviation of the P/E ratios was calculated and plotted against the mean habitat suitability for each class. In a good model the predicted-to-expected ratio should increase as habitat suitability increases (Boyce *et al.*, 2002).

The main shortcoming of the original Boyce index is that it is sensitive to the number of suitability classes that are used. To overcome this problem the continuous Boyce index was used as it uses a "moving window" with a default fixed-width of 20 units, instead of a fixed number of classes (Hirzel *et al.*, 2006b). The moving window starts at the lowest habitat suitability value and after calculating the P/E ratio is shifted a small amount upwards where the P/E is plotted again. This operation was repeated until the moving window reached the

last habitat suitability value (Hirzel *et al.*, 2006b). All other procedures for the continuous Boyce index are the same as the original Boyce index.

The continuous Boyce index value was calculated as a measure of the increase in the mean P/E ratio as habitat suitability increases using a Spearman rank correlation coefficient (Boyce *et al.*, 2002) in *Biomapper 3.2*. Results can vary from -1 to 1, with absolute values close to 1 indicating that the model is not different from a random model. Positive values indicate that the model correctly predicts presences based on habitat suitability values, while negative Boyce index values indicate the model has poor predictive power (Hirzel *et al.*, 2006b).

4.2.7   *Habitat suitability maps*

The first few factors resulting from the ENFA analysis for each model can be used to compute the suitability of any cell in the study area for breeders and non-breeders (Hirzel *et al.*, 2002). To maximise the explained information in the habitat suitability maps, the number of factors included was determined by a comparison of the factors' eigenvalues based on MacArthur's broken-stick distribution (Hirzel *et al.*, 2002). Several algorithms are available to compute habitat suitability (Hirzel *et al.*, 2006a). The distance geometric-mean algorithm was used in this study as it has been shown to provide a good trade-off between the opposing constraints of precision and generality (Hirzel & Arlettaz, 2003). Unlike other algorithms, the distance geometric-mean makes no assumption about the shape of the species distribution along the different factors. Instead it computes the density of species points around a focal cell, by calculating the geometric mean of the distances from the focal cell to all surrounding species points (Hirzel & Arlettaz, 2003). The algorithm is based on the assumption that the higher the density of species points surrounding a focal cell, the higher the habitat suitability of the focal cell and its corresponding environmental conditions (Hirzel *et al.*, 2002).

To compute habitat suitability values, envelopes were delineated enclosing various proportions of species records (Hirzel & Arlettaz, 2003). For example a core envelope may enclose 50% of the innermost species records, a broader envelope may enclose 60% of records and so on, until even the marginal species records are included (100%). Finally a habitat suitability value is assigned to each envelope by counting the proportion of species records they encompass (Hirzel *et al.*, 2006a). Habitat suitability values range from 0 to 1, where 0 is the least suitable habitat and 1 is optimal habitat for the species (Hirzel *et al.*,

2002). Habitat-suitability maps were produced from the ENFA models for both breeders and non-breeders using this distance geometric-mean algorithm. Maps were reclassified into the following four habitat suitability classes in ArcGIS 9.1: unsuitable (< 0.25), marginal (0.26 – 0.50, suitable (0.51 – 0.75) and optimal habitat (> 0.76).

4.3   Results

4.3.1   Exploratory analysis of kakapo vegetation use

Exploratory analysis based on the raw vegetation map showed that adult female kakapo did not use four of the sixteen vegetation types on the island: kamahi, kamahi-rata, manuka-broadleaf and the sand dunes (Table 4.3). In addition, non-breeders also did not use another four vegetation types: rata-podocarp, coastal scrub, rimu-rata and mixed-podocarp-tall. Two vegetation types were commonly used by adult female kakapo regardless of breeding status: rimu-miro and rata-podocarp-short. Breeders also commonly used mixed-podocarp-stunted vegetation. Non-breeders commonly used coastal daisy and pakahi scrub, vegetation types that were not significantly used by breeders (Table 4.3).

Table 4.3. The area (ha) and proportion of the raw vegetation types in the 75% kernel home ranges for breeders and non-breeders.

Raw vegetation classes (Brabyn, 2005)	Breeders		Non-breeders	
	Area	Prop.	Area	Prop.
Rimu-miro	25.96	0.29	3.71	0.10
Podocarp-mixed-stunted	14.46	0.16	2.99	0.08
Rata-podocarp-short	24.69	0.28	8.12	0.21
Kamahi-podocarp	1.99	0.02	0.99	0.03
Rata	5.07	0.06	7.78	0.20
Miro-rimu	8.52	0.10	5.69	0.15
Podocarp-mixed-tall	1.24	0.01	0	0
Coastal scrub	2.24	0.03	0	0
Rimu-rata	3.56	0.04	0	0
Rata-podocarp	1.38	0.02	0.01	0
Pakahi scrub	0.14	0	3.88	0.10
Coastal daisy	0	0	5.63	0.15
Kamahi rata	0	0	0	0
Sand dunes	0	0	0	0
Kamahi	0	0	0	0
Manuka-broadleaf	0	0	0	0
Totals	89.25	1.00	38.8	1.00

Aggregated vegetation map

Exploratory analysis using the aggregated vegetation map showed that the most common vegetation types in the home ranges of both breeders and non-breeders were rimu-miro and rata-podocarp-short (Table 4.4). Non-breeders also had a large proportion of coastal daisy-pakahi scrub vegetation in their home ranges, a vegetation type that was not used in any significant proportion by breeders (Figure 4.4 and Figure 4.3).

Table 4.4. The area (ha) and proportion of vegetation types from the aggregated vegetation map inside the 75% kernel foraging home ranges of breeders and non-breeders.

Aggregated Vegetation classes	Breeders		Non-breeders	
	Area	Prop.	Area	Prop.
Coastal daisy-pakahi scrub	0.1	0	9.5	0.25
Rimu-miro	34.5	0.39	9.4	0.25
Mixed-podocarp-stunted	14.5	0.16	3.0	0.07
Rata-podocarp-short	29.8	0.33	15.9	0.40
Other (5% or less)	10.4	0.12	1.0	0.03
Total	89.3	1.00	38.8	1.00
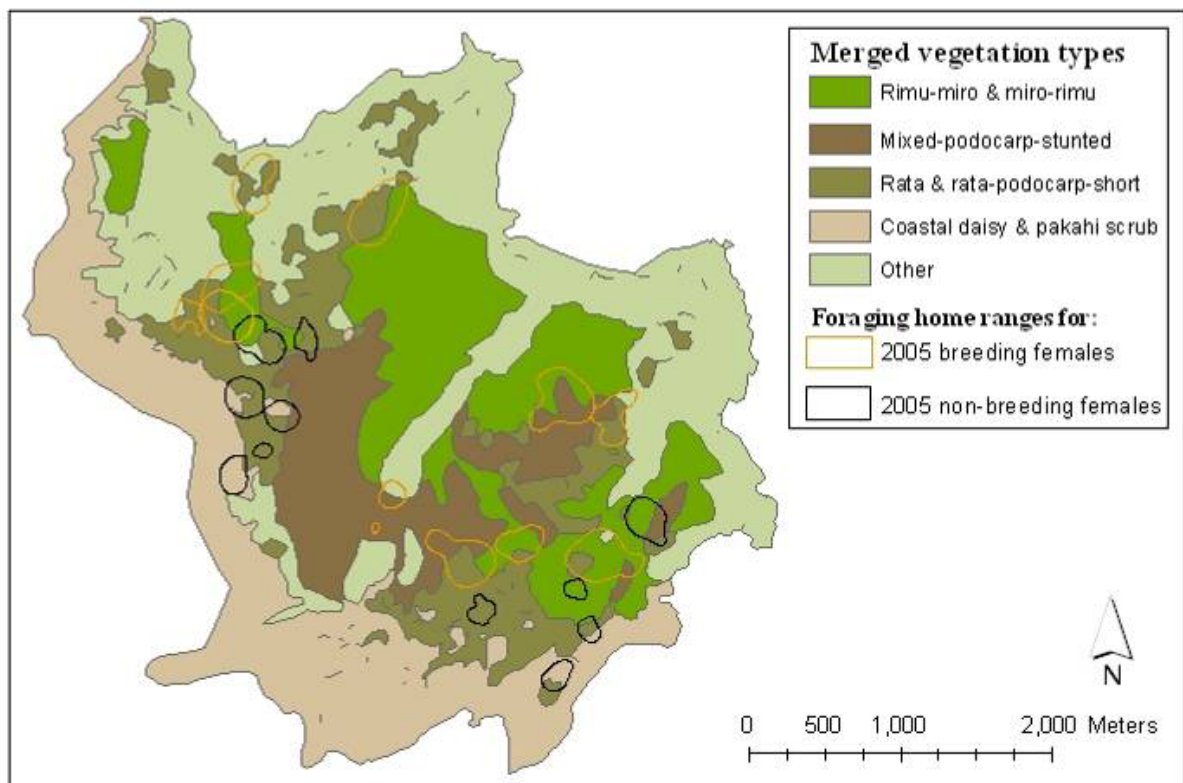
Figure 4.3. The location of aggregated vegetation types on Codfish Island and 75% kernel foraging home ranges estimated for adult female kakapo (breeders- yellow; non-breeders- black).

The proportion of aggregated vegetation types used by breeders and non-breeders was compared to the proportion of each available on the island (Figure 4.4). Non-breeders used a similar proportion of coastal daisy-pakahi scrub to what was available, but breeders did not use this vegetation type. The proportion of aggregated vegetation types used by adult female kakapo was significantly different from the proportion available on the island for both breeders ($\chi^2_{df=4}$ = 77, p < 0.01) and non-breeders ($\chi^2_{df=4}$ = 34.8, p < 0.01), indicating that adult female kakapo do not occur randomly across the island.
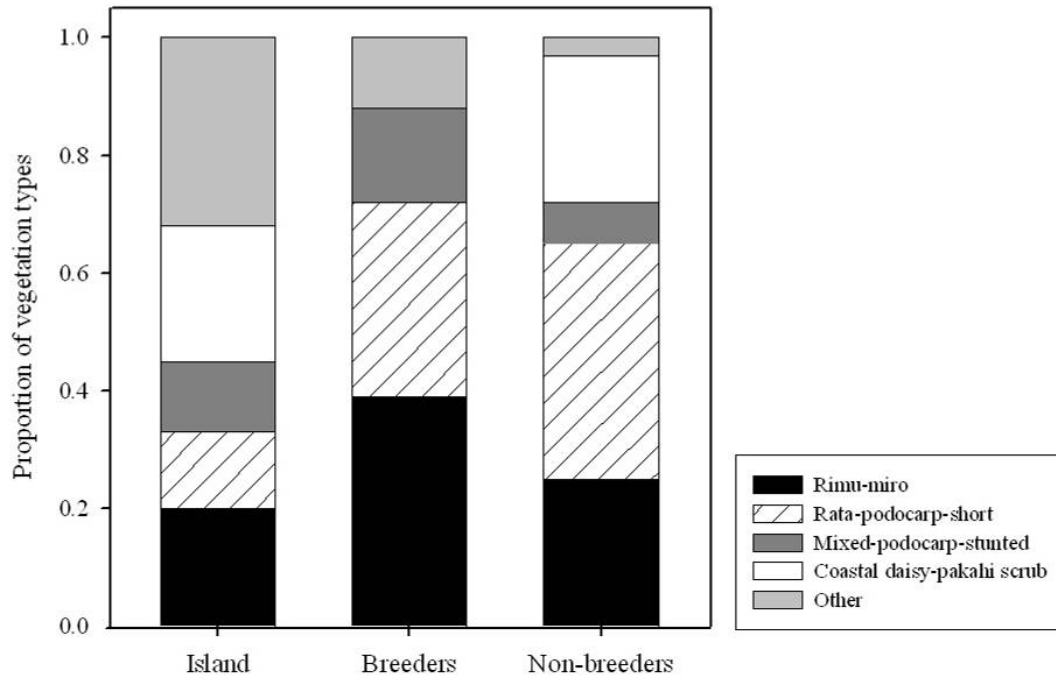
Figure 4.4. Comparison of the proportion of aggregated vegetation types on Codfish Island and inside the 75% kernel foraging home ranges of breeders and non-breeders.

Rimu-abundance map

Aggregation of the raw vegetation classes into three classes based on the abundance of mature rimu trees in each, found that the area of the island was divided approximately evenly with high, moderate and no rimu classes each occupying around one third of the islands area (Table 4.5). Forest containing a high abundance of mature rimu trees was located mostly in the central, higher elevation areas of the island while forest containing no rimu trees was mostly located in coastal areas (Figure 4.5). Foraging home ranges of breeders were mostly located in high or moderate rimu abundance forest. Non-breeders home ranges were mostly located in vegetation containing no rimu forest, although a significant proportion of non-breeders home ranges were also located in either moderate or high rimu abundance forest (Table 4.5 and Figure 4.5).

Table 4.5. For each rimu abundance class the proportion on the island is shown, along with the total area (ha) and proportion in the combined foraging home ranges for breeders and non-breeders.

Rimu abundance classes	Proportion on island	Breeders		Non-breeders	
		Area	Prop.	Area	Prop.
High	0.31	53.7	0.60	12.4	0.31
Moderate	0.32	28.0	0.31	9.1	0.24
No	0.37	7.6	0.09	17.3	0.45
Total	1.00	89.3	1.00	38.8	1.00
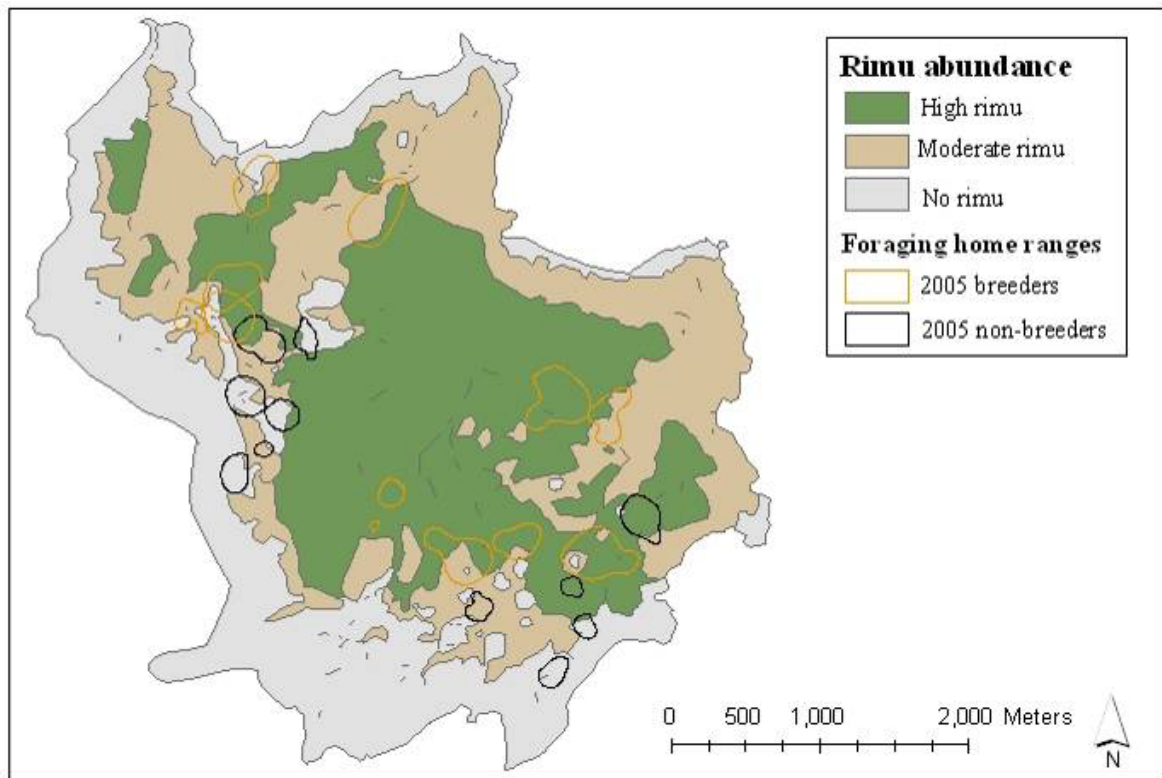
Figure 4.5. The location of vegetation with varying abundance of mature rimu trees, based on the description from the raw vegetation map in Appendix 8.

4.3.2   Ecological Niche Factor Analysis

The global marginality value for breeders was 0.48 and for non-breeders was 0.72, indicating that non-breeders occurred in habitats that were more different from the mean available habitat on the island than breeders. Both breeders and non-breeders had a global tolerance value of 0.67 indicating that adult female kakapo had a wide niche breadth and were able to tolerate relatively large deviations from their optimal habitat for a range of EGVs. Results of the models for (a) breeders and (b) non-breeders is shown for each EGV as coefficients of marginality and specialisation in Table 4.6 below. Coefficients of marginality are shown in the first column, while the second and subsequent columns show the coefficients for the specialisation factors.

Table 4.6. Marginality and specialisation coefficients for the nine eco-geographical variables (EGVs) included in the ENFA models for a) breeders and b) non-breeders are shown for 6 variables.

a) Breeders	Marginality (27%)	Spec. 1 (33%)	Spec. 2 (15%)	Spec. 3 (7%)	Spec. 4 (5%)	Spec. 5 (5%)
Elevation	0.627	-0.08	-0.459	0.147	0.331	0.034
Frequency of high rimu forest	0.472	0.159	0.551	-0.576	-0.364	0.346
Frequency of no rimu forest	-0.433	-0.193	0.153	-0.439	-0.033	0.045
Slope	-0.313	0.083	-0.321	0.127	-0.338	0.182
Frequency of up to 20 m canopy	0.233	0.01	-0.279	0.486	-0.276	-0.588
Frequency of moderate rimu forest	0.204	-0.52	0.256	-0.382	-0.393	0.158
Aspect	-0.042	-0.003	-0.035	0.208	-0.004	-0.079
Frequency of up to 5 m canopy	0.027	0.808	-0.125	0.073	-0.577	-0.521
Frequency of up to 15 m canopy	-0.016	0.003	-0.445	-0.084	-0.281	-0.443
b) Non-breeders	Marginality (25%)	Spec. 1 (31%)	Spec. 2 (14%)	Spec. 3 (9%)	Spec. 4 (7%)	Spec. 5 (5%)
Elevation	0.710	-0.286	0.289	0.248	-0.115	0.113
Slope	-0.515	0.08	0.205	0.247	-0.209	0.102
Frequency of up to 5 m canopy	0.318	0.431	-0.41	0.379	-0.527	-0.612
Frequency of up to 15 m canopy	-0.282	-0.343	-0.065	0.288	-0.39	-0.542
Aspect	-0.154	0.035	0.087	0.303	0.158	-0.108
Frequency of no rimu forest	0.152	-0.082	-0.1	-0.023	0.284	-0.188
Frequency of up to 20 m canopy	-0.051	-0.371	-0.713	0.739	-0.323	-0.455
Frequency of moderate rimu forest	-0.029	-0.026	0.027	-0.045	0.326	-0.146
Frequency of high rimu forest	0.012	0.68	0.418	-0.101	0.444	-0.182

Notes: EGVs are sorted by decreasing absolute value of coefficients on the marginality factor. Positive values on this factor mean that adult female kakapo prefer locations with higher values on the corresponding EGV than the mean location on the island. Signs of coefficients have no meaning on the specialisation factors. The amount of specialisation accounted for is given in brackets in each column heading.

The EGV with the largest absolute marginality value for both breeders (0.627) and non-breeders (0.710) was elevation, indicating that regardless of breeding status adult female kakapo occurred in areas that were higher in elevation than the mean available on the island. Kakapo distributions were negatively correlated with slope, with both breeders (-0.313) and non-breeders (-0.515) occurring in areas of the island that were flatter than the mean available (Table 4.6). Aspect did not appear to largely influence the location of breeders (-0.042) or non-breeders (-0.154) with both marginality coefficients showing only a small difference from the mean aspect available on the island.

The main difference between the types of habitats used by breeders and non-breeders detected by ENFA was their occurrence in forest with differing abundance of mature rimu trees. Results for the breeders model (Table 4.6a) showed that the location of breeding females was strongly correlated with forest containing a high (0.472) and moderate (0.204) abundance of mature rimu trees and negatively correlated with forest containing no mature rimu trees (-0.433). In contrast, the results for the non-breeders model (Table 4.6b) showed that the location of non-breeding females was not strongly correlated with the abundance of mature

rimu trees in the forest they occupied. The locations of non-breeders were slightly correlated with forest containing no mature rimu trees (0.152), but there was virtually no correlation (negative or positive) with forest containing a high (-0.029) or moderate (0.012) abundance of mature rimu trees (Table 4.6b).

Results from the ENFA for canopy height showed that breeders occurred in tall forest with a maximum canopy height of up to 20 m more often than would be expected by chance (0.233). In contrast, non-breeders occurred in short vegetation types with a maximum canopy height of up to 5 m more often than would be expected by chance (0.318) and less often in vegetation types with a maximum canopy height of up to 15 m (-0.282).

4.3.3   Evaluation of models

The quality of the models was assessed by determining how they differed from a random model of kakapo distribution relative to available habitat. The mean predicted-to-expected (P/E) ratio was calculated for different levels of habitat suitability for the breeder (Figure 4.6a) and non-breeder (Figure 4.6b) models. A P/E ratio of one indicates a random model, while values less than or greater than one suggest some degree of spatial structuring due to the habitat variables. In an accurate model, a low habitat suitability class would be expected to contain fewer evaluation presences than a random model, while a high suitability class should have more evaluation presences than random expectation (Hirzel *et al.*, 2006b).

The models for breeders (Figure 4.6a) and non-breeders (Figure 4.6b) in this study both exemplified this positive correlation: the mean P/E ratio values increased as habitat suitability increased indicating that, overall, both models were successful in predicting the dominant habitat types used by breeding and non-breeding kakapo given the modelling data. However the wide standard deviation band around the P/E values for the two models may indicate a low degree of model robustness, as the P/E ratio that would be expected for a random model (ie. P/E = 1.0) fell within the lower P/E error band for almost all levels of habitat suitability for both models (Figure 4.6).

The trend of increasing P/E ratio with increasing habitat suitability was similar for both models as calculated by the continuous Boyce index. The breeders model had a continuous Boyce index of 0.25 ± 0.46 while the non-breeders model had a continuous Boyce index of

0.25 ± 0.65.   The positive Boyce index values indicated that on the whole, the models correctly predicted habitat suitability (Hirzel *et al.*, 2006b). However, the relatively low magnitude of the index values combined with large standard errors, particularly for the non-breeders model, indicated a low degree of model robustness. (Sattler *et al.*, 2007)
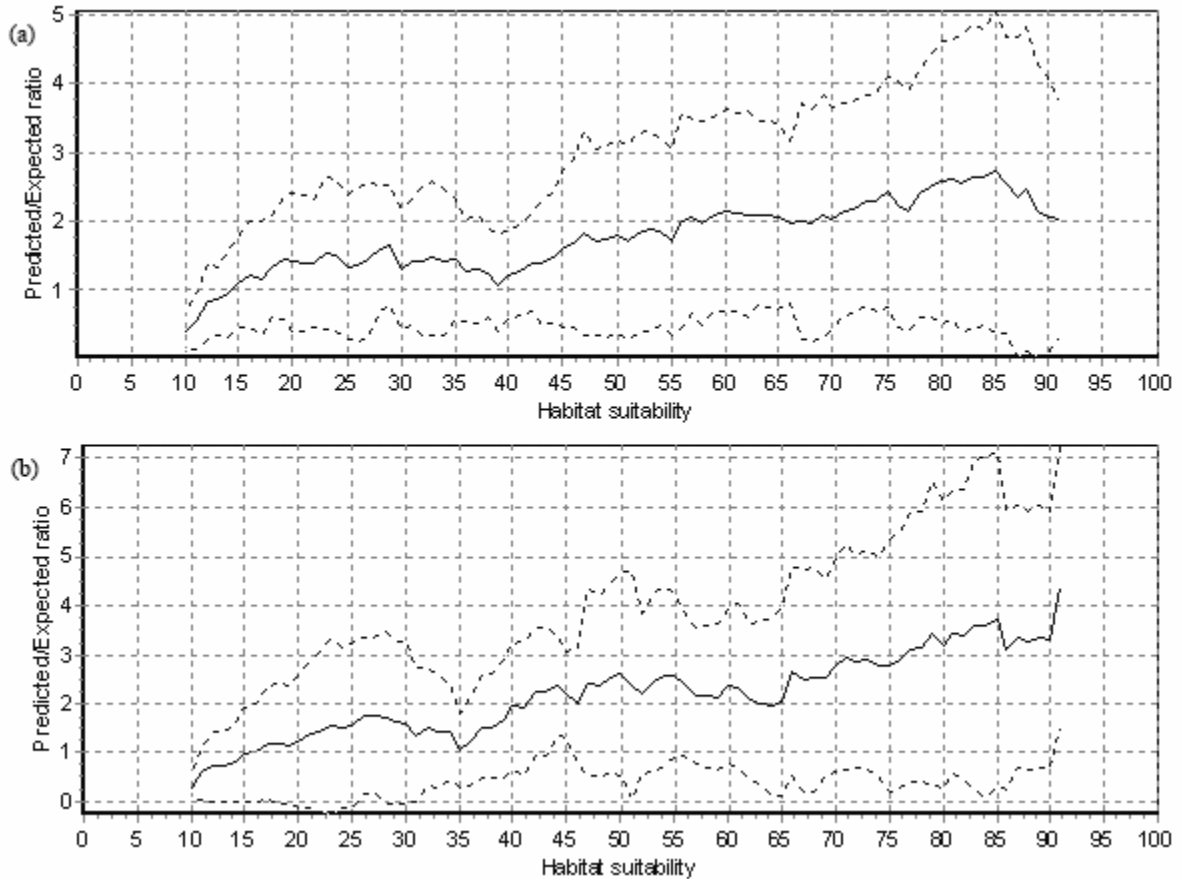
Figure 4.6. The predicted-to-expected ratio (P/E) plotted against different levels of habitat suitability for the (a) breeders model and (b) non-breeders model. The black line shows the mean P/E values and dotted lines show the standard deviation. A habitat suitability of 100 is considered optimal habitat.

4.3.4   *Habitat suitability maps*

Six significant factors of the ENFA were retained for computing habitat suitability maps. Together the six factors explained about 96% of the information contained in all variables (100% of the marginality and 92% of the specialisation). Two habitat suitability maps were computed based on ENFA results for breeders (Figure 4.7a) and non-breeders (Figure 4.7b).

Figure 4.7. The predicted suitability of different areas of Codfish Island for adult female kakapo is shown below for a) breeding females and b) non-breeding females as estimated by ENFA. Habitat suitability predictions are compared to the location of foraging home ranges (75% kernels) estimated for breeders (white) and non-breeders (black).
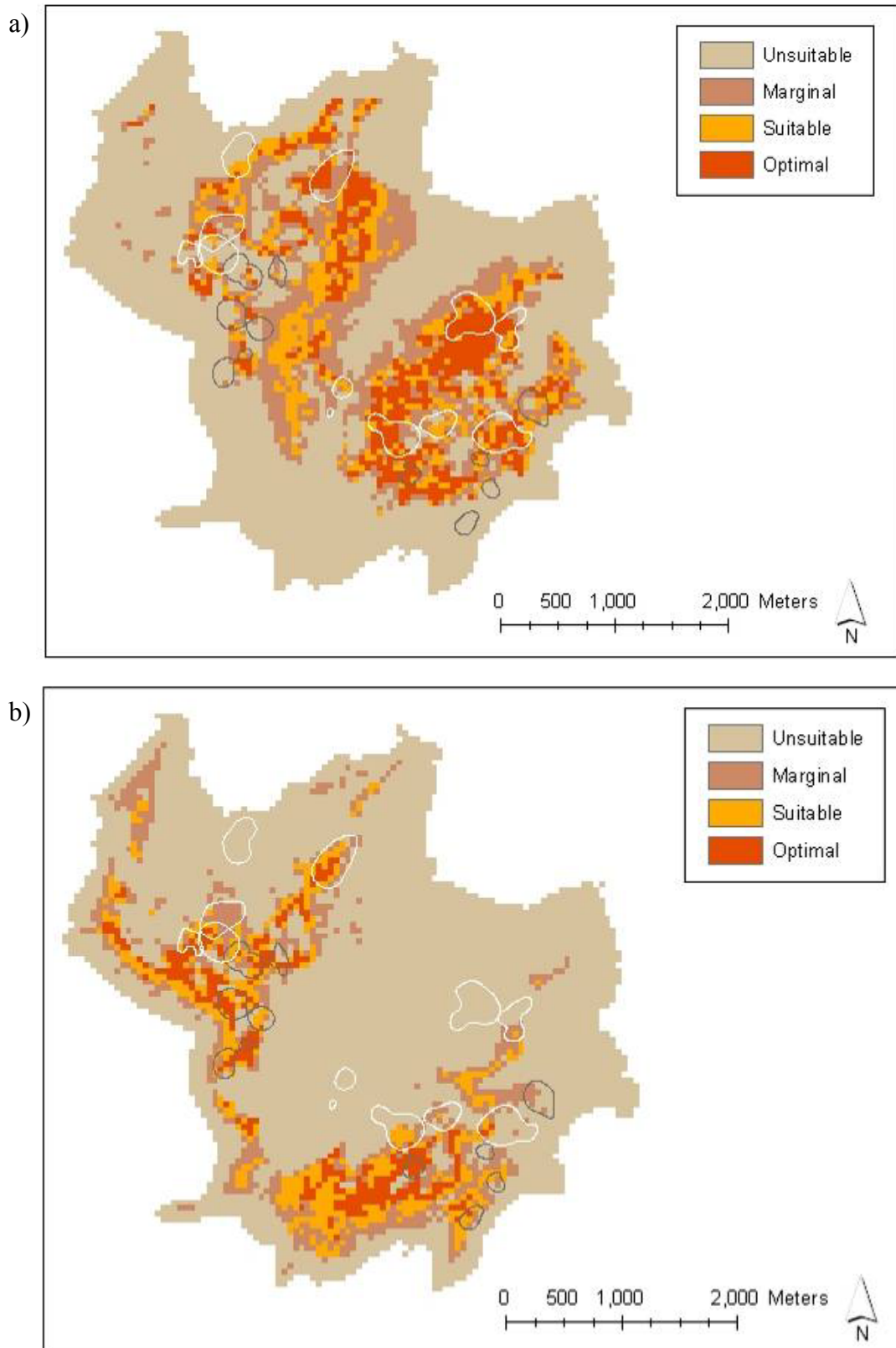
The habitat suitability map for breeders (Figure 4.7a) shows areas of optimal and suitable habitat on Codfish Island where it is predicted by the ENFA that adult female kakapo would be able to breed in low rimu mast years. These breeding areas are mostly located in the central areas of the island. Coastal areas of the island and the lower elevation areas of the main valley are predicted to be unsuitable for breeding. The habitat suitability map for non-breeders (Figure 4.7b) shows areas of the island that are not likely to provide the habitat that kakapo require to breed in low rimu mast years. If kakapo occur in the optimal or suitable areas on the habitat suitability map for non-breeders, then it is unlikely they would be able to breed in years when the rimu fruit supply is limited. Unsuitable breeding habitat mostly occurs in south-eastern higher elevation areas of the island, on ridges above the south-western coast and on a north-eastern running ridgeline (Figure 4.7b).

Overlaying the 2006 foraging home ranges onto the habitat suitability map for breeders (Figure 4.7a) showed that breeding birds were more likely to be located in good quality habitat than non-breeding birds. All ten females that bred in 2005 had at least some of their home range in suitable breeding habitat and five breeders had their home range dominated by optimal habitat. There was one exception where a breeding female (Fuchsia) had her home range mostly in unsuitable breeding habitat. In contrast, females that did not breed in 2005 were more likely to be located in sub-optimal breeding habitat. The home ranges of non-breeders were mostly dominated by unsuitable or marginal breeding habitat (Figure 4.7a), although there was one exception where a non-breeding female (Nora) was located in mostly optimal breeding habitat.

In the breeders habitat suitability map there is a significant quantity of optimal and suitable habitat not occupied by adult female kakapo (Figure 4.7). This may be an indication that the model is not predicting habitat suitability appropriately or that other kakapo on the island are occupying these areas. To assess if other kakapo were occupying optimal breeding habitats, locations collected during the study period for the 36 other kakapo on the island (that were not included in this study) were overlaid onto the habitat suitability maps (Appendix 11). Locations for adults were mostly in optimal breeding habitat but many sub-adults were located in unsuitable breeding habitat. There were many areas of optimal breeding habitat that did not appear to be occupied by the 36 other kakapo on the island, but as the data available was very limited, more research would be required to make an accurate assessment. However as previous locations recorded for adult males indicate that they are often located in high

elevation, plateau areas of the island (National Kakapo Database, 2007), it is likely that adult males may have been located in optimal breeding habitats that were not occupied by adult females during this study.

4.4 Discussion

The aims of this chapter were to provide information on habitat selection by adult female kakapo on Codfish Island and to determine if habitat quality influenced breeding success in a low rimu mast year. Results from Ecological Niche Factor Analysis (ENFA) indicated that adult female kakapo, regardless of breeding status, occupied similar niches in terms of topography utilising both higher elevation and flatter slopes of the island. The most important difference in habitat selection between breeders and non-breeders distinguished by ENFA was related to vegetation variables. Breeding females were mostly located in vegetation containing a high abundance of mature rimu trees. In contrast non-breeding females were more likely to be located in vegetation containing no mature rimu trees. It is unlikely that non-breeding females selected for inferior breeding habitat, but instead these were the only areas available for them to occupy.

This research was consistent with other studies on habitat selection in showing that kakapo do not occur randomly across a landscape, but instead occur more commonly in some habitat types than others (Moorhouse, 1985; Walsh *et al.*, 2006). Exploratory analysis and results from ENFA showed that the habitat types used by adult female kakapo differed from the mean available habitat on the island. This difference was larger for females that were not able to breed in 2005, indicating non-breeders probably occupied marginal habitats. Four vegetation types that were not used by adult female kakapo only occupied a small proportion of the islands area and contained plant species that have not commonly been found in the kakapo diet on Codfish Island, such as kamahi and broadleaf (Wilson *et al.*, 2006). In contrast, the vegetation types that made up the majority of home range areas for breeders and non-breeders occupied a large proportion of the islands area and contained species that are more commonly eaten by kakapo, such as rata, rimu and totara (Wilson *et al.*, 2006).

ENFA showed that kakapo have a wide niche breadth and are able to tolerate large deviations from their optimal habitat. These results are consistent with the history of kakapo translocations where kakapo, including the 18 adult females in this study, have been able to

survive and in some cases breed following transfers between islands with distinctly different climates and vegetation (Appendix 1). Females were transferred from the fire-modified scrubland of Stewart Island (Powlesland *et al.*, 2006) in southern New Zealand to the northern rata-tawa forest of Little Barrier Island in northern New Zealand (Moorhouse, 1985) and in subsequent years were able to breed (Elliott *et al.*, 2006). Females also survived a transfer to Maud Island, where the vegetation has been severely modified by farming and forestry (Walsh, 2002), and one female was able to successfully nest in an exotic pine plantation (Elliott *et al.*, 2006).

According to ENFA, elevation above sea level had the largest influence on kakapo distributions, with females occurring at elevations higher than the mean available on the island. This 'selection' for higher elevations is likely to be a reflection of a preference for vegetation types that grow in these areas rather than a direct preference for elevation. A preference for high elevation areas is unlikely, as kakapo have historically been recorded from near sea-level to the sub-alpine zone (> 1200 m a.s.l.) (Powlesland *et al.*, 2006). It is more likely that kakapo occurred in the central, higher elevation areas of the island because this is where optimal breeding habitat, forest containing a high abundance of mature rimu trees, was mostly located (Figure 4.7).

The ENFA models also predicted that adult female kakapo occured in areas of the island that were flatter than the mean available slopes on the island, with slope being a more important variable in predicting distribution for breeders than for non-breeders. It is likely that, as for elevation, a reported preference for flat slopes may actually reflect a preference by kakapo for vegetation that grows in relatively flat rather than steep areas of the island. The steep coastal cliffs that are characteristic of the south-western coastline of Codfish Island are covered by coastal daisy (Figure 4.2), a vegetation type that was utilised by non-breeding females but not used by breeders (Table 4.3). Historically kakapo have survived in habitats with a range of slopes (Atkinson & Merton, 2006) but these may have been marginal habitats rather than prime breeding areas.

Although adult female kakapo tended to occupy similar topographical variables regardless of breeding status, the use of vegetation characteristics was quite different between breeders and non-breeders. Due to limitations with the modelling software, the importance of the original 16 vegetation types in determining kakapo distributions could not be assessed individually.

To overcome this problem vegetation types were combined into three categories, based on the abundance of mature rimu trees in each. As adult female kakapo on Codfish Island rely on rimu fruit to breed (Elliott *et al.*, 2006) an assessment of the importance of mature rimu trees in their ecological niche seemed appropriate.

The outcomes of ENFA supports previous research that mature rimu trees are important for kakapo breeding in low rimu mast years on Codfish Island (Elliott *et al.*, 2006). The results show for the first time that this correlation between rimu abundance and breeding also occurs on a spatial scale across the island. ENFA found that adult female kakapo that occurred in habitats with more mature rimu trees than the mean available on the island were able to breed in 2005, but those in habitat with less mature rimu trees could not. Suitable breeding habitats are mostly located in the higher elevation, central areas of the island (Figure 4.7). The large marginality coefficients estimated by ENFA indicate that for breeders the abundance of mature rimu trees in their habitat has a large influence in determining their distribution. Elevation was predicted to have a larger influence on the distribution of breeders, but as a preference for elevation is probably dependent on the vegetation types that occur there, I suspect that the abundance of mature rimu trees in the vegetation has the largest influence on where adult female kakapo can breed on Codfish Island.

ENFA predicted that habitats on Codfish Island where adult female kakapo are unlikely to be able to breed in low rimu mast years will be characterised by forest with only a few or no mature rimu trees. Sub-optimal breeding habitat is also likely to be short vegetation with a canopy height of less than 5 m. Vegetation types described in the raw vegetation map where breeding is unlikely to occur include rata forest, rata-podocarp-short forest, coastal daisy, coastal scrub, manuka-broadleaf forest and pakahi scrub (Appendix 8). These sub-optimal breeding habitats are located mostly around the coastal areas of the island, the lower elevation areas of the main valley and on some ridgelines (Figure 4.7). It is unlikely that adult female kakapo would select for unsuitable breeding habitats. Instead females may be forced to occupy these areas if there is limited space on the island and they are marginalised by other kakapo. The results from this research suggest that the limited supply of mature rimu trees available to some adult female kakapo on Codfish Island may restrict their ability to breed in low rimu mast years.

Limitations of ENFA models

Evaluation of the ENFA models showed that, on the whole, both models were successful in predicting the dominant habitat types used by breeding and non-breeding kakapo. However the relatively low magnitude of the evaluation indices and large standard errors indicated a low degree of model robustness. There are a number of reasons why the evaluations indices may have predicted the models to be not very robust.

Firstly, there may not have been enough species location data available to accurately evaluate the models. When locations are scarce in presence-only models, evaluators such as the continuous Boyce index assess the model as poor (Hirzel *et al.*, 2006b). For most conservation-based studies this problem of limited location data is inevitable when evaluating ecological models as populations are likely to be unsaturated and not occupy all suitable habitats (Fielding & Bell, 1997). There were 56 kakapo present on Codfish Island during this study. The population was likely to be unsaturated as 10 females transferred to the island after the study were able to survive and establish settled home ranges (Jo Ledington, pers. comm.). However as these females may have been living in sub-optimal breeding habitat the island may still be at or beyond carrying-capacity for breeding females. Even if locations from the whole kakapo population on Codfish Island had been used in an ENFA model, as the population was likely to be unsaturated an evaluation of the model would most likely have shown the model accuracy to be poor (Fielding & Bell, 1997; Hirzel *et al.*, 2006b).

The problem of using an unsaturated population in ENFA modelling was exemplified in my analysis as locations from only 10 and 8 individuals respectively were used to model distributions for breeding and non-breeding adult females. The large standard deviations recorded in the continuous Boyce index were probably caused by using a small proportion of the total population in the modelling and increased because these locations were clumped in areas on the island. As the cross-validation technique used to evaluate the model spatially partitioned the island into 10 equal sized partitions, the number of location points recorded in each partition would have depended on where it was located relative to the location points on the island. The large variation in the number of location points recorded in each partition would have been responsible for a large proportion of the variance recorded in the evaluation indices.

Another factor that may have affected the accuracy of the ENFA models is the relevance of the eco-geographical variables to kakapo. When the environmental variables are irrelevant to the species niche, a model cannot efficiently predict species distributions (Hirzel *et al.*, 2006b). Due to limitations with the vegetation data available for this study and the requirements of the modelling software, only two coarse measures of vegetation were included in the models: the abundance of mature rimu trees and the maximum canopy height of vegetation. Both variables were found to have some influence on kakapo distributions but if more detailed variables could have been included it is likely that these would have created better quality models.

Finally, the distribution of kakapo may have been hard to predict because of their ability to live in a range of different habitats, as demonstrated by the large global tolerance value predicted by the ENFA and their previous ability to adapt to living on different islands with variable vegetation and climatic conditions (Moorhouse, 1985). Several studies have shown that it is easier to predict habitat suitability for species that occupy a marginal rather than wide niche breadth, purely for methodological reasons (Stockwell & Peterson, 2002).

Chapter 5   General Discussion

The preceding chapters examined the importance of foraging home range size and habitat selection in breeding success of adult female kakapo on Codfish Island during a low rimu mast year. This summary chapter discusses the main results of this work and their significance in contributing to our knowledge of kakapo ecology. Several management applications are recommended based on results from this research with the aim of increasing the number of adult female kakapo that breed in low rimu mast years. Suggestions are also made for future research that would add to this work in further understanding the factors limiting breeding success of adult female kakapo on Codfish Island.

5.1   How this study contributed to knowledge of kakapo ecology

- Foraging home range sizes (estimated using 95% kernel methods) varied from 3.5 to 26.5 ha with a mean size of 11.8 ha, estimations that were similar to a previous study of kakapo home ranges on Codfish Island (Farrimond *et al.*, 2006). The large variation in home range sizes estimated in this study is consistent with results from other islands around New Zealand (Moorhouse, 1985; Trinder, 1998; Walsh *et al.*, 2006). As these islands have distinctly different vegetation types, it appears that a large variation in home range size may be a reflection of individual preference by kakapo rather than a result of the quality of the habitat types available.

- Core home range areas did not overlap between adult females, with one exception. Six females had their core foraging areas represented by two polygons, indicating movement between foraging sites. As there was a tendency for females to move to lower elevations as the air temperature decreased, movement between foraging sites may be in response to changes in climate. Home ranges were found to vary with seasons on Maud Island, although the pattern of variation differed between birds (Walsh *et al.*, 2006). As kakapo are opportunistic feeders utilising food sources that become available for only short periods seasonally (Higgins, 1999), it is also likely that females have more than one core area as a result of movements between patchily distributed food resources.

- Foraging home ranges differed significantly in size between females that bred in 2005 and those that did not. On average breeders had home ranges that were twice the size of non-breeders' home ranges. This is the first evidence that some adult female kakapo may be limited in their ability to breed in low rimu mast years by the size of the

foraging area they occupy. Larger home ranges are likely to provide access to more food resources so that when food supplies are limited, females may still be able to find enough food to successfully reproduce.

- Adult female kakapo on Codfish Island had a wide niche breadth being able to survive in a range of habitats, but females with the largest tolerance levels were not able to breed as they occurred in habitats that differed significantly from their optimal breeding habitat. This ability to survive in a range of habitats is consistent with previous translocations where kakapo have been able to survive on islands around New Zealand that have distinctly different vegetation and climatic conditions (Elliott *et al.*, 2006). In some cases females have been able to breed when transferred to different islands, but often breeding success has been limited especially when habitat conditions differed significantly from their previous residence (Elliott *et al.*, 2006).

- Adult female kakapo on Codfish Island mostly occurred in habitats with high elevation and relatively flat slopes, but this distribution may be a reflection of the location of suitable vegetation for breeding rather than a direct selection for these types of topography. On Codfish Island suitable breeding habitat has a high abundance of mature rimu trees and is located in mostly the high elevation, central plateau areas of the island. Historically kakapo have occurred over altitude gradients of 1000 m from near sea-level to the sub-alpine zone (Butler, 2006; Powlesland *et al.*, 2006) and occupied areas with either steep or relatively flat gradients (Atkinson & Merton, 2006), so a specific selection for certain topographical characteristics is unlikely.

- The main difference between the habitats occupied by breeders and non-breeders was the abundance of mature rimu trees in the vegetation. Breeders were more likely to occur in vegetation containing a high abundance of mature rimu trees and non-breeders were more likely to occur in vegetation containing few or no mature rimu trees. This is the first evidence for kakapo that the ability of females to breed is probably related to the quality of the habitat they occupy, but this correlation between breeding performance and habitat gradients has been previously demonstrated for a number of other bird species (Martin, 1987; Tremblay *et al.*, 2003).

- A limited supply of mature rimu trees available to some adult female kakapo on Codfish Island probably restricts their ability to breed in low rimu mast years. Although previous research has shown that the proportion of females that breed increases as the supply of rimu fruit increases (Elliott, 2006), this research is the first evidence to indicate that this correlation between rimu fruit supply and breeding also occurs spatially across the island. Only adult female kakapo that have a high or moderate abundance of mature rimu trees in their foraging home ranges are likely to breed in low rimu mast years on Codfish Island. This pattern is also likely to occur on other islands, where the abundance of one or more mast fruiting species required by kakapo to breed may influence their ability to reproduce, especially in years when these food supplies are limited.

- Habitat suitability maps based on the Ecological Niche Factor Analysis models predicted that optimal and suitable habitat for kakapo to breed in low rimu mast years is mostly located in the central and high elevation areas of Codfish Island. Habitat along the coastlines, areas of low elevation of the main valleys and some ridgelines were predicted to be unsuitable habitat for breeding in low rimu mast years, but females may be able to breed in these areas in high mast years when there is an abundant supply of rimu fruit available. If the habitat suitability maps produced in this research are correct then in future breeding seasons when there is a low rimu mast it could be expected that females that occupy sub-optimal breeding habitat would not be able to breed.

- There was a significant quantity of optimal breeding habitat on Codfish Island that was not occupied by adult female kakapo. Eleven females occurred in sub-optimal breeding habitat even though it appears from the habitat suitability maps that optimal habitat was available. However the actual area of unoccupied optimal breeding habitat available may actually be quite small if the home ranges of the 36 other kakapo on the island, not included in this study, are considered. Some of the locations collected during the study period for the other kakapo on the island were located in optimal breeding habitat, but many of the optimal breeding habitats not occupied by adult females in this study still appeared to be unoccupied (Appendix 11). However as the location data was very limited, a study showing the home ranges of the other kakapo on the island would be required to accurately assess if any of the optimal breeding habitat on the island was not occupied by kakapo. As kakapo usually have mutually exclusive, non-overlapping

home ranges, if other kakapo occurred in optimal breeding habitats then it is unlikely that the home ranges of adult female kakapo would overlap with these areas. If a social hierarchy does exist amongst kakapo then the most dominant individuals (perhaps adult males) could be expected to occupy optimal habitat over less dominant kakapo, perhaps explaining why some females occur in sub-optimal breeding habitat.

- Differences in home range size and habitat use were not correlated with the number of years that a female had spent consecutively on the island, her expected minimum age or general health. If kakapo have a social hierarchy then the most dominant females could be expected to occupy optimal breeding habitat, but this was not possible to assess in this research.

5.2   Management recommendations

- If females living in sub-optimal breeding habitat are to have the opportunity to breed in low rimu mast years then they need to be able to occupy suitable or optimal breeding habitat. This could be achieved by removing non-adult female kakapo living in optimal habitat from the island if they are not required for breeding, such as juveniles and sub-ordinate adult males. This would allow females living in sub-optimal habitat the opportunity to shift their home range to a more appropriate area of the island where there would be sufficient mature rimu trees to allow them to breed in low rimu mast years. However as kakapo tend to stay in similar home ranges for a number of years (Merton *et al.*, 1984), even if non-adult female kakapo were removed from optimal breeding habitat there is a chance that females in sub-optimal habitat would not shift to these vacated areas.

- An alternative option to increase the number of females that breed in low rimu mast years would be to transfer females living in sub-optimal breeding habitat on Codfish Island to other islands that have suitable breeding habitat currently unoccupied by kakapo. Anchor Island in Dusky Sound, Fiordland is the only other island where kakapo are currently managed. Anchor Island may provide better breeding habitat than Codfish Island as along with rimu, there are four other plant species present on the island that kakapo have previously been known to breed from: pink pine (*Halocarpus biformis*), yellow-silver pine (*Lepidothamnus intermedius*), southern beech (*Nothofagus*

spp.) and tussock (*Chionochloa acicularis*.). However the breeding potential of Anchor Island has not yet been tested as no adult female kakapo have yet been transferred there.

- Recommendations on which adult female kakapo should be transferred to Anchor Island are outlined in a report produced for the National Kakapo Team in March 2007 prior to a transfer of females planned for April 2007 (Appendix 12). The females recommended for transfer did not breed in 2005, were located in sub-optimal breeding habitat and had not recently been transferred to Codfish Island. As a very low rimu mast was recorded on Anchor Island (4%) and a slightly higher mast was recorded on Codfish Island (13%), it was decided that females may have a greater chance of breeding on Codfish Island than Anchor Island this coming summer so the transfer did not go ahead. However if females remain in similar home ranges in future years, and breeding success in these home ranges is still limited in low rimu mast years, then many of the transfer recommendations made in this report may still be valid in years to come.

- If females living in suboptimal habitat can not be moved to more suitable breeding habitat on either Codfish Island or other islands, then a suitable supplementary food needs to be found that could be fed to females to increase their chances of breeding in low rimu mast years. Numerous supplementary foods including freeze-dried rimu and kahikatea (*Dacrocarpus* dacrydiodes) fruits have previously been trialled but have not been able to increase the frequency of nesting on Codfish Island (Elliott *et al.*, 2001; Harper *et al.*, 2006). Although kakapo have a broad diet and are able to utilise a range of plant species and part of plants (Wilson *et al.*, 2006), it appears that female kakapo have very specific dietary requirements when it comes to breeding. Hopefully a supplementary food trial planned by the National Kakapo Team for this coming summer will appropriately target the dietary requirements of breeding females by providing them with rimu branches laden with fruit (R. Moorhouse, pers. comm.). Ideally all adult females should be provided with this trial food source, but if supply is limited females identified in this research to be living in sub-optimal breeding habitat should be given highest priority.

5.3   Future research

- Future research could provide more detailed information on habitat requirements of kakapo if more detailed and relevant ecological variables were used. Future modelling of kakapo habitat selection could be improved by using vegetation data that provides information on the frequency of plant species that are important in the kakapo diet. Studies on Codfish Island have shown that diet differs significantly between breeding and non-breeding years (Wilson *et al.*, 2006), so including plant species favoured in both breeding and non-breeding years may help to provide a better quality model to distinguish areas with suitable vegetation for breeding. Vegetation data that provides a quantitative measure of the frequency of plant species in each grid cell would also allow a more detailed assessment of kakapo habitat selection than was possible with the categorical map used in this research. The relevance of using canopy species to categorise vegetation types should also be investigated in future work to determine the relevance of canopy species to kakapo niche requirements and to determine any correlation between canopy species and understorey species important in the kakapo diet. The topographical variables included in the ENFA models could have been improved if a finer scale resolution could have been used. The inclusion of solar radiation variables across the island may also have provided another valuable aspect to identifying the niche requirements of kakapo.

- Ecological modelling of kakapo habitat selection may also be improved if location data from a larger proportion of the kakapo population is used as inputs to models. Including two groups of adult female kakapo (breeders and non-breeders) as the location data for the models in this research probably reduced their robustness as large areas of the island that may have been suitable breeding habitat were not occupied by kakapo. Although including the whole kakapo population on Codfish Island in an ENFA model would reduce the ability to compare between sub-populations, it would provide useful information on the overall habitat requirements of the kakapo population.

- The habitat suitability maps generated in this research estimated that there was significant optimal breeding habitat available on Codfish Island that was not occupied by adult female kakapo, yet some adult females occurred in sub-optimal breeding habitat. Future research that could provide information on the foraging home ranges of non-adult

female kakapo may help to explain why some adult female kakapo occurred in sub-optimal breeding habitat. If future research could show that all optimal breeding habitats on Codfish Island are occupied by either adult female or other kakapo, then this would suggest that the island is at or beyond a carrying-capacity that allows adult female kakapo to breed in low rimu mast years. Such information would confirm the need to either shift non-adult female kakapo from breeding habitats on Codfish Island or to transfer females in sub-optimal breeding habitat to other islands.

• An assessment of any difference between foraging and roosting home ranges was beyond the scope of this study. Research that adds to the work by Trinder (1998) in comparing day and night home ranges would be helpful in determining the relative merits of conducting radio-tracking fieldwork by day or night. As night-time field work is both physically and mentally challenging, I recommend that if extended periods of night-time field work are to be conducted in future studies significant benefits need to be shown to arise from using kakapo foraging rather than roosting information.

• Ideally, any future research comparing breeding success with home range or habitat selection should use breeding data from the same year that radio-tracking data was collected. This was not possible in this study as kakapo did not breed over the 2005/ 2006 summer. Although it was still possible to make comparisons based on breeding status in this research, as females did not appear to move home range locations significantly between breeding and non-breeding years, future work would benefit by relying on less assumptions if breeding data was available from the same year.

• As this coming summer of 2007/ 2008 is predicted to be a similar breeding season to 2005, as a low rimu mast has also been recorded (D. Eason, pers. comm.), collecting information on home ranges used by adult female kakapo would provide a useful independent test of the reliability of the habitat suitability maps estimated in this research. If females over this coming summer occur in sub-optimal breeding habitat and do not breed, then this would indicate that the maps are a reliable estimation of areas that are unsuitable for breeding in low rimu mast years. Similarly, if females that occur in optimal or suitable breeding habitat are able to breed then this would provide independent evidence that the maps reliably predict suitable breeding habitat. Ideally home range information would also be collected this coming summer for other kakapo

on the island, although this would be extremely time consuming. Any information collected on home ranges of non-adult female kakapo thought to be living in optimal breeding habitat would be the most useful to collect, in addition to home ranges of adult females, as this would help to determine if all optimal breeding habitat on Codfish Island is currently occupied.

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Appendices
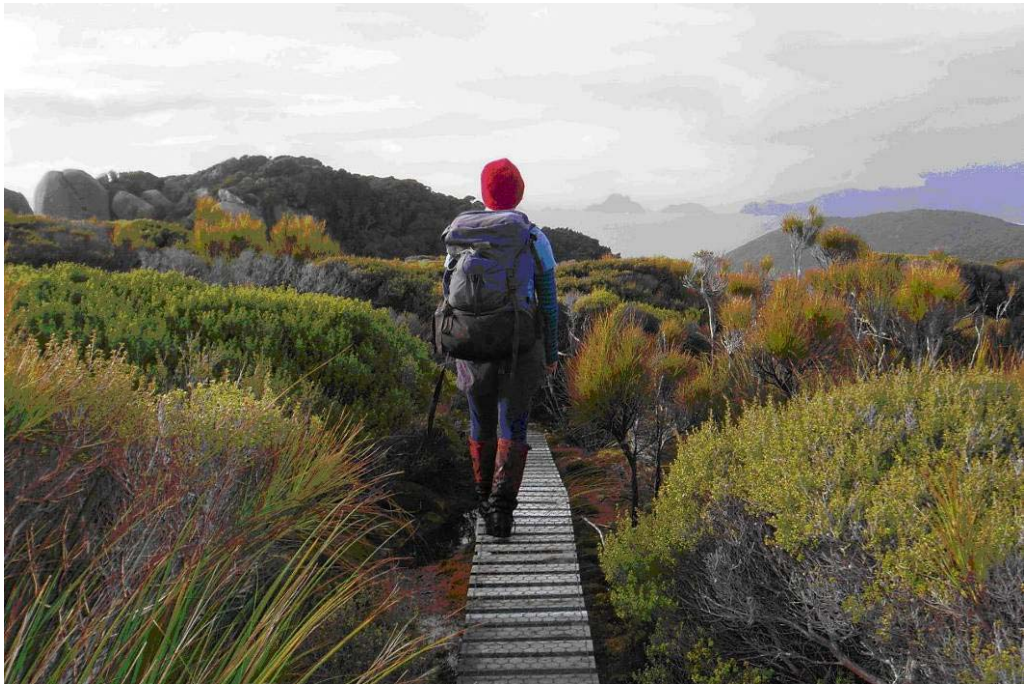
Appendix 1. Historical information for adult female kakapo on Codfish Island: date and location of first capture, age (minimum age in 2006 based on date of capture), island tenures (time spent on islands), CI (consecutive years on Codfish Island up until 2006) and nesting attempts (when & where nested), and nests (number of known nesting attempts on all islands).

Bird	First capture	Age	Island tenure	CI	Known nests	Nests
Alice	Stewart Is, 1981 (adult)	25	CI (1987-1998), PI(1998–1999), CI (1999–present)	7	StI (1981 & 1985), CI (1997), PI (1999), CI (2002 & **2005**)	6
Bella	Stewart Is, 1982	24	LB (1982-1997) CI (1997-1998), PI (1998 – 1999), CI (1999-present)	7	CI (2002 & **2005**)	2
Cyndy	Stewart Is, 1987 (adult)	19	CI (1987–1998), PI (1998-1999), CI (1999-present)	7	CI (1997,2002 & **2005**), PI (1999)	4
Flossie	Stewart Is, 1982	24	LB (1982 – 1996), Maud (1996 – 2001), CI (2001 – present)	5	MI (1998), CI (2002 & **2005**)	3
Fuchsia	Stewart Is, 1991 (adult)	15	MI (1991-2001), CI (2001-present)	5	CI (2002 & **2005**)	2
Heather	Stewart Is, 1982 (juvenile)	24	LB (1982-1998), MI (1998-2001), CI (2001-present)	5	LB (1990, 1991 & 1995), CI (2002)	4
Jane	Stewart Is, 1989 (adult)	17	CI (1989-1998), PI (1998-1999), CI (1999-2002), CH (2002-2005), CI (2005- present)	1	Not known to have nested.	0
Jean	Stewart Is, 1981 (adult)	25	MI (1981-1982), LB (1982-1998), MI (1998-2001), CI (2001-present)	5	StI (1981), LB (1993), CI (2002)	3
Lisa	Stewart Is, 1982	24	LB (1982-1999), MI (1999-2001), CI (2001-present)	5	LB (1999), CI (2002 & **2005**)	3
MM	Stewart Is, 1985 (adult)	21	CI (1988-1998), PI (1998-1999), CI (1999-present)	7	CI (1992, 2002, **2005**)	3
Nora	Stewart Is, 1980 (adult)	26	CI (1987-1998), MI (1998-2001), CI (2001-present)	5	StI (1981 & 1985), CI (1992 & 2002)	4
Ruth	Stewart Is, 1991 (adult)	15	MI (1991-2001), CI (2001-present)	5	CI (2002)	1
Sandra	Stewart Is, 1992 (adult)	14	CI (1992-1998), PI (1998-1999), CI (1999-2002), CH (2002-2004), CI (2004-present)	2	CI (1997 & 2002), PI (1999)	3
Sarah	Stewart Is, 1989	17	CI (1989-1998), PI (1998-1999), CI (1999-2002), CH (2002-2004), CI (2004-present)	2	CI (1992, 1997, 2002 & **2005**)	4
Solstice	Stewart Is, 1997	9	CI (1997-1998), PI (1998-1999), CI (1999-2002), CH (2002-2004), CI (2004-present)	2	CI (2002)	1
Sue	Stewart Is, 1983 (adult)	23	CI (1988-1998), PI (1998-1999), CI (1999-present)	7	StI (1985), CI (1997, 2002 & **2005**)	4
Suzanne	Stewart Is, 1989 (adult)	17	CI (1989-1998), PI (1998-1999), CI (1999-present)	7	CI (1992, 2002 & **2005**), PI (1999)	4
Zephyr	Stewart Is, 1981 (Nora's chick)	25	CI (1990-1998), PI (1998-1999), CI (1999-2002), CH (2002-2004), CI (2004-present)	2	CI (1992, 1997 & 2002), PI (1999)	4

Bird	First capture	Age	Island tenure	CI	Known nests	Nests
Adult females not included in this study						
Hoki	Codfish Is, 1992 (Zephyr's chick)	14	CI (1992), hand-reared & on MI (1992-1997), CI (1997-1998), PI (1998-1999), CI (1999-2002), CH (2002-2004), CI (2004-present)	2	CI (2002)	1
Maggie	Stewart Is, 1980	26	MI (1980-1982), LB (1982-1997), CI (1997-1998), PI (1998-1999), CI (1999-present)	7	LB (1990, 1991 & 1995), CI (2002)	4
Wendy	Stewart Is, 1982 (adult)	24	LB (1982-1998), MI (1998-2001), CI (2001-2002), CH (2002-2004), CI (2004-present)	2	LB (1991, 1993 & 1995), CI (2002)	4

Key: StI = Stewart Island, CI = Codfish Island, LB = Little Barrier Island, PI = Pearl Island, MI = Maud Island

Appendix 2. The number and type of location points collected between 28 March - 30 May 2006 for 18 adult female kakapo on Codfish Island. The mean time (in minutes) taken between the first and last bearings used for triangulations is also shown.

Bird	Triangulations	Sightings	Total points	Mean triangulation time (min)
Alice	32	2	34	17.3 ± 8.9
Bella	23	2	25	18.3 ± 11.0
Cyndy	25	2	27	17.3 ± 9.7
Flossie	28	1	29	13.6 ± 5.6
Fuchsia	29	2	31	15.4 ± 7.6
Heather	22	1	23	13.8 ± 5.0
Jane	32	1	33	13.9 ± 7.8
Jean	27	0	27	14.2 ± 5.8
Lisa	29	0	29	15.1 ± 7.4
Margaret- Maree	27	1	28	12.5 ± 5.0
Nora	31	0	31	18.9 ± 9.3
Ruth	24	4	28	15.0 ± 5.8
Sandra	32	2	34	10.0 ± 4.6
Sarah	20	2	22	11.8 ± 7.1
Solstice	32	1	33	17.7 ± 7.1
Sue	29	1	30	15.3 ± 7.2
Suzanne	23	2	25	7.9 ± 3.0
Zephyr	17	0	17	12.1 ± 4.9
Totals	482	24	506	-
Overall Mean ± Std. dev	26.8 ± 4.5	1.3 ± 1	28.1 ± 4.5	14.6 ± 7.6
Range	17 - 32	0 - 4	17 - 34	$7.9 \pm 3.0 - 18.9 \pm 9.3$

Appendix 3. Actual and triangulated locations of test transmitters (in New Zealand Map Grid co-ordinates) with distance between the two locations shown as an indication of the location error involved in the triangulation method.

Test No.	Actual		Triangulated		Distance between two locations (m)
	Easting	Northing	Easting	Northing	
1	2099244	5368647	2099251	5368650	7
2	2099098	5368694	2099079	5368697	19
3	2098772	5368549	2098773	5368543	6
4	2099022	5368169	2099015	5368174	9
5	2099873	5369629	2099865	5369620	11
6	2099142	5368522	2099138	5368521	4
7	2098772	5368549	2098788	5368516	37
8	2098942	5369054	2098946	5369047	8
9	2098990	5368887	2099003	5368876	17
10	2099038	5368166	2099020	5368151	24
11	2099784	5369654	2099798	5369659	14
12	2101638	5367444	2101611	5367464	33
13	2101334	5367241	2101330	5367246	6
14	2101055	5366668	2101092	5366675	37
15	2100880	5366548	2100865	5366562	22
16	2100942	5368131	2100941	5368138	7
17	2101224	5368205	2101258	5368232	43
18	2101316	5368160	2101326	5368188	30
19	2098914	5367981	2098919	5367989	10
20	2101569	5367298	2101548	5367277	30
21	2101057	5366945	2101065	5366934	14
22	2100880	5366571	2100879	5366566	5
23	2099921	5367358	2099941	5367384	33
24	2100360	5366850	2100391	5366845	30
25	2100560	5367213	2100541	5367228	24
Mean ± standard deviation					19.3 ± 12.2

98

Appendix 4. The number of location points (no. of pts) recorded for each individual between 28 March and 30 May of two breeding years (2002 and 2005) and two non-breeding years (2003 and 2004) on Codfish Island. The proportion of these points (prop. of overlap) that overlapped with the 2006 MCP foraging home range (2DP) was used in a mixed-model ANOVA, explained in the general methods chapter. The breeding status of individuals during the 2005 breeding season is shown by breeders (B) and non-breeders (NB).

Females	2005 breeding status	no. pts in 2006	2006 MCP size (ha)	Breeding years				Non-breeding years			
				2002		2005		2003		2004	
				no. pts	prop. of overlap	no. pts	prop. of overlap	no. pts	prop. of overlap	no. pts	prop. of overlap
Alice	B	34	14.36	11	1.00	15	0.93	4	0.25	1	1.00
Bella	B	25	14.81	11	0.91	19	0.68	4	0.25	3	1.00
Cyndy	B	27	14.76	7	0.29	15	0.40	3	0.33	3	0.67
Flossie	B	29	6.37	18	0.50	14	0.57	4	0.50	3	0.67
Fuchsia	B	31	4.26	11	1.00	14	0.36	-	-	-	-
Lisa	B	29	17.96	3	0.67	9	0.78	4	1.00	3	0.67
MM	B	28	9.26	10	0.70	27	0.85	3	0.67	2	0.50
Sarah	B	22	32.95	9	0.67	19	0.58	-	-	-	-
Sue	B	30	6.16	1	1.00	12	0.50	4	0.75	3	1.00
Suzanne	B	25	13.83	16	0.00	7	0.86	5	0.60	3	0.00
Nora	NB	31	3.13	9	0.11	48	0.17	5	0.20	3	0.67
Heather	NB	23	6.6	12	0.17	13	0.00	5	0.60	3	0.33
Jane	NB	33	14.49	14	0.00	13	0.00	-	-	-	-
Jean	NB	27	5.85	11	0.09	10	0.40	5	0.20	3	0.67
Ruth	NB	28	8.91	14	1.00	10	0.80	4	0.00	3	1.00
Sandra	NB	34	4.09	8	0.38	12	1.00	-	-	-	-
Solstice	NB	33	7.54	8	0.63	15	0.67	-	-	-	-
Zephyr	NB	17	5.21	6	0.00	13	0.23	-	-	-	-
Mean: -all birds present		28.11	10.59	5.49	0.51	15.83	0.54	4.17	0.45	2.75	0.68
- 2005 breeders		28.00	13.47	9.70	0.67	15.10	0.65	3.88	0.54	2.63	0.69
- 2005 non-breeders		28.25	6.98	10.25	0.30	16.75	0.41	4.75	0.25	3.00	0.67

Note: A dash (-) indicates that the female was not resident on Codfish Island during that period. Only females that were resident in all years were included in the mixed-model ANOVA and included in calculations of mean values.

Appendix 5. Diagrams showing foraging location points, MCP and kernel (95, 75 and 50%) home ranges for each of the 18 adult female kakapo selected for this study.

(a)

(b)
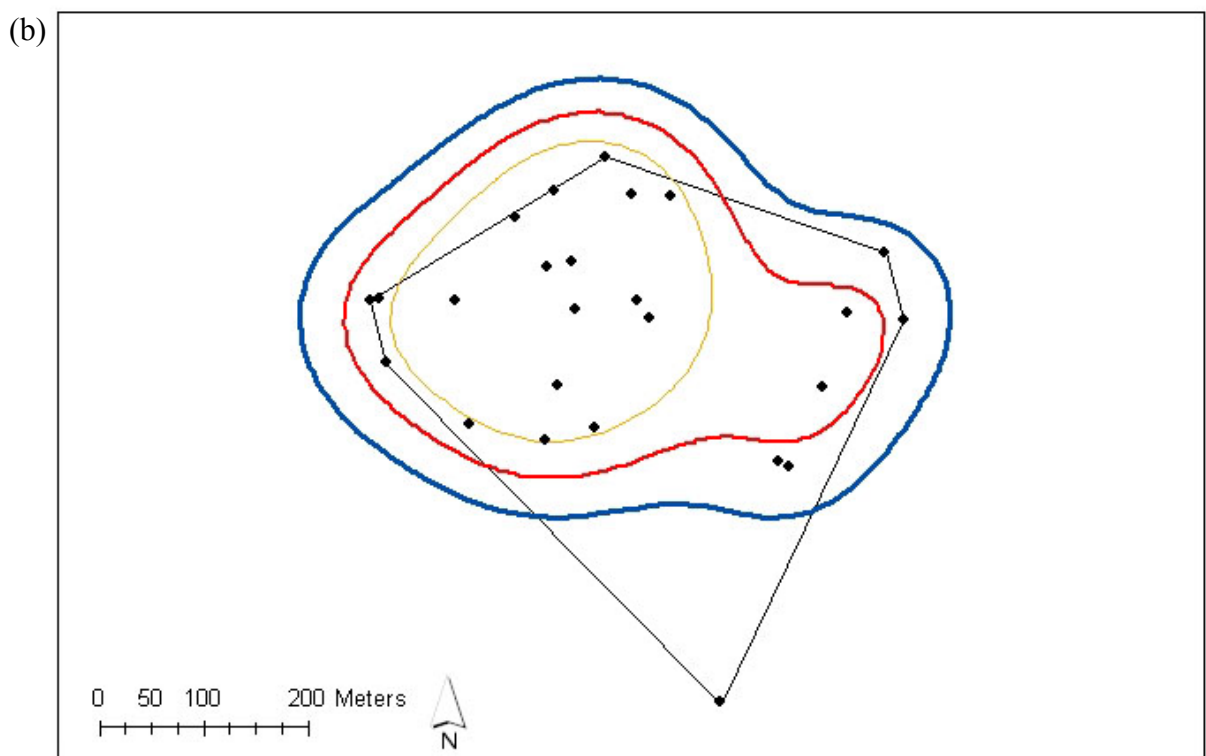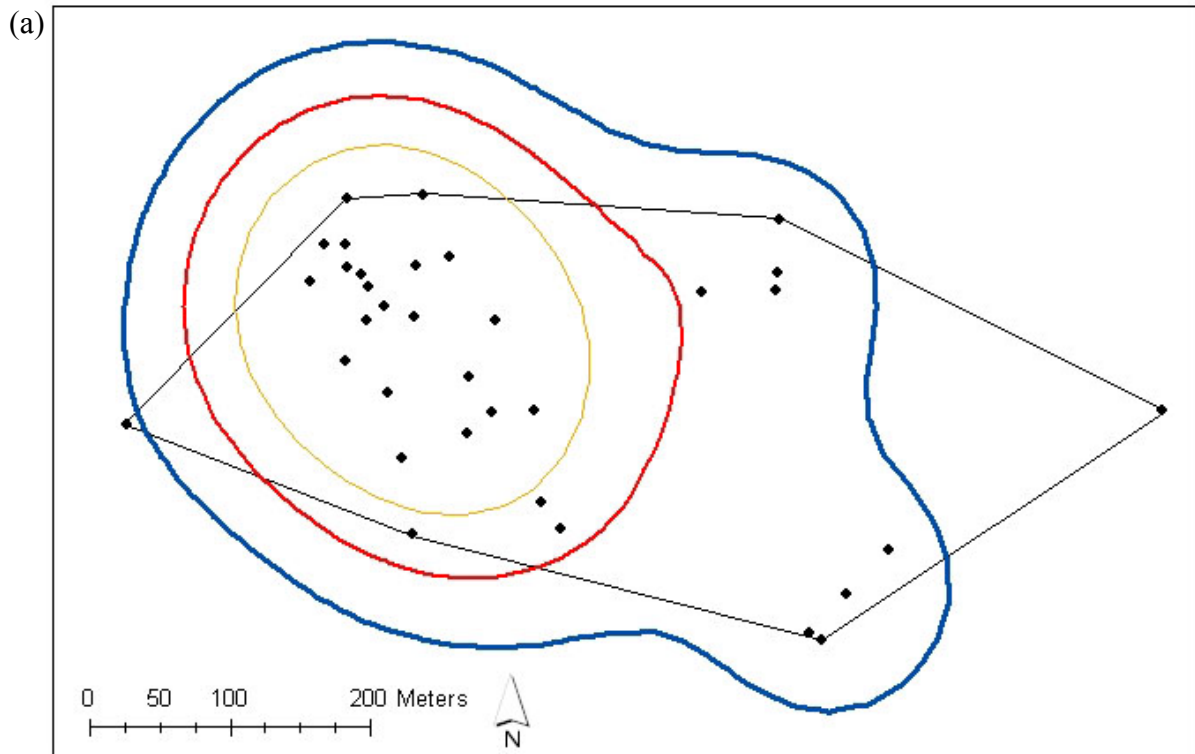
Appendix 5.1. Foraging locations and home ranges for (a) Alice and (b) Bella, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.
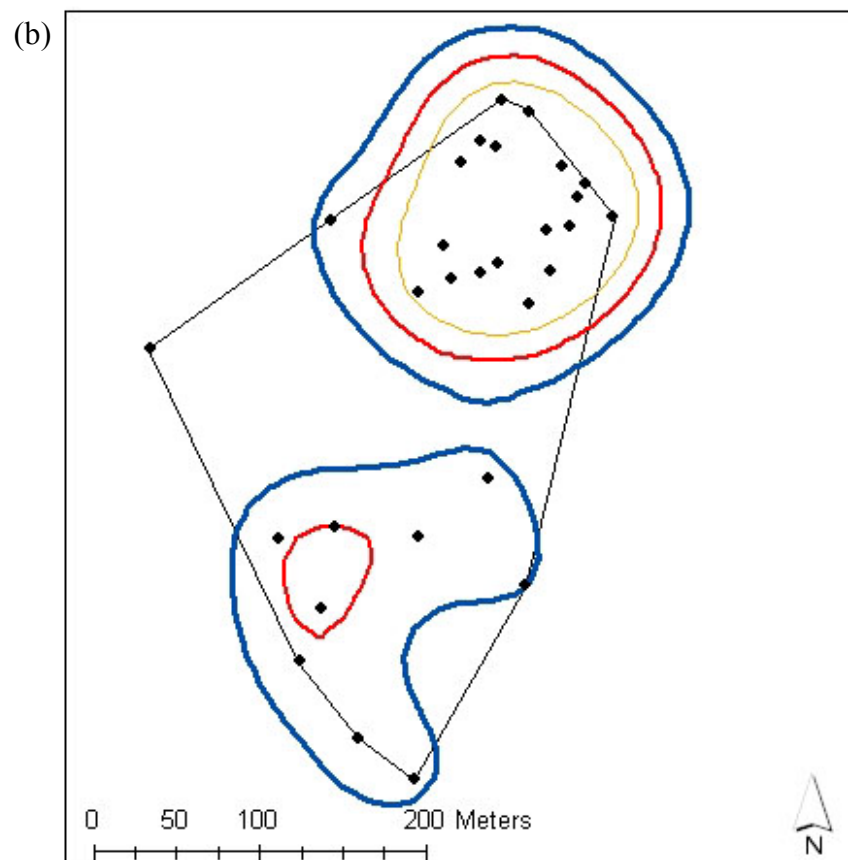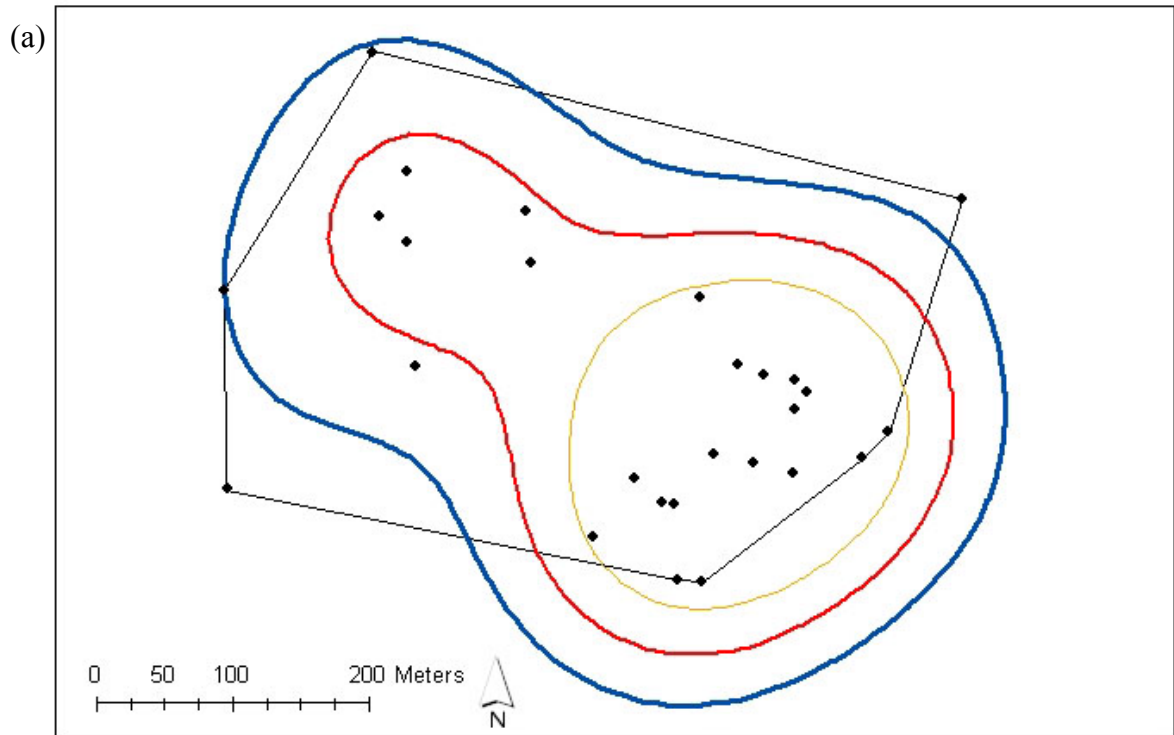
Appendix 5.2. Foraging locations and home ranges for (a) Cyndy and (b) Flossie, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.
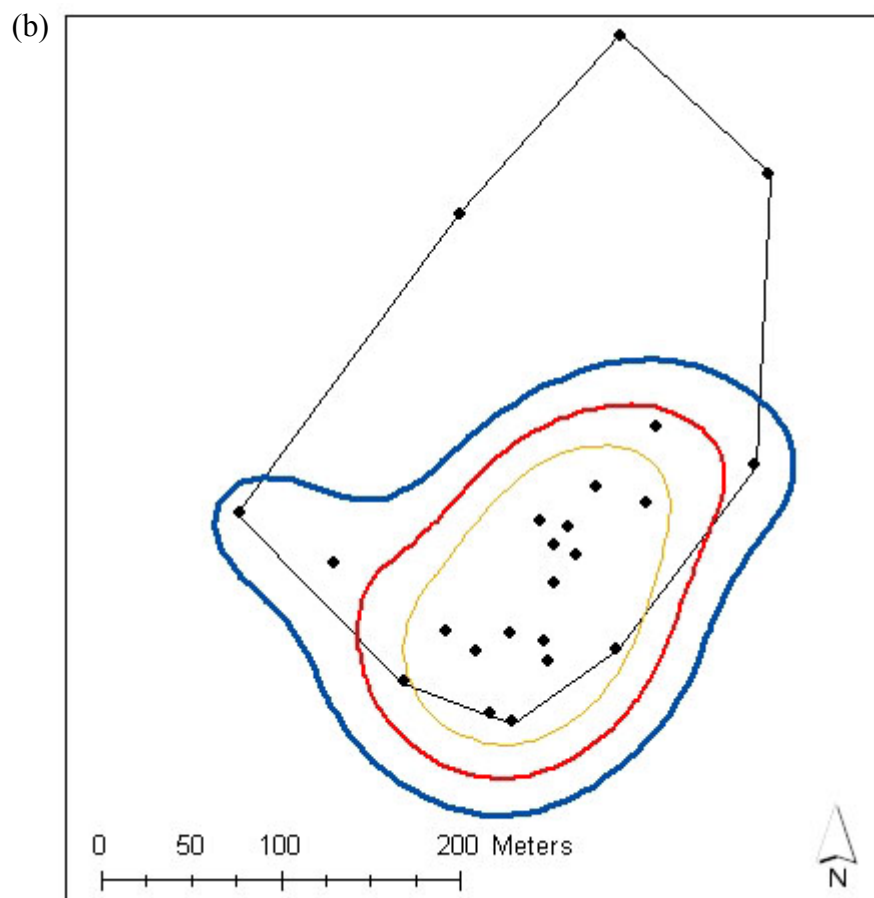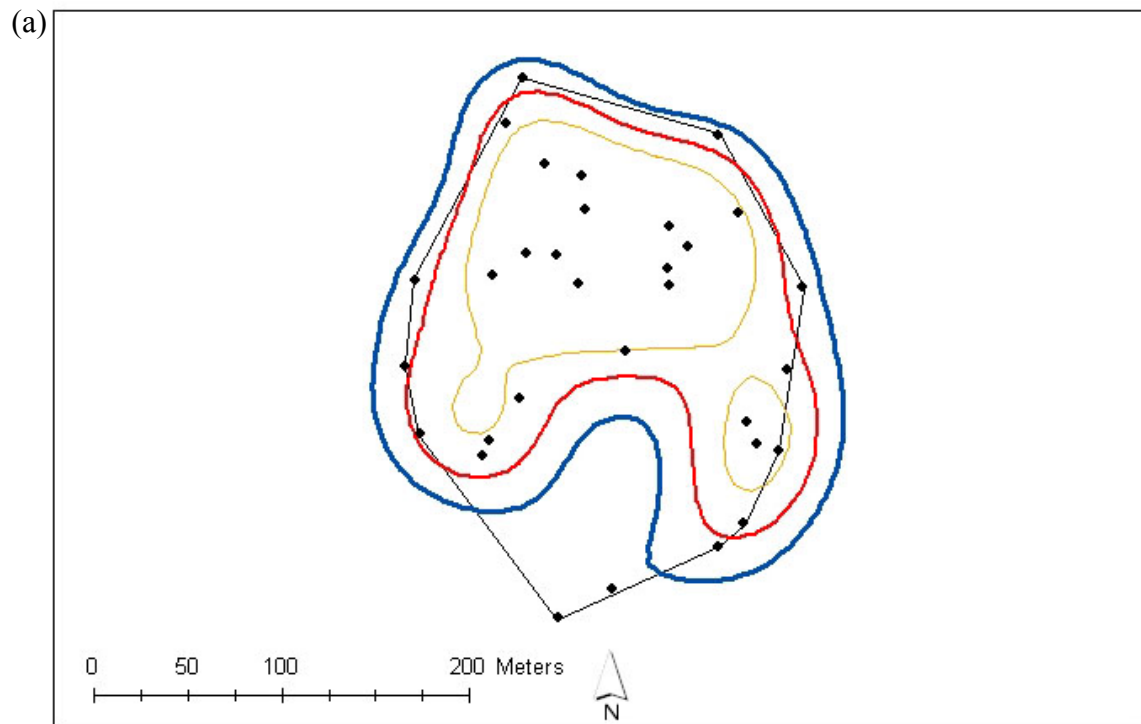
Appendix 5.3. Foraging locations and home ranges for (a) Fuchsia and (b) Heather, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.

Appendix 5.4. Foraging locations and home ranges for (a) Jane and (b) Jean, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.
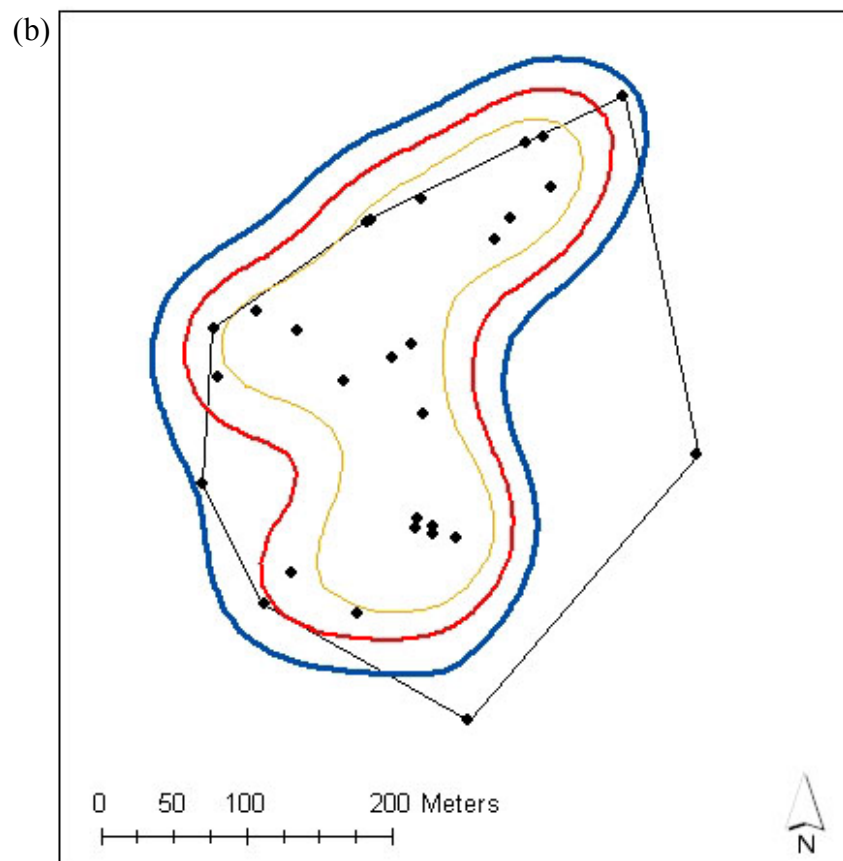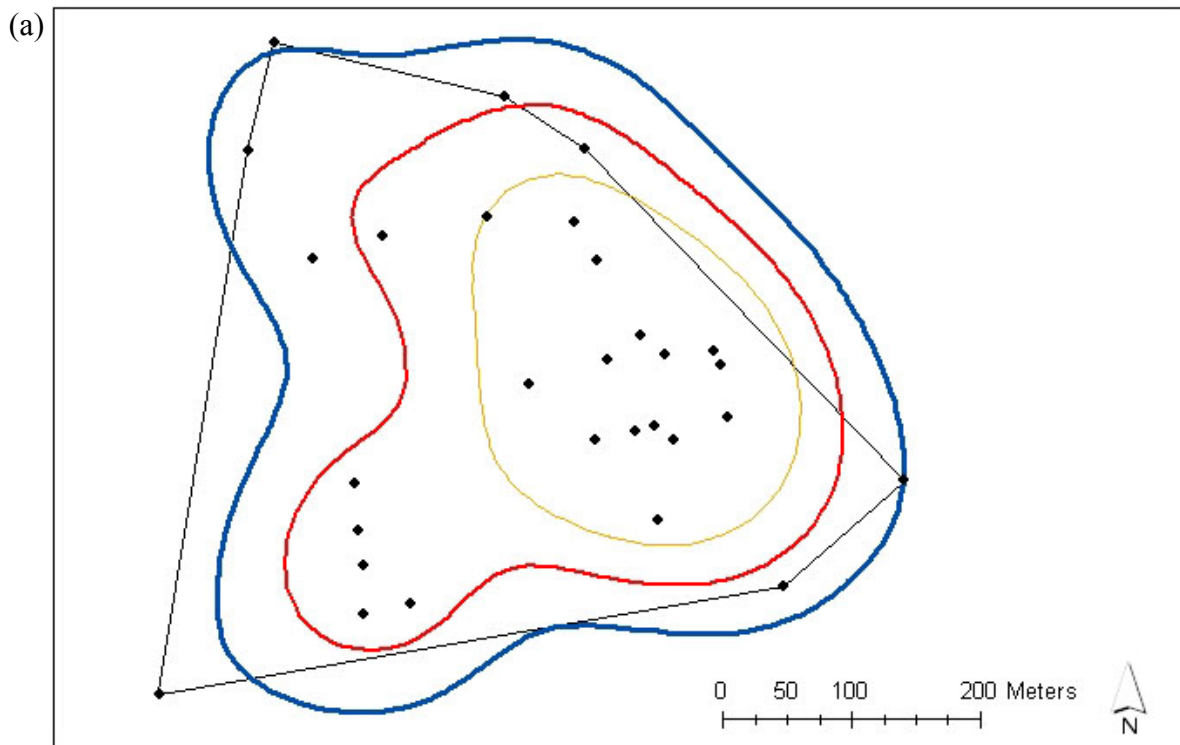
Appendix 5.5. Foraging locations and home ranges for (a) Lisa and (b) Margaret-maree, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.
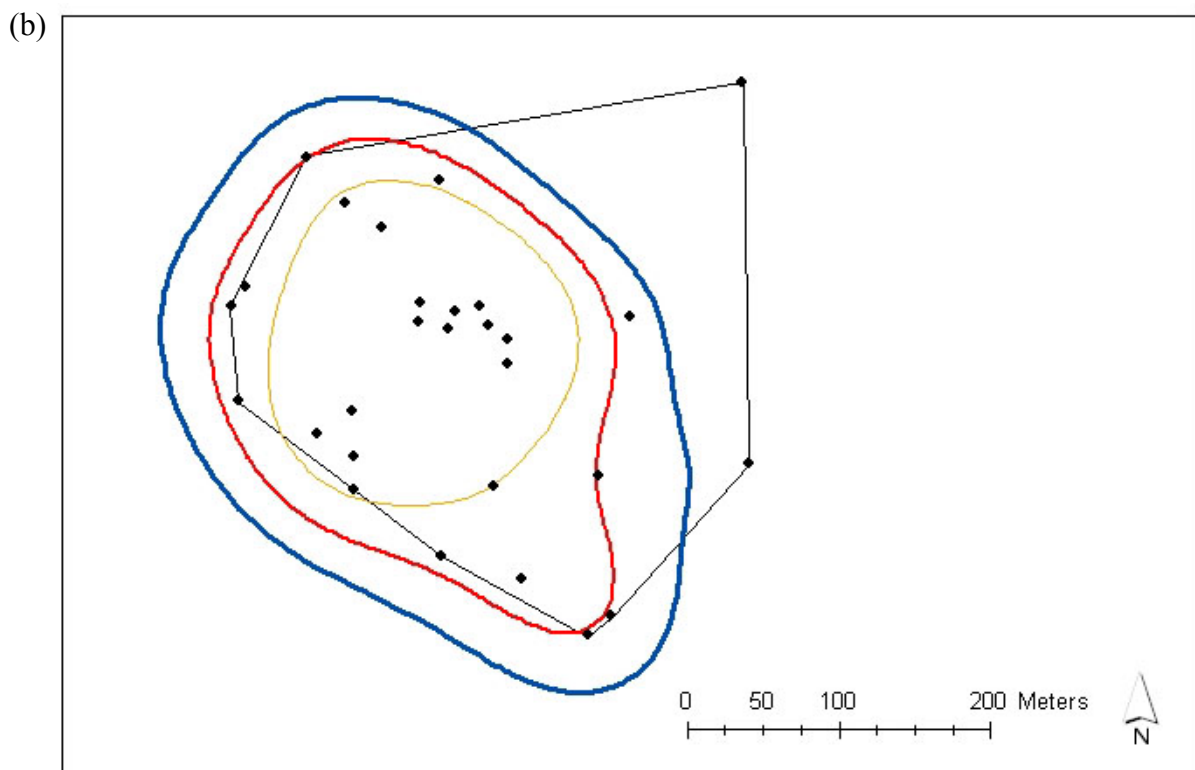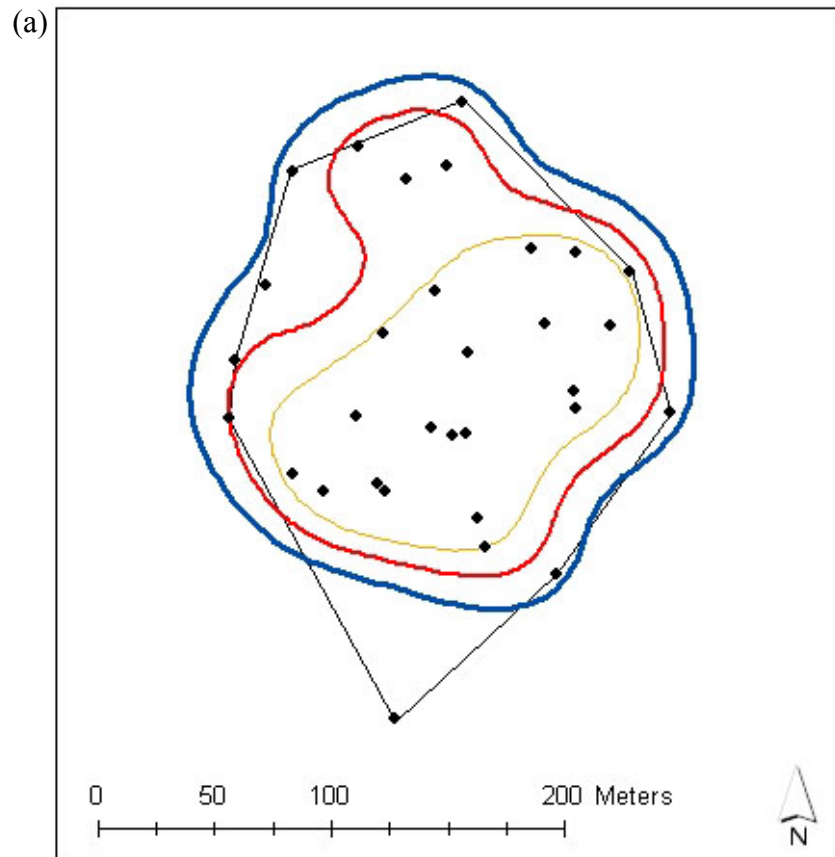
Appendix 5.6. Foraging locations and home ranges for (a) Nora and (b) Ruth, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.
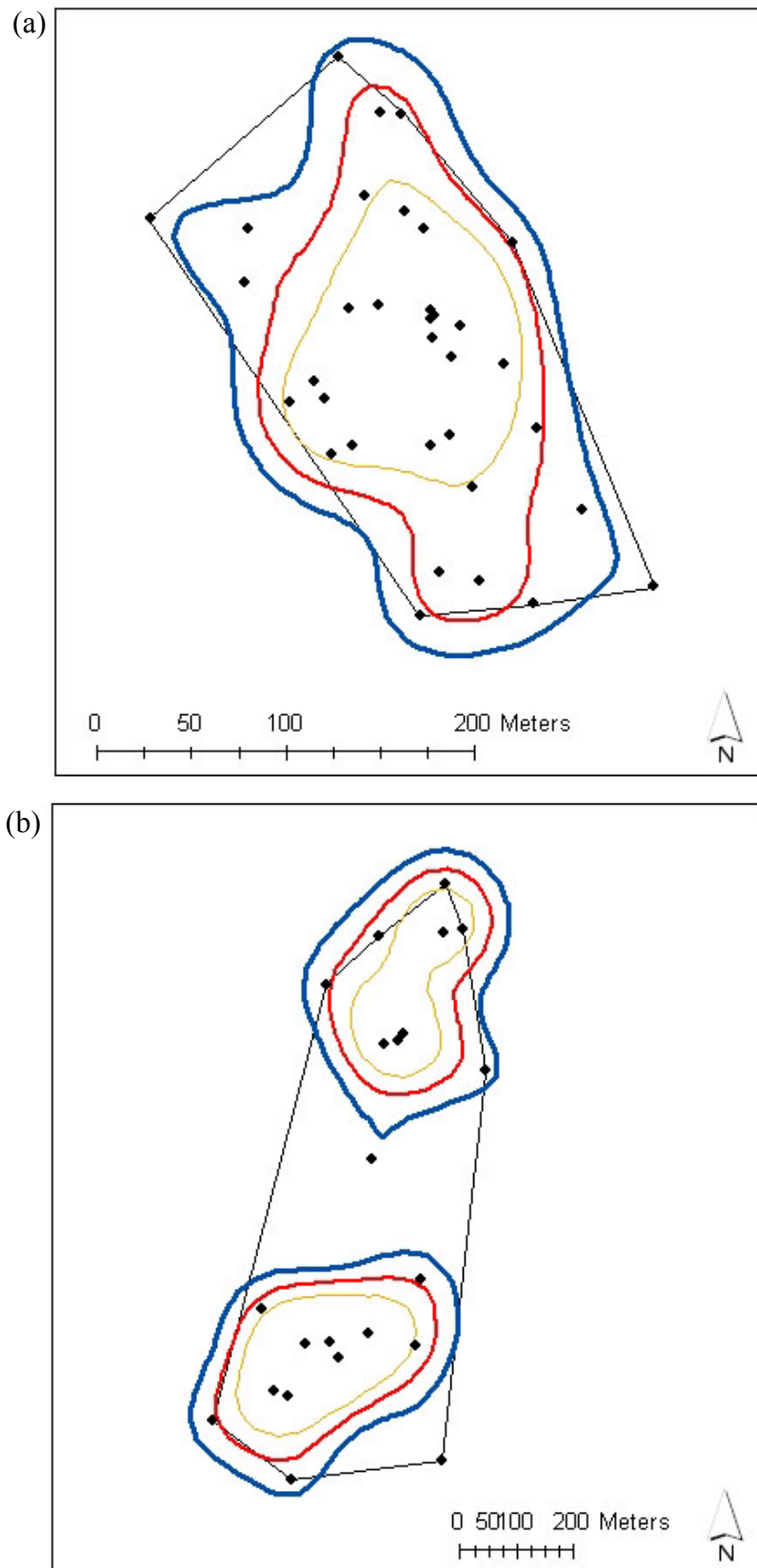
Appendix 5.7. Foraging locations and home ranges for (a) Sandra and (b) Sarah, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.
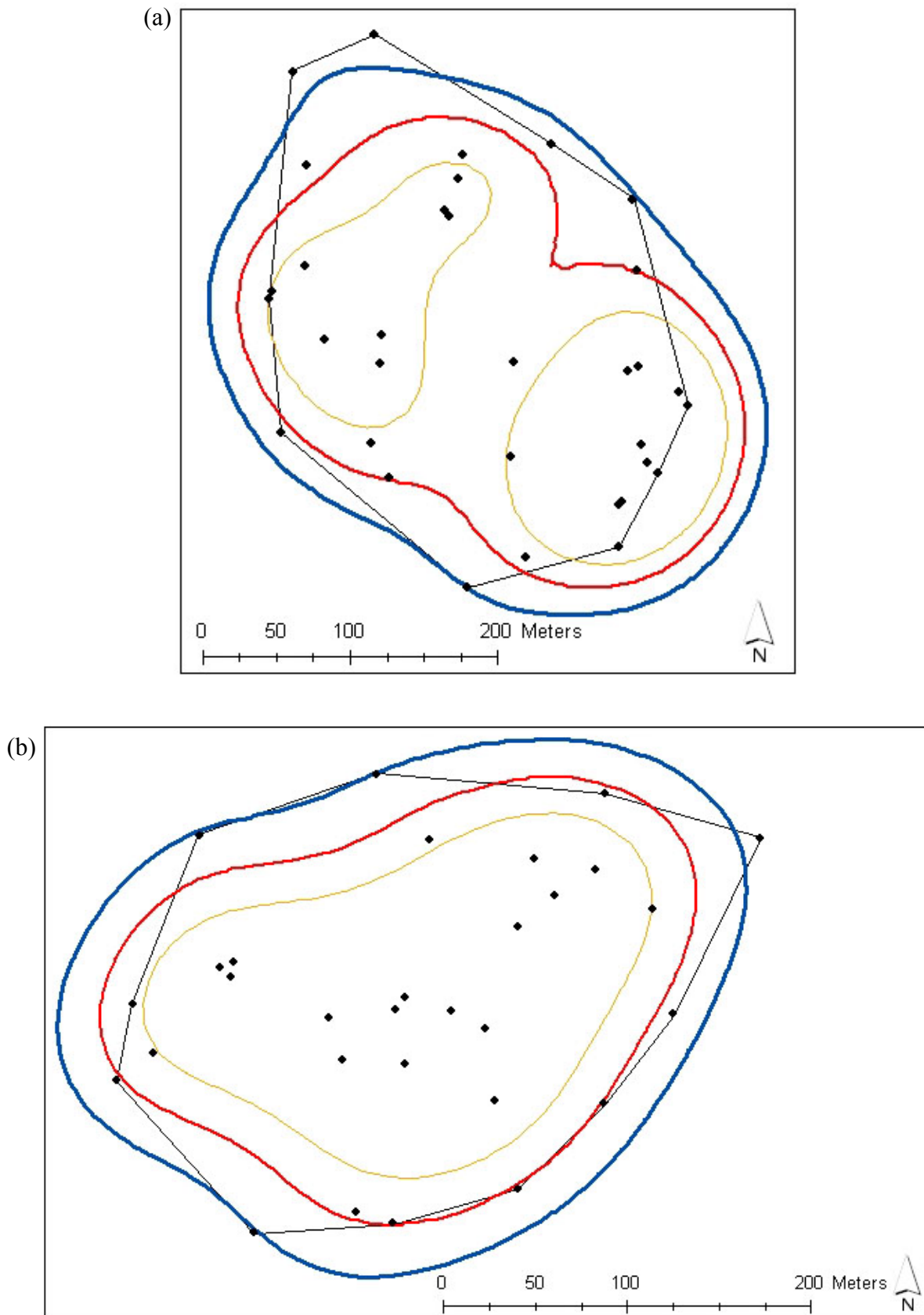
Appendix 5.8. Foraging locations and home ranges for (a) Solstice and (b) Sue, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.

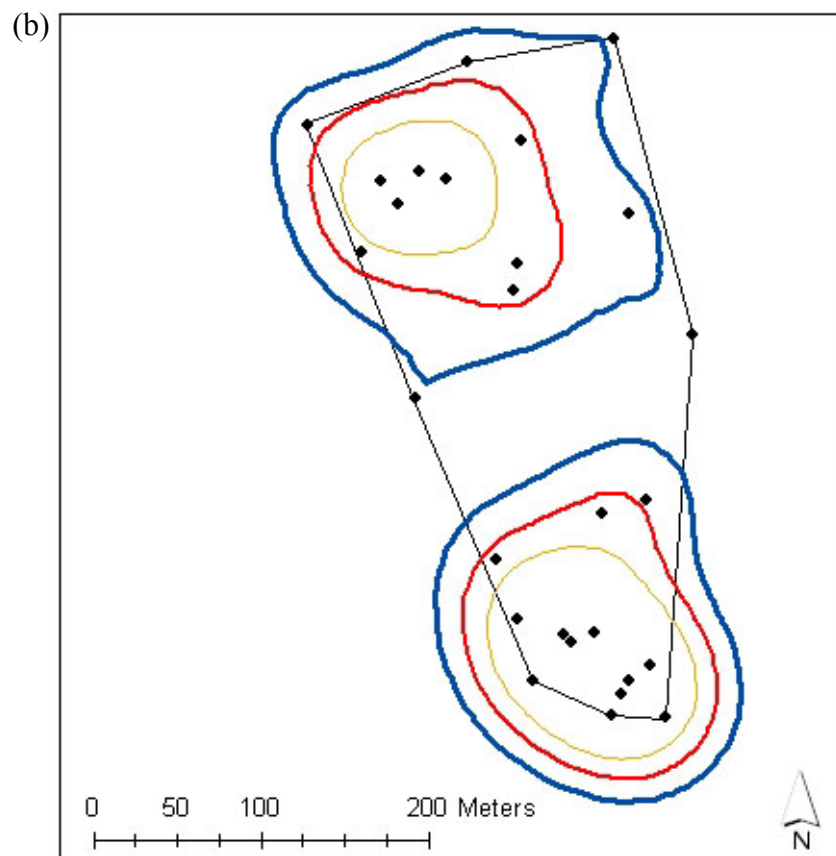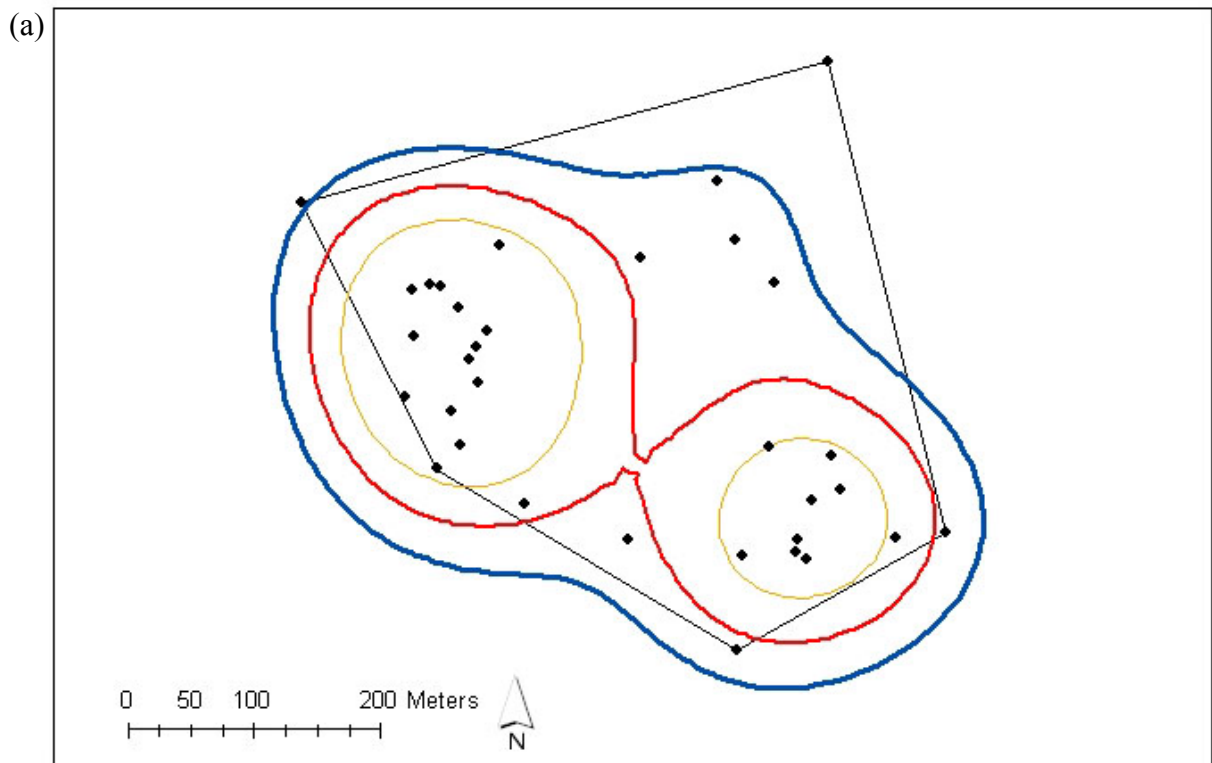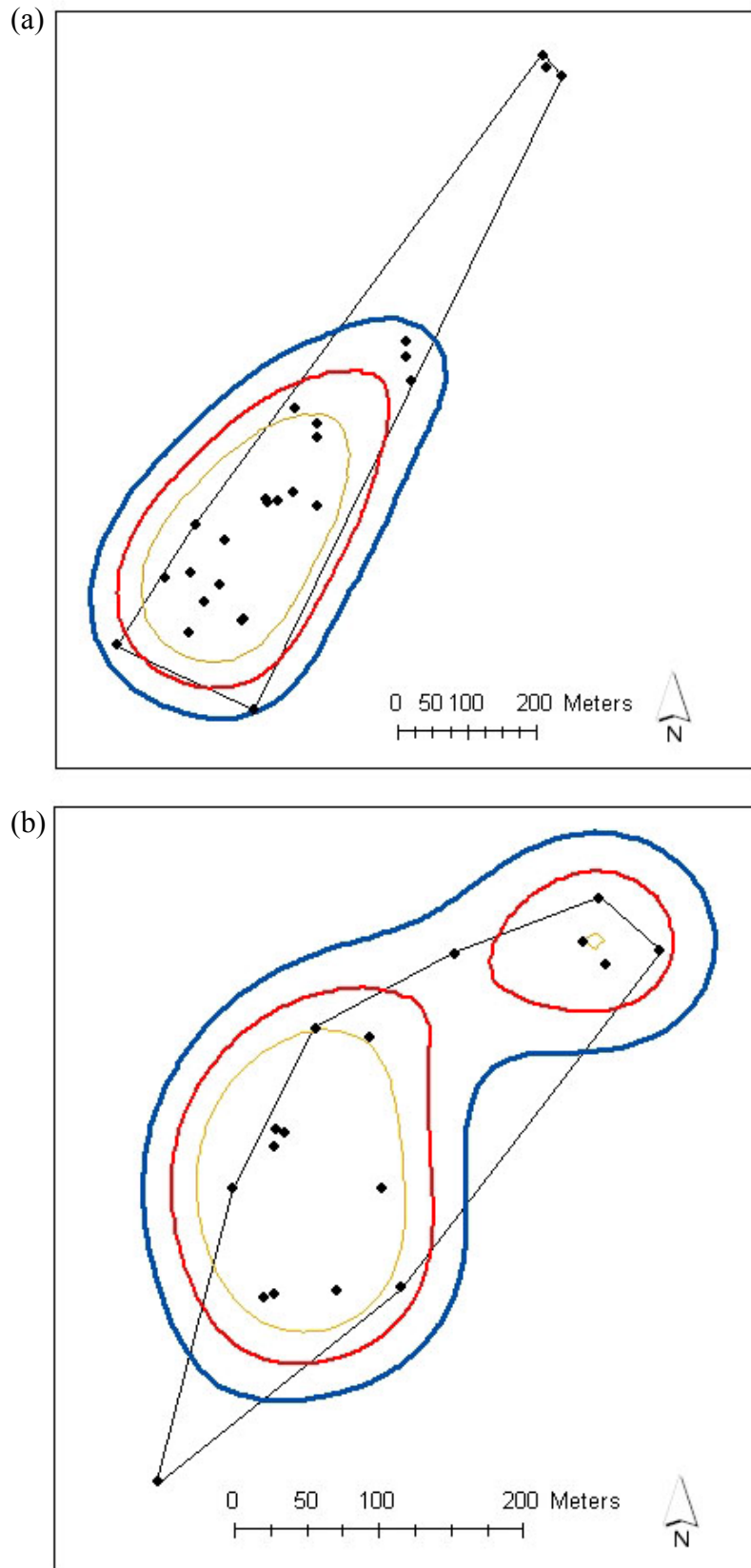Appendix 5.9. Foraging locations and home ranges for (a) Suzanne and (b) Zephyr, showing foraging location points (black circles), MCP home ranges (black polygon), 95% kernel (blue), 75% kernel (red) and 50% kernel (yellow) home ranges.

Appendix 6. Incremental area analysis plots used to estimate home range asymptotes for MCP home ranges.
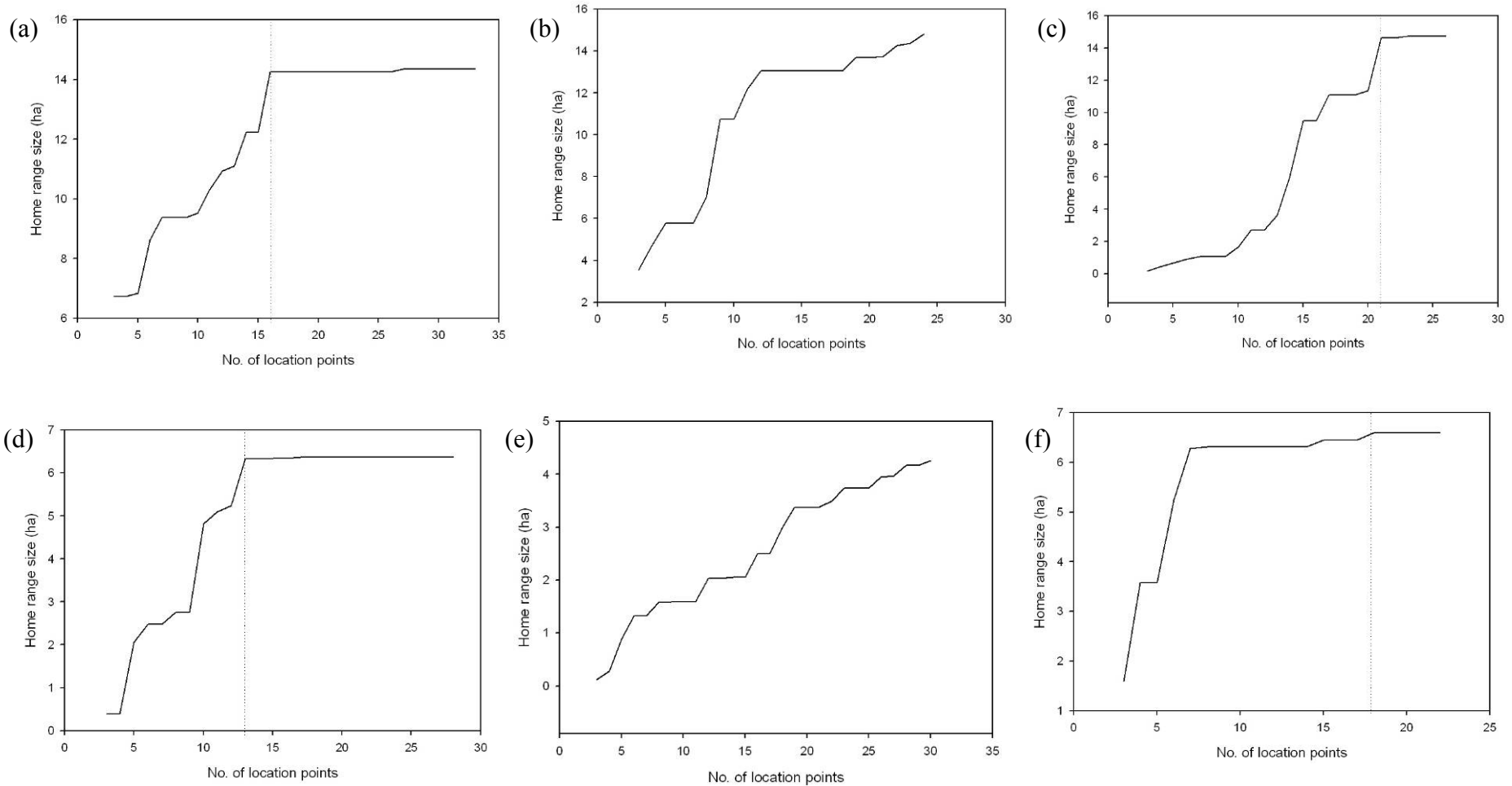
Appendix 6.1. Incremental area analysis charts for (a) Alice, (b) Bella, (c) Cyndy, (d) Flossie, (e) Fuchsia and (f) Heather. The point at which an asymptote is reached is shown by a dotted line. No line indicates the home range was not fully estimated.
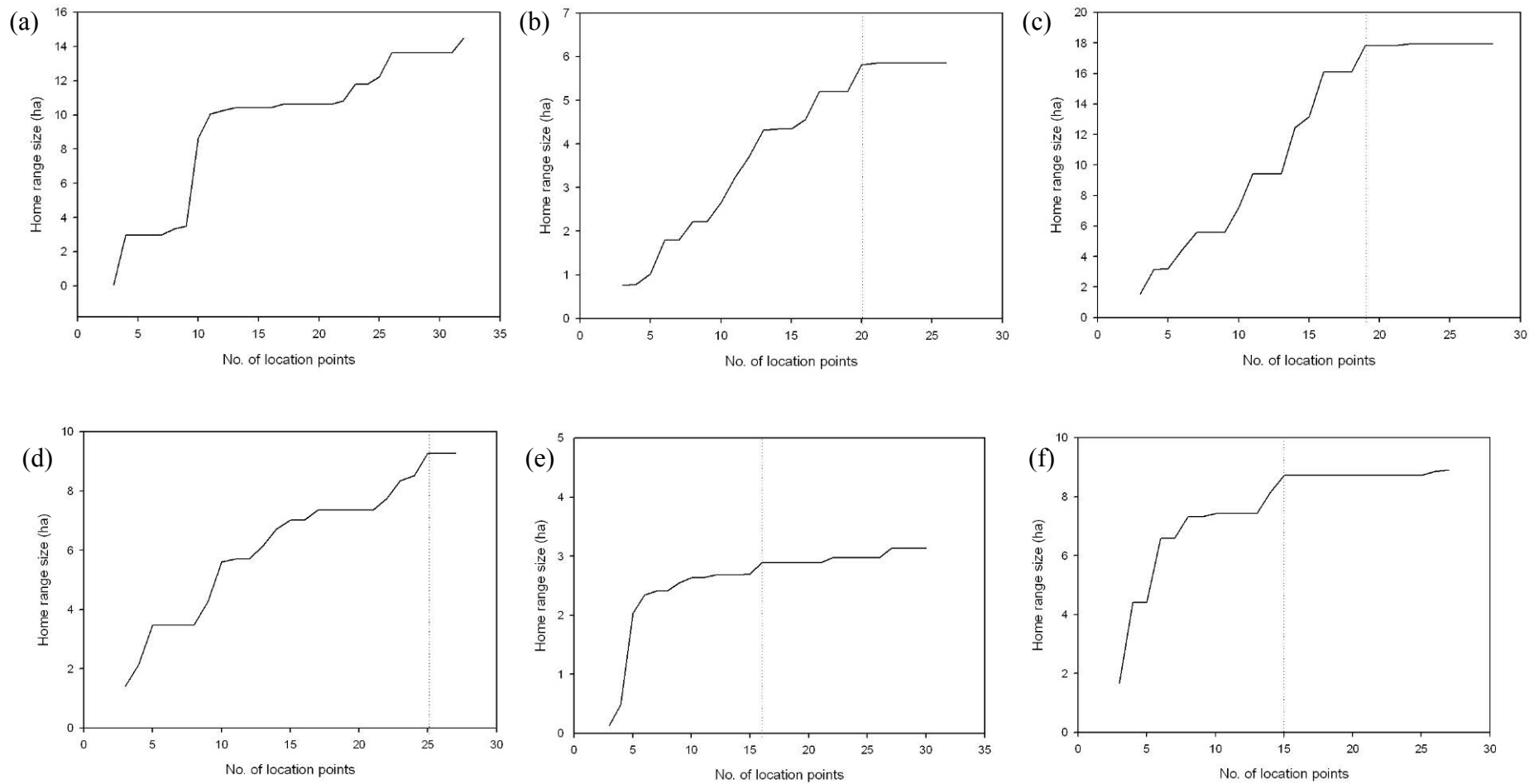
Appendix 6.2. Incremental area analysis charts for (a) Jane, (b) Jean, (c) Lisa, (d) Margaret-maree, (e) Nora and (f) Ruth. The point at which an asymptote is reached is shown by a dotted line. No line indicates the home range was not fully estimated.
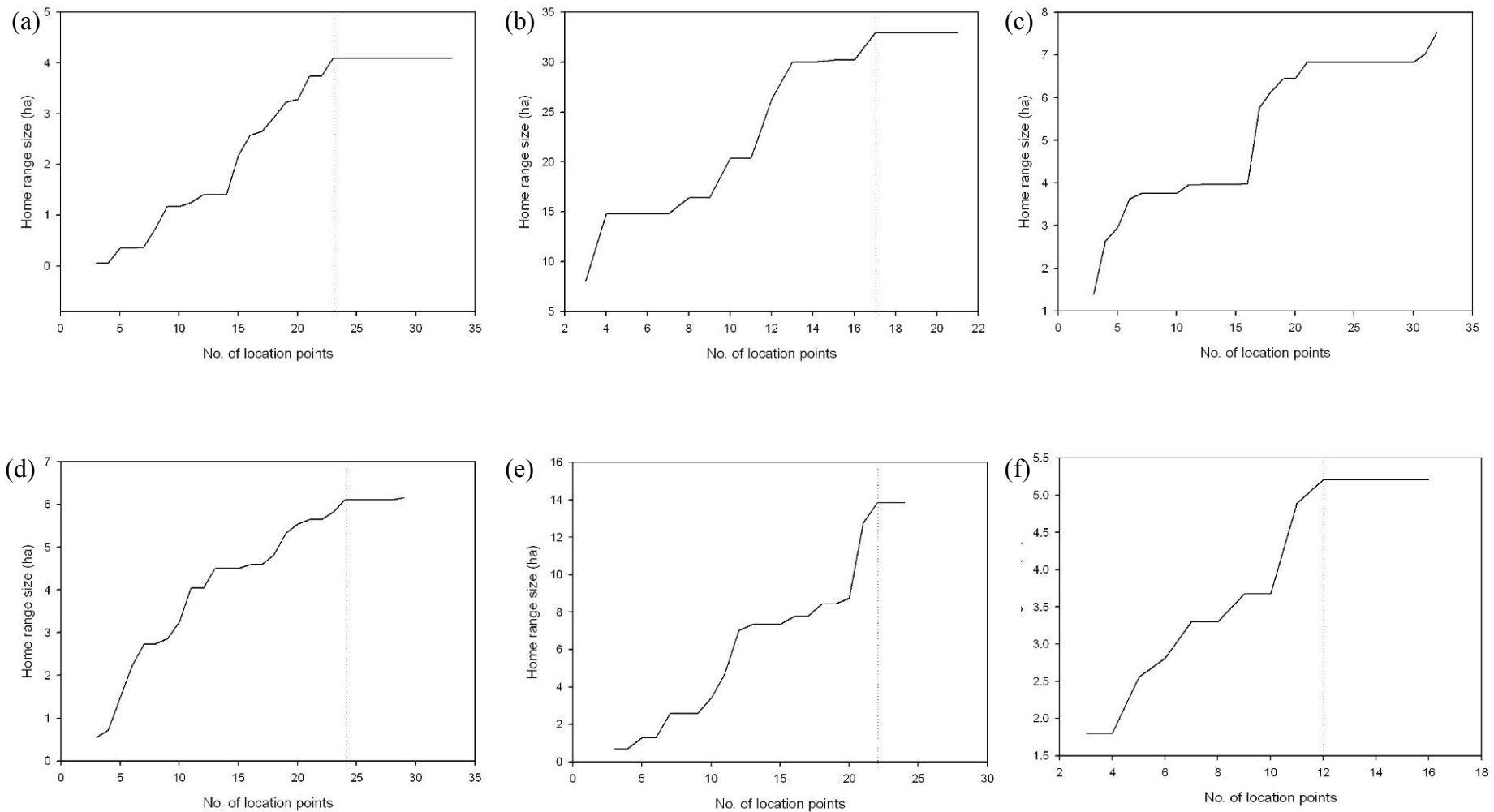
Appendix 6.3. Incremental area analysis charts for (a) Sandra, (b) Sarah, (c) Solstice, (d) Sue, (e) Suzanne and (f) Zephyr. The point at which an asymptote is reached is shown by a dotted line. No line indicates the home range was not fully estimated.

Appendix 7. Analysis of air temperature differences during March/ April and May during the study, used to explain why locations were often recorded at lower elevations in the later period.

The mean minimum and maximum temperatures collected at sea level on Codfish Island were compared for two periods: March/ April and May 2006. Using the statistical package R (R Development Core Team, 2005) the mean minimum temperatures were compared using the non-parametric Wilcoxon rank sum test, as the data was not normally distributed. The mean minimum temperature for the first study period was 8.8 ± 3.0 $^{\circ}$C, significantly higher than the mean minimum temperature for the second study period of 3.5 ± 3.5 $^{\circ}$C (W = 560.5, p-value = 6.335e-06). The mean maximum temperatures were normally distributed so these data sets were compared using a two sample t-test. The mean maximum temperature for the first study period was 17.2 ± 2.9 $^{\circ}$C, significantly higher than the mean maximum temperature for the later study period of 12.9 ± 2.0 $^{\circ}$C (t = 6.2329, df = 49, p-value = 1.023e-07).
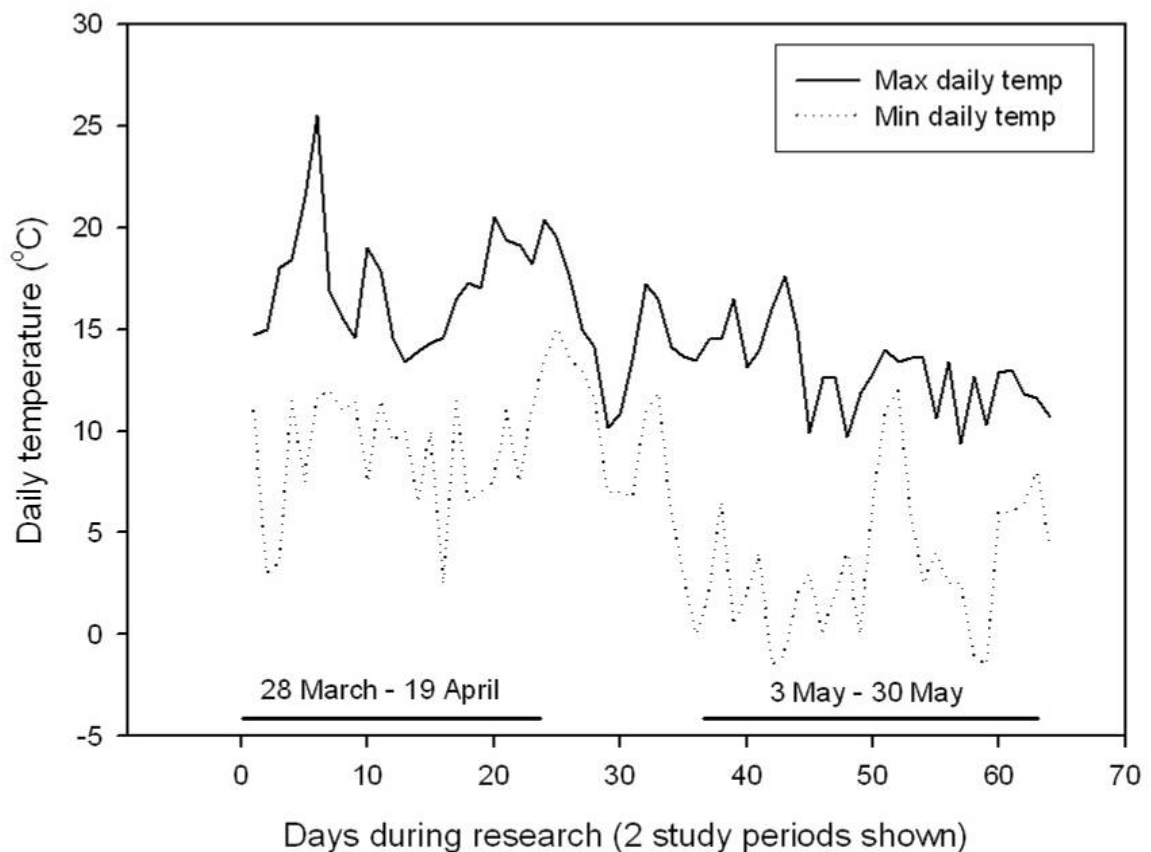
Appendix 7a. Daily maximum and minimum temperatures recorded at sea level on Codfish Island during the two study periods March/April and May 2006.

Appendix 8. The sixteen vegetation classes from the original vegetation map of Codfish Island (Waikato University, 2005) are described according to the main species present in the canopy and sub-canopy, with some references made to the understorey vegetation. The abundance of mature rimu forest in the original vegetation classes is highlighted in bold and the corresponding rimu abundance class shown for each vegetation type. The maximum canopy height is shown for each vegetation type and the original vegetation classes merged to make the aggregated vegetation map are also shown.

Original Vegetation Classes	Description of original vegetation classes	Rimu classes	Canopy height classes	Aggregated Vegetation Classes
MIRO-RIMU	**Dense** miro and **rimu forest**, greater than 20 metres tall, and with a predominance of miro. Additional secondary species include kamahi, rata and occasional totara.	High rimu	20m	Rimu-miro
RIMU-MIRO	**Dense rimu forest**, greater than 20 metres tall. Secondary species include miro and rata, but kamahi can be locally common. The forest class can be interspersed with occasional totara.	High rimu	20m	
RATA	Predominantly rata forest, typically less than 5 metres tall, often with patches of manuka. Understorey often consists of draco.	No rimu	5m	Rata-podocarp
RATA-POD-SH	Short Rata dominated forest **interspersed with podocarps** that are generally less than 5 metres tall. Occasional kamahi. Understorey is commonly draco. Possibly regenerating forest.	Moderate rimu	5m	
POD-MIX-STUNTED	**Predominantly mixed rimu**, miro and totara forest between 10 to 20 metres tall, with numerous rata, occasional kamahi and an understorey often consisting of draco.	High rimu	15m	Mixed-podocarp-stunted
COASTAL-DAISY	Daisy forest scrub with olearia and draco.	No rimu	5m	Coastal daisy/ pakahi
PAKAHI-SCRUB	Manuka and draco scrub, predominantly between 1 and 2 metres tall, interspersed with rata, oleria and mingimingi. Mostly in pakahi.	No rimu	5m	
COASTAL-SCRUB	Scrub with strong coastal influence including senecio, broadleaf, hebe, and kamahi. In wetter areas fern.	No rimu	5m	Other
KAMAHI	Predominantly kamahi forest, often in pure stands, but occasionally **interspersed with podocarps** and rata	Moderate rimu	15m	
KAM-RATA	Predominantly kamahi forest with frequent rata. Also **occasionally interspersed with podocarps.**	Moderate rimu	15m	
RIMU-RATA	**Rimu forest** interspersed with rata and miro. Canopy height is typically greater than 20 metres. The class differs from 5) by rata dominating over miro as the predominant secondary species	High rimu	20m	
KAM-POD	**Mixed** kamahi/**podocarp forest** typically greater than 20m in height, with occasional rata. Kamahi is a canopy species and comprises of approximately half the forest type composition.	Moderate rimu	20m	
RATA-POD	Tall Rata dominated forest **interspersed with podocarps** that are generally less than 10 metres tall. Occasional kamahi. Understorey is commonly draco.	Moderate rimu	15m	
POD-MIX-TALL	Predominantly **mixed rimu,** miro and totara forest generally greater than 20 metres, with some rata. Found in the valley floor. Typically no draco. Widespread podocarp seedlings	High rimu	20m	
MANUKA-BROADLEAF	Mix of manuka, broadleaf, and hebe found around the hut.	No rimu	5m	
SAND_DUNE	Sand dunes	No rimu	5m	

Appendix 9. The area (in hectares) of each of the 16 vegetation types on the original vegetation map of Codfish Island and the proportion of the island they occupy. The area and proportion of each vegetation type in the 75% kernel home ranges was calculated for all females combined, females that bred (breeders) and those that did not breed (non-breeders) in 2005.

Original vegetation classes	Total for Island		All birds (n = 18)		2005 breeders (n = 10)		2005 non-breeders (n = 8)	
	Area	Prop.	Area	Prop.	Area	Prop.	Area	Prop.
COASTAL-DAISY	292.90	0.20	5.63	0.04	0	0	5.63	0.15
RIMU-MIRO	243.50	0.17	29.67	0.23	25.96	0.29	3.71	0.10
POD-MIX-STUNTED	172.70	0.12	17.45	0.14	14.46	0.16	2.99	0.08
RATA-POD-SH	157.90	0.11	32.81	0.26	24.69	0.28	8.12	0.21
KAM-POD	143.60	0.10	2.98	0.02	1.99	0.02	0.99	0.03
RATA-POD	75.80	0.05	1.39	0.01	1.38	0.02	0.01	0
COASTAL-SCRUB	70.50	0.05	2.24	0.02	2.24	0.03	0	0
KAMAHI	68.00	0.05	0	0	0	0	0	0
RIMU-RATA	51.90	0.04	3.56	0.03	3.56	0.04	0	0
RATA	46.90	0.03	12.85	0.10	5.07	0.06	7.78	0.20
MIRO-RIMU	45.20	0.03	14.21	0.11	8.52	0.10	5.69	0.15
PAKAHI-SCRUB	41.40	0.03	4.02	0.03	0.14	0	3.88	0.10
POD-MIX-TALL	33.80	0.02	1.24	0.01	1.24	0.01	0	0
KAM-RATA	24.20	0.02	0	0	0	0	0	0
SAND_DUNE	4.80	0	0	0	0	0	0	0
MANUKA-BROADLEAF	2.20	0	0	0	0	0	0	0
Totals	1475.3	1.00	128.05	1.00	89.25	1.00	38.8	1.00

Appendix 10. The area (in hectares) and proportion of the five vegetation types on the merged vegetation map of Codfish Island inside the 75% kernel home range estimated for each of the 18 adult female kakapo in this study.

	Coastal daisy-pakahi		Rimu-miro		Mixed-podocarp stunted		Rata-podocarp		Other	
	Area	Prop	Area	Prop	Area	Prop	Area	Prop	Area	Prop
Breeding females in 2005										
Alice	0.14	0.02	5	0.54	0	0	4.07	0.44	0	0
Bella	0	0	9.08	0.75	0.56	0.05	1.9	0.16	0.54	0.04
Cyndy	0	0	1.7	0.17	3.96	0.38	4.52	0.44	0.11	0.01
Flossie	0	0	0	0	1.48	0.54	0	0	1.24	0.46
Fuchsia	0	0	0	0	0	0	2.62	0.82	0.58	0.18
Lisa	0	0	5.78	0.48	6.34	0.52	0	0	0	0
MM	0	0	0.21	0.03	1.59	0.26	3.39	0.55	1.00	0.16
Sarah	0	0	5.06	0.30	0	0	5.33	0.32	6.27	0.38
Sue	0	0	4.01	0.74	0.53	0.10	0.88	0.16	0	0
Suzanne	0	0	3.64	0.32	0	0	7.05	0.62	0.67	0.06
Non-breeding females in 2005										
Heather	2.21	0.77	0	0	0	0	0.66	0.23	0	0
Jane	3.12	0.34	0	0	0.92	0.10	5.24	0.56	0	0
Jean	0.58	0.17	1.9	0.55	0	0.00	0.95	0.28	0	0
Nora	0	0.00	0	0.00	0	0.00	2.41	1.00	0	0
Ruth	0	0.00	3.79	0.61	1.79	0.29	0.65	0.10	0	0
Sandra	0	0.00	0.41	0.15	0.28	0.10	2.02	0.75	0	0
Solstice	0	0.00	3.3	0.47	0	0	2.76	0.39	0.99	0.14
Zephyr	3.6	0.75	0	0	0	0	1.21	0.25	0.01	0.00
Mean ± S.D.										
Breeders	0.01 ± 0.04	0 ± 0	3.45 ± 2.98	0.33 ± 0.29	1.45 ± 2.12	0.19 ± 0.22	2.98 ± 2.34	0.35 ± 0.27	1.04 ± 1.89	0.13 ± 0.17
Non-breeders	1.19 ± 1.54	0.25 ± 0.33	1.18 ± 1.60	0.22 ± 0.27	0.37 ± 0.66	0.06 ± 0.10	1.99 ± 1.54	0.45 ± 0.30	0.13 ± 0.35	0.02 ± 0.05

Appendix 11. Maps of Codfish Island showing the predicted suitability of habitat based on the ENFA models for (a) breeders and (b) non-breeders. Foraging home ranges for breeders (white polygons) and non-breeders (black polygons) are shown. Locations collected for the other 36 kakapo on the island during the study period, that were not included in the radio-tracking study, are also shown. Locations for adult kakapo are shown as black dots and sub-adults are shown as blue dots.

a)
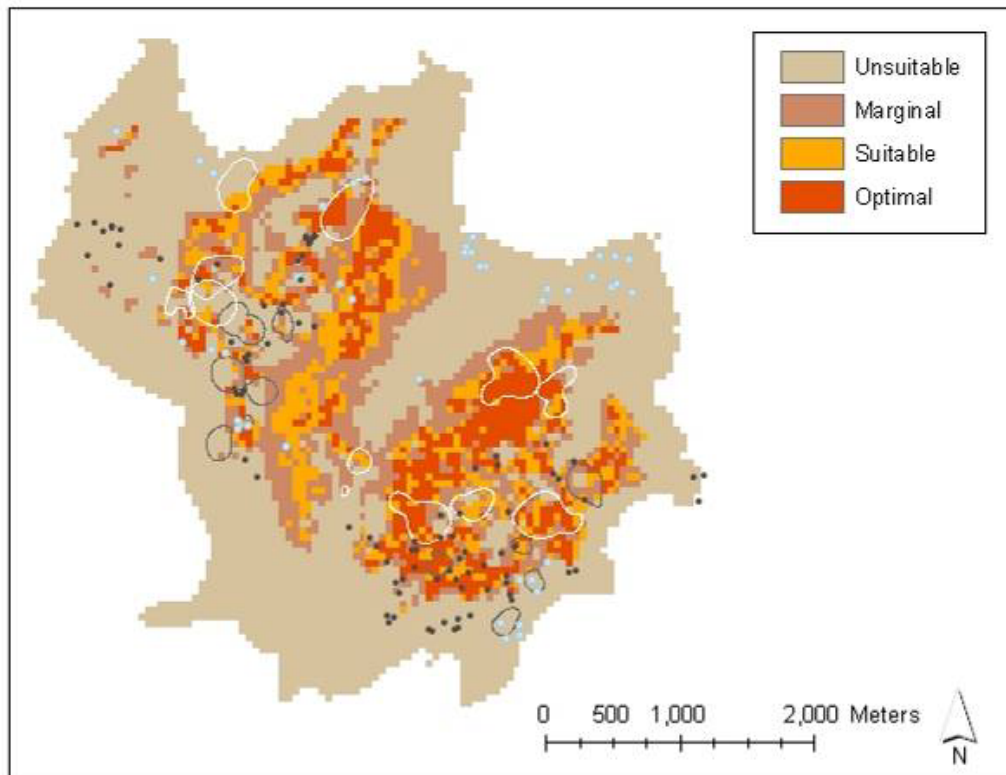
b)
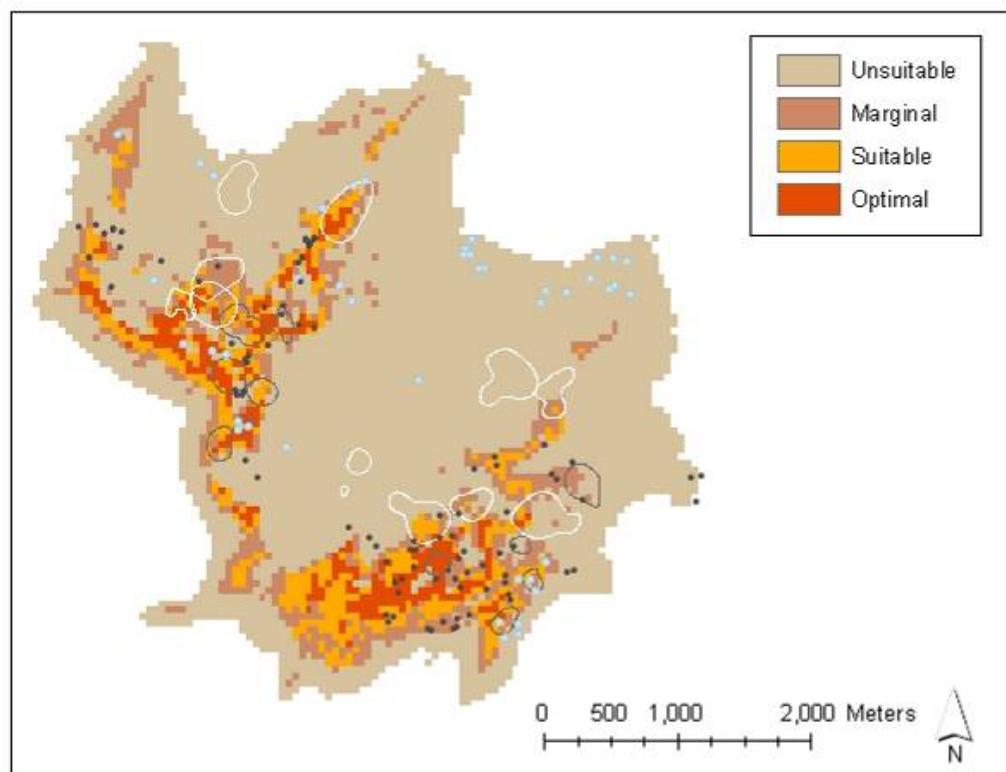
Appendix 12.   Report written in March 2007 based on the results from this thesis research, recommending to the Department of Conservation's National Kakapo Team which adult female kakapo should be transferred from Codfish Island to Anchor Island in Fiordland. It was recommended that females that did not breed in 2005, that were predicted to live in low quality breeding habitats be transferred. The transfer was planned for April 2007, but did not occur due to a larger rimu mast recorded on Codfish Island compared to Anchor Island, indicating that females are more likely to breed on Codfish Island than Anchor Island this coming summer (R. Moorhouse, pers. comm.). As females do not usually move home range locations significantly, the recommendations in this report will probably still be useful for determining which females to transfer to Anchor Island in future years.

Note: Any figures or appendices that were originally included in this report but are also included in the thesis chapters, are not included in this copy of the report to avoid unnecessary repetition. Instead references are made in the text of this report to refer to the relevant figures or appendices in the thesis. References cited in this report are included in the reference list of the thesis.

Recommendations for transferring adult female kakapo to Anchor Island

Report for National Kakapo Team: 16 March 2007

Proposal: To shift five adult female kakapo from Codfish Island to Anchor Island in Fiordland on 18th April 2007, with the aim of increasing the likelihood that the moved birds will breed successfully during the 2007/2008 summer.

Why move breeding-age females?

In low mast years (as occurred in 2005 and is again expected during the 2007/2008 summer) not all adult female kakapo on Codfish Island will attempt to breed. A possible explanation of why some females breed and others don't in low mast years could be differences in availability of natural food resources within a female's home range, especially the presence of mature rimu trees which are thought to trigger kakapo breeding and are the staple diet fed to young chicks. If females are in a habitat that contains few mature rimu trees then it is unlikely that they will breed due to the limited supply of this important food source.

Current research

In my thesis research I am currently investigating the relationship between habitat composition within female home ranges and their breeding history. I have included and expanded on part of this research in the following report in the hope that it will be useful for helping to decide which females to transfer to Anchor Island. The information is as correct as

possible but as it is preliminary it may contain some errors I have not yet been able to assess. Please let me know if you can think of any improvements that could be made or other aspects I should consider.

Analysis for this report

The following analysis aims to test the hypothesis that females with small areas of mature rimu forest within their home ranges are less likely to breed in low mast years. If this is the case then it may be possible to conclude that the area of rimu forest within a female's home range is a limiting factor in her breeding success.

To determine which females should be transferred the following three factors were considered: the size of a female's home range, the area of rimu forest inside her home range and the time a female has spent consecutively on Codfish Island since her last transfer. Some females were transferred from Chalky Island to Codfish Island in mid 2004, so these females may not have been able to find a home range that contained enough rimu for breeding because of the limited space available on the island.

In this report I have presented the data to test this hypothesis (see appendices) and in the limited time available, have attempted to figure out what it all means. There are many constraints of small sample sizes that you will be all too familiar with that have made interpretation of the results difficult. But hopefully the information will be useful for helping to decide which females should be transferred to Anchor Island.

METHODS

General methods

Foraging location data was collected at night for 18 of the 21 adult female kakapo on Codfish Island, between 28th March and 30th May 2006, by triangulation and sightings. After an initial study it was decided not to include Wendy and Maggie as their presence in coastal areas with few tracks made triangulation attempts too inaccurate to be useful for the study. Hoki was also excluded due to bias in sighting locations as she often sought our attention during night time field work. There was no supplementary feeding during this time. A maximum of one location point was collected per bird each evening to avoid pseudo-replication.

Estimates of foraging home ranges

Home ranges were estimated for each female based on the night time foraging location data collected as described above. The Ranges6 software was used to estimate home ranges. Minimum convex polygons (MCP), 95%, 75% and 50% kernels were estimated.

Comparing individuals based on breeding status

The aim of this research was to find out if the home ranges and their vegetation types differed between birds that have bred and those that have not in low rimu mast years to try to determine if these factors may influence breeding attempts. As there was no breeding in 2006 when this detailed study of foraging home ranges was made, it was not possible to use the breeding status (breeder or non-breeder) from this year. As the next best alternative the breeding status of females in the previous breeding season of 2005 was used to classify each individual into breeder or non-breeder that was then used for home range comparisons.

However using the 2005 breeding status to compare the foraging behaviour of individuals in 2006 requires the assumption that females occupied the same home ranges during these two periods. This may not be the case as although kakapo generally stay within similar home ranges for much of the year for a number of years (Merton *et al.*, 1984; Moorhouse & Powlesland, 1991) their foraging behaviour may change between breeding and non-breeding years, which is effectively what is being compared in a 2005 vs 2006 comparison.

To test if individuals used similar home ranges in breeding and non-breeding years, location points for two breeding years (2002 and 2005) and two non-breeding years (2003 and 2004) were compared to the location of the 2006 MCP home range for each individual. The proportion of location points that overlapped with the 2006 home range were compared using a mixed-model ANOVA (refer to section *2.6* in General Methods Chapter and Appendix 4 of thesis).

Comparison of home range sizes

Mean home range sizes for breeders and non-breeders (based on the 2005 breeding season) were compared using the statistical package R (R Development Core Team, 2005). Two sample t-tests were used to compare MCP and 95% kernel ranges, after normality of the data and equality of variances had been confirmed. Comparisons of home range sizes for 75% and 50% kernels were calculated using the non-parametric Wilcoxon rank sum test as this data was not normally distributed.

Calculating rimu abundance in home ranges

A vegetation map of Codfish Island was created by Waikato University during the summer of 2005 (refer to Figure 4.2 in thesis). There are 16 vegetation classes on the map, each with a detailed description of the vegetation composition (refer to Appendix 8). For the purposes of this analysis the vegetation types were grouped into three classes based on the abundance of mature rimu trees (Appendix 8). The number of vegetation types in each rimu class and the total area is shown in Table 1 below. Forest with a different abundance of mature rimu trees differed in it's location across the island (refer to Figure 4.5 in thesis). No rimu areas are mainly coastal, high rimu areas mostly occur in the centre of the island and moderate rimu areas fall between the two.

Table 1. The rimu abundance classes that were used in this analysis including a description, the number of vegetation types included and the area of each rimu abundance class.

Rimu class	Description	No. veg types	Total area (ha)	% of Island area
No rimu	No rimu present	6	458	31
Moderate rimu	Podocarps (occasionally) interspersed in forest, possibility of being rimu	5	470	32
High rimu	Forest dominated by mature rimu	5	547	37

To determine what types of rimu forest were inhabited by the 18 adult female kakapo during this study the MCP home range estimated for each individual was overlaid onto the vegetation map that had been reclassified into a rimu abundance map. The area of each of the three rimu abundance classes that fall within each home range was calculated. This process was repeated for 95% and 75% kernel home range estimates.

Comparison of rimu abundance in home ranges

The mean area of high rimu forest in the home ranges of females that bred in 2005 and those that did not was compared using two sample t-tests for each of the three home range estimation techniques. Tests were conducted in the statistical package R, after normality of the data and equality of variances had been confirmed.

RESULTS

Foraging location data

A total of 506 foraging location points were collected for this analysis, 482 triangulations and 24 sightings. The number of foraging location points collected for each individual kakapo ranged from 17 to 34, with a mean of 28.1 ± 4.52 points.

Comparing individuals based on breeding status

For all individuals combined, 54% of the location points collected in 2005 overlapped with the 2006 foraging home range (Appendix 4). This meant that 46% of location points collected for females in 2005 did not fall within the area used during 2006 for foraging. However this mean value may be deceiving as the actual proportion of overlapping locations is highly variable between individuals (Appendix 4). Proportions range from 0 to 1, with an even spread in between indicating that some birds moved their home range slightly between these two years.

To determine if the degree of overlap between 2005 and 2006 home ranges varied depending on the breeding status of an individual, the mean proportion of 2005 points overlapping with the 2006 home range was compared for breeders and non-breeders using the non-parametric Wilcoxon rank sum test. There was no significant difference between the mean proportion of 2005 points that overlapped with the 2006 home range for breeders and non-breeders from the 2005 season (p-value = 0.155). Breeding status during 2005 made no difference to the proportion of 2005 points that overlapped with the 2006 home range, so it was assumed that 2005 and 2006 home ranges were similar enough to allow 2006 home ranges to be compared based on an individuals 2005 breeding status.

Home range locations

The distribution of female home ranges across Whenua Hou does not appear to be influenced by the breeding status of individuals during the 2005 breeding season, as the foraging home ranges of both breeders and non-breeders were located in similar areas during this study (refer to Figure 3.2 in Chapter 3).

Home range sizes

Home range size was variable between individuals for both MCP and kernel methods, as shown by the large range and high standard deviation of means (Table 2). The size of MCP foraging home ranges varied from 3.13 to 32.95 ha, with a mean size of 10.59 ± 7.22 ha. The size of 95% kernel home ranges varied from 3.47 to 26.51 ha, with a mean size of 11.88 ± 7.07 ha.

Table 2. Size of MCP and kernel home ranges, number (N) of locations used for analysis and individuals that bred during the 2005 breeding season (shown in bold text).

Female	N	MCP (ha)	95% kernel (ha)	75% kernel (ha)	50% kernel (ha)
Alice	34	14.36	19.93	9.21	5.1
Bella	25	14.81	19.02	12.08	6.53
Cyndy	27	14.76	18.02	10.28	4.70
Flossie	29	6.37	6.06	2.71	1.65
Fuchsia	31	4.26	4.71	3.20	1.78
Heather	23	6.60	4.99	2.86	1.69
Jane	33	14.49	16.61	9.28	4.47
Jean	27	5.85	6.32	3.42	1.78
Lisa	29	17.96	21.17	12.12	5.59
Margaret- Maree	28	9.26	8.98	6.18	3.86
Nora	31	3.13	3.47	2.41	1.40
Ruth	28	8.91	9.61	6.23	3.38
Sandra	34	4.09	4.43	2.71	1.44
Sarah	22	32.95	26.51	16.66	9.71
Solstice	33	7.54	9.95	7.05	3.52
Sue	30	6.16	7.84	5.42	3.59
Suzanne	25	13.83	17.97	11.36	6.94
Zephyr	17	5.21	8.30	4.82	2.44
Mean ± Std. dev.	28.1 ± 4.5	10.59 ± 7.22	11.88 ± 7.07	7.11 ± 4.17	3.87 ± 2.29
Range	17 - 34	3.13 – 32.95	3.47 – 26.51	2.41 – 16.66	1.40 – 9.71

Comparison between 2005 breeders and non-breeders

Females that bred during the 2005 breeding season (n = 10) statistically had significantly larger 2006 foraging home ranges than non-breeders (n = 8) for three of the four home range estimation techniques (Table 3).

Table 3. Comparison of mean home range sizes for breeders and non-breeders using different estimation techniques, with results testing for statistical significance.

Estimation technique	Breeders	Non-breeders	Size difference (p-value)
Mean size of MCP (ha)	13.47 ± 8.24	6.98 ± 3.55	< 0.05 (0.043)
Mean size of 95% kernel (ha)	15.02 ± 7.47	7.96 ± 4.24	< 0.05 (0.030)
Mean size of 75% kernel (ha)	8.92 ± 4.46	4.85 ± 2.48	> 0.05 (0.062)
Mean size of 50% kernel (ha)	4.95 ± 2.44	2.52 ± 1.15	< 0.05 (0.016)

Size differences also appear to be biologically significant between breeders and non-breeders with the mean MCP size for breeders (13.47 ± 8.24 ha) being almost twice the size of that for non-breeders (6.98 ± 3.55 ha). This pattern was also repeated for the other home range estimates with breeders on average having home range sizes around twice the size of non-breeders from the 2005 season.

Abundance of rimu forest in home ranges

The area of forest that contained different levels of rimu abundance in the MCP home ranges of each of the 18 adult female kakapo is included as Appendix 1 to this report. Additional tables are included that show the area of high, moderate and no rimu forest in the home ranges of 95% and 75% kernel home ranges (Appendix 2 and 3).

The area of forest containing high rimu abundance is likely to be the most important factor of vegetation types that may impact breeding attempts of female kakapo on Codfish Island. The area of high rimu abundance forest in MCP, 95% and 75% kernel home ranges is shown in Table 4 below for each of the adult females in this study. The proportion of their home range occupied by high rimu forest is also shown as an indication of its importance in their range.

The area of high rimu forest in the MCP home ranges for all birds in the study ranged from zero to 24.2 hectares. There was a lot of variation in the results with a mean of 6.09 ha and a large standard deviation of 6.64 ha. As expected the 95% kernel home range estimate had similar estimates of high rimu abundance with a mean of 6.23 ha and again a large variation of 5.90 ha for the standard deviation. The 75% kernel estimate, that was expected to represent the core home range area, ranged from zero to 12.12 ha of high rimu forest, so some females had no high abundance rimu forest even within their core areas.

Although it appeared that the mean area of high rimu forest differed between 2005 breeders and non-breeders, with breeders having more rimu forest than non-breeders, the difference was not statistically significant because of the variation between individuals. An unpaired Wilcoxon rank sum test was carried out in R comparing the high rimu areas between breeders and non-breeders for each of the three home range estimation methods. The difference between high rimu areas for breeders and non-breeders was almost significant for MCP home ranges (W = 62.5, p-value = 0.049, n = 18) and not significant for 95% kernel (W = 45, p-value = 0.688, n = 18) and not significant for 75% kernel home ranges (W = 43, p-value = 0.823, n = 18).

Table 4. Area of forest with high rimu abundance present in different types of home range estimates for each of the 18 adult female kakapo included in this study. Mean ± standard deviations are included for all females. The breeding status of individuals in the 2005 breeding season is shown by birds that bred (B) and non-breeders (NB). Birds that were transferred from Chalky Island to Codfish Island in July 2004 are shown by yes (Y) or no (N).

Individual	Breeding status in 2005 breeding season	Transferred from Chalky Is in July 2004?	MCP home ranges		95% kernel ranges		75% kernel ranges	
			Area (ha)	Prop. in range	Area (ha)	Prop. in range	Area (ha)	Prop. in range
Alice	B	N	7.61	0.53	9.06	0.45	5	0.54
Bella	B	N	13.03	0.88	15.44	0.81	9.64	0.80
Cyndy	B	N	10.33	0.70	11.26	0.62	5.66	0.55
Flossie	B	N	6.23	0.98	5.71	0.94	2.71	1.00
Fuchsia	B	Y	0	0	0	0	0	0
Heather	NB	N	0	0	0	0	0	0
Jane	NB	Y	2.38	0.16	2.46	0.15	0.92	0.10
Jean	NB	N	5.02	0.86	4.14	0.66	1.9	0.55
Lisa	B	N	17.39	0.97	20.79	0.98	12.12	1.00
MM	B	N	1.25	0.13	2.74	0.31	1.8	0.29
Nora	NB	N	0	0	0	0	0	0
Ruth	NB	N	8.13	0.91	7.47	0.78	5.58	0.90
Sandra	NB	Y	1.34	0.33	1.54	0.35	0.69	0.25
Sarah	B	Y	24.2	0.73	13.31	0.50	8.35	0.50
Solstice	NB	Y	3.93	0.52	4.75	0.48	3.3	0.47
Sue	B	N	5.22	0.85	6.55	0.84	4.54	0.84
Suzanne	B	N	3.48	0.25	6.87	0.38	3.91	0.34
Zephyr	NB	Y	0	0	0	0	0	0
Hoki	NB	Y						
Wendy	NB	Y	These three females were not able to be included in the 2006 foraging study.					
Maggie	NB	N						
Overall: Mean ± s.d.	–	–	6.09 ± 6.64	0.49 ± 0.40	6.23 ± 5.90	0.46 ± 0.34	3.67 ± 3.57	0.45 ± 0.35
Breeders: Mean ± s.d.	–	–	8.87 ± 7.56	0.60 ± 0.36	9.17 ± 6.20	0.58 ± 0.31	5.37 ± 3.72	0.59 ± 0.33
Nonbreeders Mean ± s.d.	–	–	2.60 ± 2.93	0.35 ± 0.38	2.55 ± 2.73	0.30 ± 0.31	1.55 ± 1.99	0.28 ± 0.33

Combining categories- rimu only analysis

A second analysis was conducted combining the two areas of forest that contained rimu (high rimu and moderate rimu) into one category called rimu (Appendix 4). The mean areas of "rimu" forest within the home ranges of 2005 breeders and non-breeders appeared to be different but again each had large standard deviations. To test if these differences were statistically significant the area of rimu forest inside the home ranges of 2005 breeders and non-breeders was compared using the unpaired Wilcoxon rank sum test.

Surprisingly the results for the combined areas of high rimu and moderate rimu showed that the mean area was significantly different in the 2006 home ranges when compared between 2005 breeders and non-breeders. Although the standard deviations were still high, they were smaller than in the previous tests of high rimu only, so this may have accounted for why the results were significant. For the MCP home ranges the mean area of rimu forest in home ranges for breeders was 12.84 ± 7.77 ha, significantly larger than the area for non-breeders of 4.65 ± 2.90 ha (W = 70, p-value = 0.0062, n = 18). For 95% kernel home ranges the mean area of rimu forest inside the home ranges of breeders was 13.95 ± 6.71 ha, significantly larger than the area for non-breeders of 4.79 ± 3.58 ha (W = 69, p-value = 0.0085, n = 18). For 75% kernels the mean area of rimu forest inside the home ranges of breeders was 8.17 ± 4.05 ha, significantly larger than the area for non-breeders of 2.69 ± 2.54 ha (W = 71.5, p-value = 0.0059, n = 18).

Despite the above results being statistically significant they should still be interpreted with caution as a large amount of variation still exists in the data set. For example, despite on average breeders having more rimu in their home ranges than non-breeders this is not always the case. One female that did not breed in 2005 (Solstice) had an area of rimu in her 75% kernel home range that was larger than the area of rimu occupied by five of the females that did breed. Another female that did not breed in 2005 (Ruth) had a rimu area larger than three of the females that did breed. Because of exceptions such as these it is probably not possible to conclude that females require a certain quantity of rimu forest within their home range to be able to breed.

Comparisons based on date of last transfer

It is possible that the time that a female has spent consecutively on Codfish Island (since her last transfer) may impact on the quality of the habitat she is able to occupy. For example females that have been transferred most recently to Codfish Island may have home ranges that have less high rimu areas than birds that have been present for longer time periods. This would occur if kakapo occupy areas because "they were there first" rather than occupying areas based on their social hierarchy.

This concept is again difficult to test statistically because of small sample sizes. Eight females were transferred from Chalky Island to Codfish Island in July of 2004 so had less than a year on Codfish before the 2005 breeding season (Appendix 5). Of these eight females only two (Sarah and Fuchsia) bred during the 2005 breeding season. In my 2006 foraging

home range study Sarah had an exceptionally large home range (32 ha) that contained over 70% high rimu forest, so it is perhaps not surprising that she was able to breed in 2005 if she occupied a similar home range to that recorded during 2006. Fuchsia on the other hand only had a very small home range (4 ha) and was estimated to have no high rimu forest. She did however have access to medium rimu forest which made up 67% of her home range.

Unfortunately I have no home range data for Wendy and Hoki, who were both transferred from Chalky in 2004, because they were not included in the 2006 foraging home range study. From the few points that were collected during the study and from what is known of their home range locations, it appears that Wendy is located in mostly "no rimu" and "moderate rimu" forest habitat. She is unlikely to have any "high rimu" forest in her home range down the long drop track. Hoki is likely to be in areas of moderate rimu, but I unfortunately did not have time to assess this in detail.

For the remaining three females that were transferred from Chalky to Codfish in July 2004 that did not breed in 2005, I do have information on their home range locations for the 2006 foraging period. Sandra had an MCP home range of 4 ha and had 1.34 ha of high rimu forest in her home range representing 33% of the home range area. Solstice had an MCP area of 7 ha, 3.93 ha of this was high rimu forest, just over 50%. Zephyr had a home range area of 5 ha but had no high rimu in her home range during the 2006 study period. She did however have 1.92 ha of moderate rimu and 3.28 ha of "no rimu" type forest. These three females had a reasonable area of high and moderate rimu in their home ranges, although these areas were not overly large.

Potential birds for transfer

The five females that did not breed in the 2005 season and that were not transferred from Chalky to Codfish Island in July 2004 could be shifted to Anchor Island in April 2007. This is because it is expected that these five females may have home ranges that are not suitable for breeding in low mast years. These five females, Heather, Jean, Nora, Ruth and Maggie have been present on Codfish Island for between five and seven years since the date of their last transfer. It could have been expected that this would have been sufficient time for them to find home range areas suitable for breeding. Or did factors other than habitat availability influence their non-breeding attempt in 2005?

Unfortunately I do not have detailed foraging information for Maggie as she was not included in the 2006 study. Of the remaining four females, two had mostly high rimu in their home range (Jean and Ruth) while two had no high rimu (Nora and Heather) as explained below.

During the 2006 study period Heather lived in mostly coastal areas that may not be truly representative of where she lived during the 2005 breeding season. There was no high rimu in Heather's 2006 home range, 2 ha of moderate and 4.6 ha of no rimu vegetation (Appendices 1 to 3). Similarly Nora had no high rimu in her 2006 home range, although she did have 2.8 ha of moderate rimu and just 0.34 ha of no rimu vegetation. If the 2006 home ranges are representative of where these females were located during the 2005 breeding season, then with the lack of high rimu forest in their home ranges it is perhaps understandable why these females did not attempt to breed in 2005.

Contrastingly, Jean's 2006 home range contained mostly high rimu forest (5 ha) and only small areas of moderate and no rimu forest. Ruth's home range was also dominated by high rimu forest (8 ha) with only small patches of moderate and no rimu forest. If a presence of high rimu forest in a home range enabled breeding then it would perhaps have been expected that Ruth and Jean would have both bred in 2005 based on the composition of their 2006 foraging home ranges. Although again the sample sizes are small, perhaps this may suggest that factors other than the area of rimu forest in a home range are important in determining if a female will attempt to breed or not in a low rimu mast year. Or it may suggest that the 2006 foraging home ranges are not a very good reflection of the areas occupied by females in the 2005 breeding season, although I tried to address this issue under the earlier section "comparing individuals based on breeding status". This issue may need more clarification, although the options for analysis are limited due to the limited location data collected in previous years.

SUMMARY

The aim of this analysis was to test the hypothesis that females with less mature rimu forest within their home ranges are the least likely to breed in low rimu mast years on Codfish Island. The results found that the area of high rimu forest in the 2006 foraging home ranges of females that bred in 2005 and those that did not was variable between individuals, but on average breeding females had more rimu in their home ranges than non-breeders. But due to large variations in the data and small sample sizes these differences were only statistically significant in some cases. The large standard deviation was caused in part by the breeding

female Fuchsia having no area of high rimu within her 2006 foraging home range. This is not to say that the differences are not however biologically significant, although again this is difficult to interpret because of the small sample sizes.

Another interesting result was that the mean size of 2006 home ranges was significantly different between 2005 breeders and non-breeders. On average 2006 foraging home ranges for breeders were twice the size of non-breeders, but again there were some exceptions with several non-breeding females having larger home ranges than some breeders. Perhaps it is possible to say that on average breeding is more likely to occur if a female occupies a larger home range area, but there are likely to be exceptions.

It could have been expected that females that were transferred to Codfish Island most recently (July 2004) would have habitat containing the least rimu trees. This however was not the case, although sample sizes were again small (four) so the results are difficult to assess.

Proposed transfer

It has been proposed that the females that did not breed in the 2005 breeding season and that were not transferred to Codfish Island most recently would be the most appropriate birds to transfer to Anchor Island, as they are likely to inhabit areas that are most unsuitable for breeding. It is perhaps understandable why the females recently transferred to Codfish Island did not breed in 2005 as they had under one year to settle into suitable home ranges before the breeding season. The females that were not transferred recently had no such excuse however, as they had all been present on Codfish for between four and six years prior to the 2005 breeding season.

Although this sounds reasonable in theory, the habitat analysis of 2006 foraging home ranges shows no clear indication that females that did not breed in 2005 and were not transferred in 2004 occupied home ranges with less rimu forest than other individuals. Two of these females (Jean and Ruth) had home ranges dominated by high rimu forest while two other females (Heather and Nora) had 2006 foraging home ranges containing no high rimu, although they did have some areas of moderate rimu. The fifth female (Maggie) was not included in the 2006 foraging study.

From what I can understand in the limited time I have had available to assess the data, the habitat analysis appears to neither support nor reject the proposal to transfer the five females

(Maggie, Ruth, Nora, Heather and Jean) that did not breed in 2005 and were not transferred to Codfish in 2004. There was no clear conclusion mainly because of variability in the data and small sample sizes, problems all too common in endangered species conservation.

Alternative suggestion

As 2005 breeders had significantly larger 2006 foraging home ranges than non-breeders, and breeders appear to have more rimu in their home ranges than non-breeders (although this mean value was variable and insignificant), it appears worthwhile to compare home range sizes and habitat composition of all eleven females that did not breed in the 2005 breeding season, regardless of the date of their last transfer to Codfish Island. As Sarah was transferred to Codfish in July 2004 and bred in 2005, recent transfer to an island does not necessarily prevent a female from breeding in the following breeding season (as was also evident on Pearl Island in 1999). It is perhaps unreasonable to think that all the females transferred to Codfish in July 2004 did not breed because they did not have enough time to establish a home range as this was clearly not the case for Sarah. From the eleven females that did not breed in 2005 the five females with the smallest home ranges and the least high rimu in their home ranges may be the most suitable candidates for transfer to Anchor Island.

Table 5 below details the home range size and habitat composition for all females that did not breed in the 2005 breeding season, that were included in the 2006 foraging study. Wendy, Hoki and Maggie did not breed in 2005 but were not included in the 2006 foraging study due to difficulties in triangulation. The 75% kernel was used in the below table as this appears to be the best estimate of core areas used by individuals. The time that females had spent on the island from the date of their last transfer up until the 2005 breeding season (taken as April 2005) is also included in the table.

Home range sizes varied from 2.41 to 9.28 ha for 75% kernels for females that did not breed in 2005. High rimu forest areas ranged from zero to 5.58 ha, comprising between zero and 90% of a female's home range. If you combine areas of high and moderate rimu abundance (Appendix 4) then the area of rimu inside home ranges increases, especially when home ranges contain only moderate and no high rimu vegetation types. For the purposes of this analysis it seems more important to consider areas of high rimu abundance as these presumably are the areas that contain the most mature rimu trees that are important for breeding.

Table 5. Home range sizes and habitat composition of females that did not breed in 2005, described using 75% kernel home ranges from 2006 foraging location data. The area of high, moderate and no rimu forest in each home range is shown, along with the rimu area (combined high and moderate rimu classes). The proportion (P.) of home range (HR) containing high rimu or rimu is shown.

Female	75% kernel (ha)	**High rimu (ha)**	Mod. rimu (ha)	No rimu (ha)	Rimu area (ha)	**P. HR high rimu**	P. HR rimu	Tenure on Codfish till April '05
Sandra	2.71	0.69	0.1	1.92	0.79	0.25	0.29	< 1 year
Zephyr*	4.82	0	1.06	3.76	1.06	0	0.22	< 1year
Solstice	7.05	3.3	3.76	0	7.06	0.47	1.00	< 1 year
Jane**	9.28	0.92	1.38	6.98	2.3	0.10	0.25	< 1 year
Nora	2.41	0	2.26	0.15	2.26	0	0.94	4 years
Heather*	2.86	0	0	2.86	0	0	0	4 years
Jean	3.42	1.9	0.04	1.49	1.94	0.56	0.57	4 years
Ruth	6.23	5.58	0.53	0.12	6.11	0.90	0.98	4 years

* Not confident that 2006 home range reflects breeding home range.

** Will probably not be transferred to Anchor for other reasons.

Solstice and Ruth both have large home ranges that contain 3.3 ha and 5.8 ha of high rimu forest respectively (Table 5). Solstice's home range consists of only high and moderate rimu, with high rimu comprising 47% of the home range area. Ruth's home range contains 90% high rimu with just small areas of moderate and no rimu forest. From this data is appears that both Solstice and Ruth would have a good chance of breeding in the next season given the quantity of rimu available in their home ranges, so it is probably not worth transferring them to Anchor Island.

With the exception of Jane, females with the smaller home ranges had the smallest areas of high rimu forest. Jane occupied a large home range, but most of this was made up of vegetation containing no rimu forest.   As Jane did not breed in 2002 when all other females bred she may be past breeding age. It is thought that Jane may not breed again as she also has a gammy leg. It is therefore probably not worthwhile shifting her to Anchor Island as it is unlikely she will breed wherever she lives. Jane can therefore be removed from the possible birds that could be transferred.

The females, other than Jane, that had small home ranges and small areas of high rimu forest were Nora, Heather, Sandra, Jean and Zephyr. From previous analysis it appears that these two attributes are most often associated with females that do not attempt to breed in low mast years. If these females stayed in similar small home ranges with little high rimu then it could be expected that in the upcoming 2007/2008 summer when the rimu mast is expected to be similar to the 2005 season, these females may not breed.

I do however have some reservations about how well the 2006 foraging home ranges of Heather and Zephyr reflect the areas that they would have occupied during the 2005 breeding season. This is because I know that both these birds dropped down to lower elevation areas off the coast during the later parts of my study (April/May) where they most likely would not have been during a breeding year. These shifts to coastal areas may explain why both Heather and Zephyr have no high rimu and very little moderate rimu recorded in their 2006 foraging home ranges. I therefore am hesitant to recommend if these two birds should be transferred or not based on their 2006 foraging home ranges.

With Jane not to be transferred, and the home ranges of Heather and Zephyr perhaps not being representative, this leaves three females (Nora, Sandra and Jean) that have small home ranges with only small areas of high rimu forest. If the home ranges of these three females remain similar during the 2007/2008 summer it seems likely that they would again not breed, due to their small home ranges and lack of high rimu forest. It is therefore probably advisable to transfer Nora, Sandra and Jean to Anchor Island to increase their chances of breeding.

There were three other females that did not breed in 2005 but unfortunately they were not included in the 2006 foraging study so I do not have detailed information on their home range use for this period. It is known however that both Wendy and Maggie lived in coastal areas of the island that are likely to contain few mature rimu trees. If more birds are required to be moved to Anchor Island, perhaps Wendy and Maggie would be good candidates. I do not have enough information to comment on Hoki's home range.

Comparison of recommendations

If females were to be transferred because they did not breed in 2005 and they were not transferred to the island in late 2004, then the following females would be shifted to Anchor Island regardless of home range composition: Nora, Heather, Jean, Ruth and Maggie.

If females were to be transferred to Anchor Island because they did not breed in 2005 and because they have small home range sizes with small areas of high rimu forest, then I think that the following females should be shifted: Nora, Jean and Sandra. Wendy and Maggie could also be shifted based on anecdotal evidence, and/ or Heather and Zephyr could be shifted if their 2006 foraging home ranges were thought to be a reasonable estimate of their 2005 foraging areas.

Nora and Jean were recommended in both cases so it appears that these two females should be shifted. Heather and Maggie were also recommended twice but there are some limitations here on lack of data. Sandra could be an interesting bird to shift because of her very small home range size with limited area of high rimu forest.

Disclaimer!

These are all just my ideas, but hopefully from the data and my interpretation attempts you will get some idea of what is going on. It is difficult to find patterns as I think most kakapo are quite unique individuals in their behaviour. If all else fails there is always pulling their names out of a hat….!

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16 March 2007

Appendices to NKT Report

Appendix 1. Areas (ha) of vegetation in each MCP home range based on rimu abundance and total size of MCP home ranges. Females in bold text bred in 2005.

Female	High rimu	Mod. rimu	No rimu	Total area
Alice	7.61	4.97	1.77	14.35
Bella	13.03	1.33	0.45	14.81
Cyndy	10.33	4.32	0.11	14.76
Flossie	6.23	0.15	0	6.38
Fuchsia	0	2.85	1.41	4.26
Heather	0	2	4.6	6.6
Jane	2.38	4.85	7.42	14.65
Jean	5.02	0.02	0.81	5.85
Lisa	17.39	0.56	0	17.95
Margaret-maree	1.25	8.01	0	9.26
Nora	0	2.79	0.34	3.13
Ruth	8.13	0.74	0.04	8.91
Sandra	1.34	0.5	2.25	4.09
Sarah	24.2	6.29	2.46	32.95
Solstice	3.93	3.61	0	7.54
Sue	5.22	0.93	0.01	6.16
Suzanne	3.48	10.27	0.08	13.83
Zephyr	0	1.92	3.28	5.2
Mean ± s.d.	*6.09 ± 6.64*	*3.11 ± 2.89*	*1.39 ± 2.02*	*10.59 ± 7.22*
Breeders (n=10): Mean ± s.d	8.87 ± 7.56	3.97 ± 3.44	0.63 ± 0.91	13.47 ±8.23
Non-breeders (n=8): Mean ± s.d.	2.6 ± 2.93	2.05 ± 1.65	2.34 ± 2.64	7.00 ± 3.60

Appendix 2. Areas (ha) of vegetation in each 95% kernel home range based on rimu abundance and total size of 95% kernel home ranges. Females in bold text bred in 2005.

Female	High rimu	Mod. rimu	No rimu	Total area
Alice	9.06	7.27	3.6	19.93
Bella	15.44	3.14	0.45	19.03
Cyndy	11.26	6.64	0.12	18.02
Flossie	5.71	0.35	0	6.06
Fuchsia	0	3.36	1.34	4.7
Heather	0	0	4.99	4.99
Jane	2.46	4.57	9.58	16.61
Jean	4.14	0.21	1.96	6.31
Lisa	20.79	0.38	0	21.17
Margaret-maree	2.74	6.24	0	8.98
Nora	0	3.11	0.36	3.47
Ruth	7.47	1.76	0.37	9.6
Sandra	1.54	0.38	2.52	4.44
Sarah	13.31	8.14	5.06	26.51
Solstice	4.75	5.21	0	9.96
Sue	6.55	1.14	0.15	7.84
Suzanne	6.87	11.11	0	17.98
Zephyr	0	2.72	5.57	8.29
Mean ± s.d.	6.23 ± 5.90	3.65 ± 3.22	2.00 ± 2.73	11.88 ± 7.07
Breeders (n=10): Mean ± s.d	9.17 ± 6.20	4.78 ± 3.65	1.07 ± 1.80	15.02 ± 7.47
Non-breeders (n=8): Mean ± s.d.	2.55 ± 2.73	2.25 ± 2.00	3.17 ± 3.33	7.96 ± 4.24

Appendix 3. Areas (ha) of vegetation in each 75% kernel home range based on rimu abundance, total size of MCP home range is also shown. Birds that bred in 2005 are shown in bold text. Females in bold text bred in 2005.

Female	High rimu	Mod. rimu	No rimu	Total area
Alice	5	1.46	2.75	9.21
Bella	9.64	1.99	0.45	12.08
Cyndy	5.66	4.51	0.11	10.28
Flossie	2.71	0	0	2.71
Fuchsia	0	2.3	0.91	3.21
Heather	0	0	2.86	2.86
Jane	0.92	1.38	6.98	9.28
Jean	1.9	0.04	1.49	3.43
Lisa	12.12	0	0	12.12
Margaret-maree	1.8	4.39	0	6.19
Nora	0	2.26	0.15	2.41
Ruth	5.58	0.53	0.12	6.23
Sandra	0.69	0.1	1.92	2.71
Sarah	8.35	4.99	3.32	16.66
Solstice	3.3	3.76	0	7.06
Sue	4.54	0.86	0.02	5.42
Suzanne	3.91	7.45	0	11.36
Zephyr	0	1.06	3.76	4.82
Mean ± s.d.	3.67 ± 3.57	2.06 ± 2.15	1.38 ± 1.91	7.11 ± 4.17
Breeders (n=10): Mean ± s.d	5.37 ± 3.72	2.80 ± 2.45	0.76 ± 1.24	8.92 ± 4.46
Non-breeders (n=8): Mean ± s.d.	1.55 ± 1.99	1.14 ± 1.32	2.16 ± 2.38	4.85 ± 2.48

Appendix 4: The area of rimu forest (high rimu & moderate rimu combined) inside home ranges of each individual in the study.

Female	MCP (ha)	95% kernel (ha)	75% kernel (ha)
Alice	12.58	16.33	6.46
Bella	14.36	18.58	11.63
Cyndy	14.65	17.9	10.17
Flossie	6.38	6.06	2.71
Fuchsia	2.85	3.36	2.3
Heather	2	0	0
Jane	7.23	7.03	2.3
Jean	5.04	4.35	1.94
Lisa	17.95	21.17	12.12
Margaret-maree	9.26	8.98	6.19
Nora	2.79	3.11	2.26
Ruth	8.87	9.23	6.11
Sandra	1.84	1.92	0.79
Sarah	30.49	21.45	13.34
Solstice	7.54	9.96	7.06
Sue	6.15	7.69	5.4
Suzanne	13.75	17.98	11.36
Zephyr	1.92	2.72	1.06
Mean ± s.d.	*9.20 ± 7.28*	*9.88 ± 7.15*	*5.73 ± 4.38*
Breeders (n=10): Mean ± s.d	12.84 ± 7.77	13.95 ± 6.71	8.17 ± 4.05
Non-breeders (n=8): Mean ± s.d.	4.65 ± 2.90	4.79 ± 3.58	2.69 ± 2.54

Appendix 5. Time females have spent on Codfish Island since their last transfer.

Female	Bred in 2005?	Transferred in July 2004?	Years on Codfish till April 2006	Last transfer details
Jane	N	Y	1	To Codfish from Chalky April 2005
Hoki	N	Y	2	To Codfish from Chalky July 2004
Sandra	N	Y	2	To Codfish from Chalky July 2004
Sarah	Y	Y	2	To Codfish from Chalky July 2004
Solstice	N	Y	2	To Codfish from Chalky July 2004
Wendy	N	Y	2	To Codfish from Chalky July 2004
Zephyr	N	Y	2	To Codfish from Chalky July 2004
Flossie	Y	N	5	To Codfish from Maud April 2001
Fuchsia	Y	Y	2	To Codfish from Maud in April 2001
Heather	N	N	5	To Codfish from Maud in May 2001
Jean	N	N	5	To Codfish from Maud in April 2001
Lisa	Y	N	5	To Codfish from Maud in April 2001
Nora	N	N	5	To Codfish from Maud in April 2001
Ruth	N	N	5	To Codfish from Maud in April 2001
Alice	Y	N	7	To Codfish from Pearl April 1999
Bella	Y	N	7	To Codfish from Pearl April 1999
Cyndy	Y	N	7	To Codfish from Pearl April 1999
Maggie	N	N	7	To Codfish from Pearl April 1999
MM	Y	N	7	To Codfish from Pearl April 1999
Sue	Y	N	7	To Codfish from Pearl April 1999
Suzanne	Y	N	7	To Codfish from Pearl April 1999